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**FISH LANDINGS, DISCARDS AND BENTHIC MATERIAL FROM
DEMERSAL TRAWLING IN THE WESTERN ENGLISH CHANNEL
(ICES VIIe)**

by

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in partial fulfilment for the degree of

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Abstract

Stephen Paul Cotterell

FISH LANDINGS, DISCARDS AND BENTHIC MATERIAL FROM DEMERSAL TRAWLING IN THE WESTERN ENGLISH CHANNEL (ICES VIIe)

This study examined the impact of inshore single boat otter trawling from Newlyn, Looe, Plymouth and Salcombe and pair boat demersal trawling from Looe and Plymouth on the benthic environment off the SW peninsula of the UK between 1998 and 2000.

Fish and shellfish species (54 and 11 species respectively) were measured at sea and the non-fish material (124 species) was analysed later. Overall 79.8 % of the sample was landed fish and shellfish, 15.8 % was discarded fishes and 4.4 % was invertebrates and other material (by weight).

Related information about the substrate and tide were generated from British Geological Survey data and a computer simulation of the maximum mean tidal strength.

In agreement with the different abiotic regime, the dominant fishes were different in Newlyn and the other ports. According only to port, the Looe and Plymouth samples were not significantly different, either as full samples or for their fish and non-fish components. The Salcombe samples were not significantly different to those from Looe or Plymouth for the non-fish part of the sample. Including the type of trawling meant that the greatest similarity was for the non-fish part of the sample although the relative amounts of the components varied. The pair trawling samples contained more landed, less discarded and less non-fish material than their single boat equivalents. Pair trawl samples also contained fewer examples of large invertebrate species.

Several within and between-species relationships were explored to assess the wider interpretation of the fish community data. This examined size of *Raja* spp., several predator-prey relationships and the utility of *Marthasterias glacialis* as an indicator of fishing disturbance.

Disturbance as measured by Abundance Biomass Comparison was similar whether according to the non-fish or full sample, and suggested that the whole region was relatively undisturbed (with Newlyn apparently the most impacted area).

Analysis of the relative contribution of selected groups to taxonomic diversity showed the derived conservation priorities for 'orders' of fishes were Elasmobranchs > Pleuronectiformes > Gadiformes. In general, the fact of 'losing' orders of fishes was more important for single rather than pair trawl samples, which suggests that single boat samples were collected from structurally more complex areas supporting a wider taxonomic diversity. The analysis of groups for conservation priority was also carried into the invertebrates with echinoderms being highly influential for Newlyn. Taxonomic diversity (Δ^+ and Λ^+) was also proposed as an addition to the definition of 'Good Environmental Status' according to the proposed EU Marine Strategy Directive.

When examining the abiotic and biotic data sets, the fish species bore the closest similarity to the abiotic data suggesting that much of the study area was dominated by similar invertebrate species that tended to be scavengers and in most analyses the positive influence of the voluntary Inshore Potting Agreement management regime was evident.

In a novel analysis, there was broad agreement between the data and literature sources for the location of the fishes in relation to the substrates and for eight of the most commonly occurring species it was possible to be more precise in their substrate preferences than suggested from the literature.

The landed fish part of the sample was shown to be a statistically good approximation of the landed part of the haul (for which the commercial data was known) in > 95 % of the hauls. Finally, data on the commercial landings for each port show that the boats sampled in this study were representative of these ports.

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Author's declaration

At no time during the registration for the degree of Doctor of Philosophy has the author been registered for any other University award without prior agreement of the Graduate Committee.

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Relevant scientific seminars and conferences were attended at which work was presented; external institutions were visited for consultation purposes and these are detailed on page xxxii, and several papers prepared for publication.

Presentation and Conferences Attended:

Linking Socio-Economic, Historical and Biological trends in the fishing industry, University of Southern Denmark, Esbjerg, Denmark, August 1998.

Oral Presentation: Studying the effects of fishing from sampling commercial fishing vessels. Cotterell S.P.

Ecosystem Effects of Fishing, ICES/SCOR Symposium, Montpellier, France, March 1999.

Devon's Living Coast Conference, Exeter, October 1999.

Oral Presentation: What can the local fishing industry tell us about the marine habitat? Cotterell S.P.

Benthic Habitats and the Effects of Fishing, American Fisheries Society Symposium 41, Tampa, FL, November 2002.

Poster Presentation: Fish landings, discards and benthic material from otter trawling in the western English Channel, (ICES area VIIe). Cotterell, S.P.

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Signed: *Stephen Cotterell*

Date: 8 November 2006

Chapter 1

1 General introduction

1.1 Introduction

Fishing is arguably the most widespread human exploitative activity (Jennings & Kaiser, 1998). Using old estimates of primary production Vitousek *et al.*, (1986) concluded that fishing had few fundamental effects on the structure or function of marine ecosystem apart from those on fished species, though this view is now discredited. More recently Pauly & Christensen, (1995) suggested that 20 % of primary production was required to sustain fisheries in many shallow coastal areas. They estimated 30 % for the North Sea. This is just one example where long held beliefs about the impacts of fishing have changed.

The views expressed by Vitousek *et al.*, (1986) were in keeping with their time, being derived from management via the assessment of single species, (Smith, 1994). Marine fisheries research has shifted its attention from population based to ecosystem based research (Auster *et al.*, 1996; Langton *et al.*, 1996; Laffoley *et al.*, 2004), and the moves towards a Marine Bill (DEFRA, 2006) has accelerated the ecosystem approach to management (Rogers *et al.*, 2005). This thesis continues this theme in assessing various indices of ecosystem effects of fishing, in the context of a detailed description of the fishery, through on board sampling of fish landings, discard and benthic material otter trawled in the western English Channel and linking direct sampling with indirectly acquired environmental data.

1.2 Historical perspective

The comparatively recent flurry of activity, growth of research activities, and shift in scientific philosophy on impacts of fishing should not be thought of as truly novel. The infliction of “damage” or disturbance (Hall, 1994; Hall *et al.*, 1994; Gislason & Rice, 1998) as it is referred to today has long been recognised. The famous ‘wondyrchoun’, (quoted in Graham, 1955, p 14) was documented in the reign of Edward III, (1312-77). Graham, (1955) for fishing and Smith, (1994) for its effects are excellent sources for the historical aspects. Research from early last century (Garstang, 1903) recognised, and tried to evaluate allegations surrounding the depletion of the trawling grounds. At this time area-based management of fishing was already occurring. According to a plan of fishing grounds off the South Devon coast, (Garstang, 1903, Annex) trawling was prohibited in areas in which it is allowed today. Had he seen the modern scale of activity of today’s fishing, certainly in terms of weight of gear, it is more likely that Garstang would have unequivocally attributed the “impoverishment of the sea” to the activities associated with fishing. In contrast Holme, (1983) with a life time of studying the sea floor around the western English Channel saw that the fluctuations of benthic species were “...still largely unrelated to man’s activities.” However, he qualified this by noting the profound effects of fishing and thought that given time, “...[the] man-made influences could become paramount in determining the nature of the bottom fauna in more heavily fished parts of the western Channel.” Supporting evidence came from work by Southward, (1980; 1983) which details the inconsistency of the western English Channel ecosystem and the range of long-term monitoring underway with attempts to further comprehend more recent declines in catch per unit effort.

More recently still, these same long-term data sets have been used for testing true ecosystem models. There are many of these, though that of Anderson & Williams, (1998) for carbon deserves attention, as it is derived from local data. The importance of this approach lies in its attempt to explain the seasonal cycle of dissolved organic carbon, (DOC). DOC is a major part of the total dissolved organic matter, (DOM) and DOM, in surface waters, typically exhibits a carbon rich seasonal increase, (Williams, 1995), lagged after by chlorophyll peaks, (Ittekkot, 1982; Wafar *et al.*, 1984). The ecosystem model of Anderson & Williams, (1998) describes the change in rate of breakdown of the DOM pool, which is governed by the rate that biological and other processes act to break it down. It is this breakdown rate which is likely to be modified by the activity of fishing and which has surprisingly far-reaching effects. Models such as this may have the potential to assess ecosystem health, (Sherman, 1994), given the known relation between production and biomass, (Allen, 1971). They may also have a role in separating the effects of fishing from other anthropogenic disturbances, such as pollution, (Rees, 1983). Finally mention should be made here of the contribution of Daan, (1991) who theorised the evaluation of ecosystem effects of fishing based upon production/biomass ratios of benthos and estimates of fishing mortality based on effort calculations. At the time it was not clear why this idea had not gained a wider acceptance (Daan *pers com.*) given its ability to provide a “quick and dirty” guide, which is based neither on extrapolations from limited observations of discards or by-catch, (Alverson & Hughes, 1996; Hall, 1996) nor detailed *in situ* studies, although recent effort has been directed in this area (Jennings *et al.*, 2001; Jennings *et al.*, 2002).

In some cases, the impetus for research on ecosystem effects of fishing has come from liaison with the fishing industry. The ICES investigations stem from its 58th Council Meeting in 1970, where “Members of the Gear and Behaviour Committee [were] urged to take action on the Liaison Committee’s request for information about the effect of trawls and dredges on the sea bed,” (ICES, 1970). The basis of this resolution came

from French delegates to ICES who were complaining that Dutch sole beam trawlers with heavy chain mats were causing permanent damage to the seabed. Before this date complaints, (also see below) were, so called, colloquial and brought by inshore fishermen who discovered that they could not trawl successfully as before after their grounds had been visited by heavy trawlers, (Bridger, 1970). This resolution brought the matter to the notice of the fisheries laboratories, bordering the North Sea, which had seemingly not noticed (De Groot, 1984).

The creation of the ICES Working Group on Ecosystem Effects of Fisheries has brought together many scientists with surprisingly diverse interests and the themes of the ICES symposia mirror the development in understanding. The themes of the 1998 Symposium on 'Marine Benthos Dynamics: Environmental and Fisheries Impacts' explored direct (Anon, 1992b) and indirect (Anon, 1993a) effects of fishing and the difference between anthropogenic and natural disturbance events. The 1999 Symposium addressed 'Marine Ecosystems and Fisheries Management' described effects of fishing on species and groups, effects at the ecosystem level, theoretical and practical measures to quantifying effects and ecosystem objectives. The development of new ideas in this area has been very rapid as demonstrated by the subjects covered by the 2005 'Quantitative ecosystem indicators for fisheries management.' In the preamble Cury & Christensen, (2005) say: "We have moved a long way towards an ecosystem approach to fisheries within a relatively short time..." with the themes moving onto describing and evaluating "indicators of the structure and functioning of ecosystems in time and space, and in turn how fisheries influence them." In this way, the subject area has moved from describing pattern to examining process which illustrates a level of subject maturity (Paine, 1969), although an 'unobstructed view' (Hall, *pers com.*) of the seafloor is still a dream.

1.3 Scientific investigations

The publication of studies concerned with the effects of fishing gear on the seabed and benthic communities has grown rapidly. Figure 1.1 summarises the historical and likely future trends.

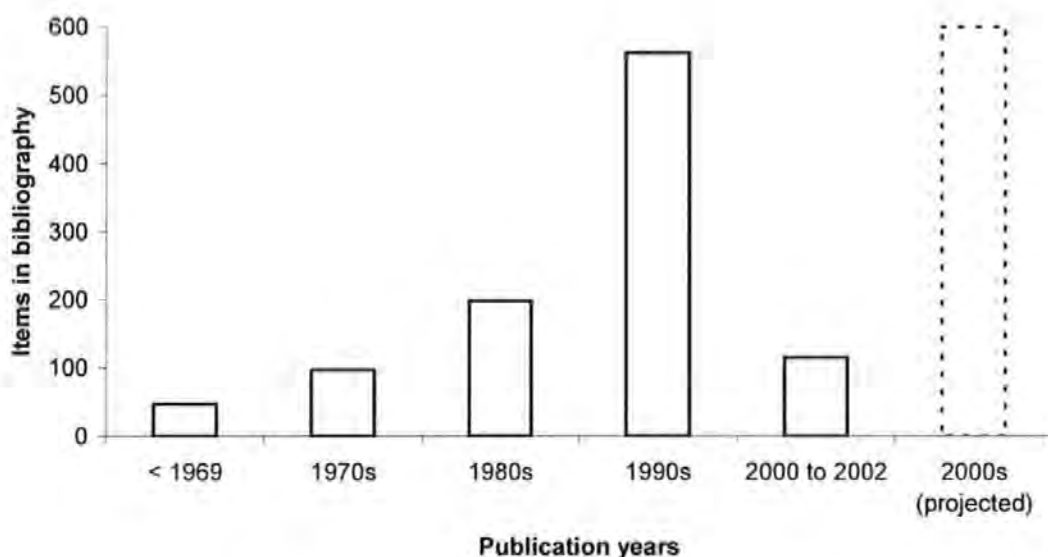


Figure 1.1. Numbers of published items on the effects of fishing gear on the seafloor and benthic communities. Source: Kenchington, (2002).

It can be seen that the subject is a product of the 1990s though it has a historical component. Caddy, (1973) presents some of earliest direct observations of the tracks of dredges and hauls. He used a submersible, so while shallow these observations can be described of as *in situ*. Earlier Ketchen, (1947) investigated the destruction of grounds by otter trawling "...along a 400 yard stretch of beach, partly covered by eel grass." The course was laid out so that the trawling took place at high water the observation of its effects could be seen at low tide. He observed it was the otter doors, which created the disturbance, while little effect, apart from some flattening of the seagrass from the light footrope, (extremely so compared to today's rock-hopper gear for example). Ketchen finished his paper asking for suggestions regarding how his experiments could be

extended into deeper, more representative waters. This was the first research paper detailing the direct effects of fishing on other parts of the ecosystem than the target species.

Intertidal, or high and low water trawling experiments have proved successful for a variety of trawling methods and direct impact experiments. These have ranged from studying fisheries which are prosecuted intertidally, e.g. Brylinsky *et al.*, (1994) or for gaining a better picture of the performance of difficult to observe parts of gear. Stewart (*pers com*) described trials of different types of footropes by dragging them behind a tractor along a beach just south of Aberdeen.

Commonly experiments to investigate both direct and indirect effects of fishing (Hall, 1999) have been conducted on more typically exploited subtidal areas. There are vast numbers of studies of this type, though focus here will be limited to discussing some aspects of scale, disturbance, succession, scavenging behaviour, the search for indicator species and developments in experimental design that have come from other areas of research, particularly pollution studies. However, attention will be first centred on examining some general principles.

Auster & Langton, (1999) reviewed 67 studies of both direct and indirect effects of fishing which divide as follows:

- Twenty-eight studies that examined the impacts of fishing gear on the structural components of fish habitats. These include beam trawls, otter trawls, scallop dredges, and hydraulic clam dredging, and cover a large range habitat types and locations.
- Fourteen studies that examined the short-term impacts of fishing gears on benthic communities. These have looked at varied taxa, with some authors reporting on only a few components, others more; and at a variety of locations, mainly around the UK, Europe, USA and Australia.
- Twenty-five that examined the long-term impacts of fishing on benthic communities.

These fall into a variety of types, either data or experimentally based, or a combination of the two. Some of the more review based types have examined changes over long periods of time, up to 100 years for Reise, (1982), while the more intensively experimental being limited to a few months to about ten years.

One particularly useful and relevant outcome from their review was a conceptual fishing gear impact model (also presented in Auster, 1998) and illustrated here as Figure 1.2.

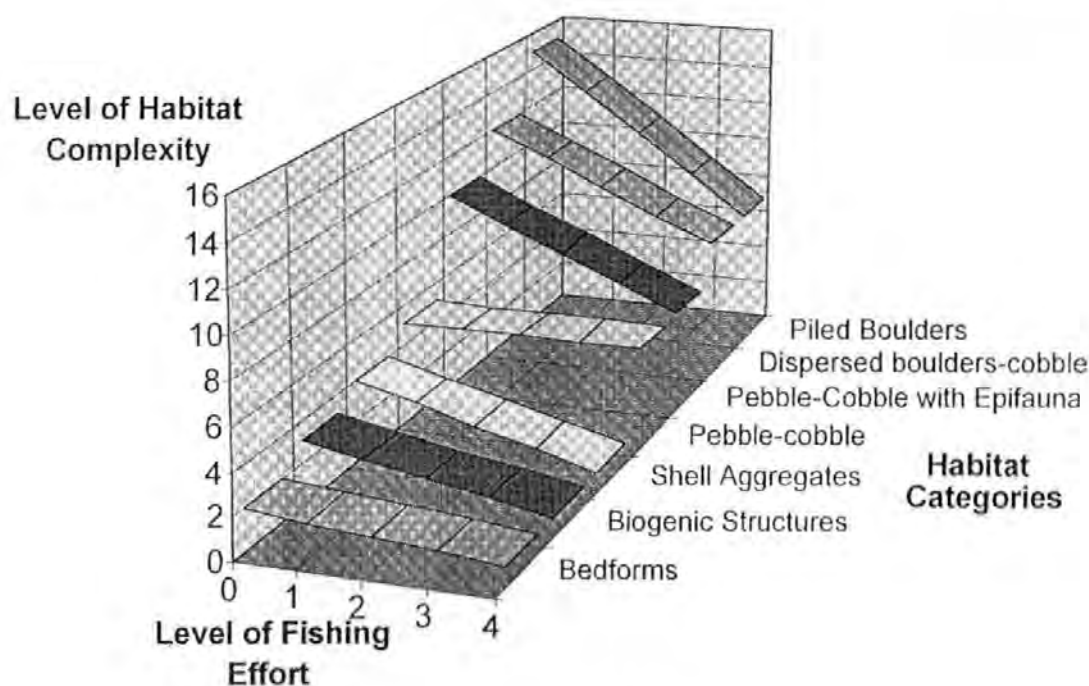


Figure 1.2. Conceptual fishing gear impact model. The range of fishing effort increases from left to right along the x axis with 0 as a pristine condition and 4 as a maximally impacted state. The y axis is a comparative index of habitat complexity, (source: Auster, 1998).

The model in Figure 1.2 indicates the response of the range of sea floor habitat types to increased fishing effort. Each habitat type, along the z axis starts at values of unimpacted complexity, (y axis) and proceeding from none to maximally affected, decreases this complexity. There are some habitats, where the model shows no significant reductions, such as gravel areas, with very little epifauna settlement. As the complexity of unimpacted areas increases, the drop in complexity towards a fully impacted state becomes larger. The model should be widely applicable as these habitat types are widely distributed worldwide and impacts are described consistently in the literature, (Auster *et*

al., 1996).

The model in Figure 1.2 serves two purposes. Firstly, it provides a holistic summary of the range of gear impacts across a variety of habitats. Secondly, it points the way for future research. While it might currently be possible to determine the ends for each line, i.e. to know the complexity of a particular habitat subjected to none and full levels of impact, the slope of the line remains unknown at the level of fishing effort required to produce specific rates of change. Responses may be linear or non-linear and there may be thresholds or “tipping points” of disturbance beyond which changes are irreversible. Regardless, responses will most likely be habitat specific and there are several habitat types which are not covered by the model, in particular deepwater coral or other fragile ecosystems (Koslow *et al.*, 2000).

The model in Figure 1.2 is useful, as it does not make a distinction between the direct or the indirect effects of fishing, merely describing the outcome of a certain application of effort on a habitat that has a level of complexity. There are a number of other important aspects that are not covered by the model though require some explanation for understanding the effects of fishing and determining how it is to be measured. These are especially **time**, **type of disturbance**, **succession** and **scale**.

The **time** component. Cushing’s match-mismatch hypothesis, (Cushing, 1975) has been applied to explain variation in fish stocks and something similar is needed to explain recruitment variation in this model. Recovery time is usually considered as the maximum life span of the longest lived species in the habitat, (Hall, 1994) but this does not explain recovering succession.

The model does not take into consideration the different **types of disturbance**; nominally types 1 and 2. Type 1 are small disturbances within a generally more complex area while type 2 are chronic disturbances over most, but not all of an area. Type 1 disturbances have recovery rates that are generally faster because they are subject to

immigration-dominated recovery, versus the dependence on larval recruitment for recovery of type 2 disturbances.

Succession, (Dean & Hurd, 1980; Arntz & Rumohr, 1982) deserves a special mention as this is the means by which, through time, recovery occurs between impacts. Succession is not readily predictable, though it can be measured. Essentially earlier colonists can have a positive, (Clements, 1916), null or negative effect of the success of later colonists. Positive to negative influences should be viewed as extremes of a continuum, and the strengths and directions of these interactions could vary within a successional sequence, (Connell *et al.*, 1987).

Both types of disturbances require a **scale**, as does much else in understanding fishing impacts and other disturbances (Guichard & Bourget, 1998). Rijnsdorp *et al.*, (1998) describing the micro-distribution of effort based on satellite tracking, report their findings as the number of visits by boats to 1x1 nm boxes. The authors also discuss the merits of using other sizes of boxes, 3x3, 10x10 and 30x30 nm and unsurprisingly, as the box-size increase the patchiness of occurrence within the box increases and the chance of random distribution decreases.

Any successful examination of the direct or indirect effects of fishing must consider these factors in addition to the impact itself. One useful example of the difficulty in studying the effects of fishing is the study of the scavenging behaviour related to fishing.

The scavenging of the benthos by fishes has been explored by repeat trawling experiments (e.g. Ramsay *et al.*, 1997a; Ramsay *et al.*, 1998) but to some extent almost all demersal fishing is repeated scavenging trawling (Kaiser & Spencer, 1994). The dependant factors being time and space as no area truly accessible to fishing is not fished. Older fishermen talk of working ground to improve catches, a notion often dismissed by scientists because of the real uncertainty of reapplication of effort on the micro-distribution scale of effort - relevant to the gear. However, the mobility of scavenging

consumers, (Breitburg, 1996) whether fishes, (Hall *et al.*, 1990; Kaiser & Spencer, 1994) invertebrates, (Ramsay *et al.*, 1998; Ramsay & Kaiser, 1998; Bergman & van Santbrink, 2000; Jenkins *et al.*, 2004), or indeed avian, (Furness, 1984; Furness *et al.*, 1988) may lead to a situation where the fishermen's generalities can apply.

Scavenging behaviour while 'directly' measurable is also undoubtedly playing a part in modifying energy flow, which is more related to indirect effects. The division of effects into direct and indirect with direct effect being 'easy' to measure and indirect being 'difficult' has been a feature of the science of understanding exploited, disturbed or polluted habitats and communities and not least the effect of fishing. However, even earliest studies examined both. Caddy, (1973) noted the density of predatory fishes in recently trawled areas was 3-30 times that in adjacent un-fished areas. Similarly Hall *et al.*, (1994) report gadoids congregating around recently dug pits in soft sediments. There are also true shifts in diet. Kaiser & Spencer, (1994) reported that adult queen scallops (*Aequipecten opercularis* L.) do not normally occur in the stomachs of whiting but analysis revealed the distinctive orange gonads in their stomachs after repeat trawling. Gurnards tend to eat large prey items such as shrimps, *Crangon* spp. and swimming crabs, *Liocarcinus* spp. though will switch, to feeding on *Ampelisca* spp. (an amphipod that lives infaunally, but close to the surface and is thus vulnerable to passing gear). Therefore, the effects of fishing should be studied as a whole, though tools are required to manage the complexity of interactions.

The search for indicator species has come about because of this complexity in understanding the whole system. Indicator species are used in many branches of biological monitoring, particularly pollution studies. Chosen species must be suitably responsive to change, but not so sensitive that they are made extinct by a dramatic alteration (Hiscock *et al.*, 2004). Much attention has been placed on using *Arctica islandica*, a large and long-lived bivalve to examine the intensity of trawling, (Klein & Witbaard, 1993). *A. islandica* live in the upper layers of soft to medium hard sediments.

It tends to poke out from the top of the substrate and is thus vulnerable to fishing, (Witbaard & Duineveld, 1990). The passage of gear chips its thick shell and this damage is retained as scars in the shell, which can be read, (Ropes, 1987). Its longevity means that older individuals often have several scars and by knowing the density of *A. islandica* estimates of the fishing intensity can be made, (Witbaard & Klein, 1994). Rumohr & Krost, (1991) used this method though Witbaard, (1996) demonstrated that particularly temperature and suspended sediment load to a lesser extent can dramatically alter growth rates and shell thickness. *A. islandica* is also not common in the Irish Sea or English Channel, (Kaiser, *pers com.*). *Glycymeris glycymeris* has been seen as a promising boreal replacement by Ramsay *et al.*, (2000a) though it does not grow as large, and tends to occur deeper in the sediment so there must be a range of indicator species to suit a range of activities and habitats.

Finally Hall, (1999) made the very obvious point that detecting changes in communities due to fishing is important but as fishing is so ubiquitous an activity there are few areas that can be said not to have been impacted by gear. Disturbances to communities occur through non-anthropogenic sources, such as from storms (VanBlaricom, 1982; Churchill, 1989), ice scour and even the feeding practises of whales and other mega-fauna (Oliver *et al.*, 1983; Oliver & Slattery, 1985). It is thus important to think of fishing as one anthropogenic source of disturbance within a non-equilibrium system (Anon, 1992).

1.4 Background to work plan: the state of the art

Much of the work in understanding the changes in ecosystems has recently come from

pollution studies, where intensive analysis usually comes only after an incident has occurred. Provided there is some monitoring of a representative site before an impact then a before, after, control, impact (BACI) study can be conducted, (Stewart-Oaten *et al.*, 1986; Walters *et al.*, 1988). This aims to assess the effect of a change in an ecosystem through the use of a statistical model that incorporates the change, (Smith *et al.*, 1993). To improve the sensitivity of the model samples may be taken at a control site as well as that receiving the impact. Thus, there are two treatments 'before-after', which is of primary interest and 'control-impact', which is of secondary interest. While this provides a powerful tool, care must be taken in the design and implementation of the experiment to meet the assumptions of the model, to sample correctly, and to reduce confounding factors, (Underwood, 1991; 1992). These experiments are expensive and sound design requires both a good statistical model and an understanding of the underlying biological processes, (what to measure) and careful planning, (how to measure it well). However, as discussed in section 1.3 there are few such 'control' or 'pre-treatment' sites available for assessment of fisheries effects. The increased attention being paid to Marine Protected Areas (Gray, 1997; Auster *et al.*, 2001; Hall, 2001; Blyth *et al.*, 2002) suggests that this is a real growth area of study. This type of comparative study often is just as intensive and therefore expensive as a BACI type.

1.5 Development of work programme

Irrespective of the desired goal, studies proceed by assessing the effects of different types and intensities of disturbance; comparing effects of fishing of different types and intensities. The expense of treatment and control type investigation can be offset by developing a sound sampling strategy and detecting and attributing differences in observed findings to pre-determined factors. This approach is also no less amenable to

being rigorously tested.

Much of the work investigating the direct and indirect effects of fishing has been conducted in the North Sea, and the English Channel is a qualitatively different environment. This is because of the differences in commercial stocks, (Pawson, 1995), geology, (King, 1954; Evans, 1990) and noted differences in biological representation as described by Hayward & Ryland, (1990a;b). This meant that the local environment is a mixed resource that warranted investigation. There is also an urgent need to evaluate the human influence on the structure and functioning of the biotic components and this must be done in a local context. There was therefore a need to examine the current status of the fish and benthic environment in the western English Channel, which was the goal of this work. Rather than design a manipulative experiment it was decided to examine the activity of the commercial sector. The SeaFish Industry Authority had recently completed a feasibility study of discarding practises in the ICES area d and e (Course *et al.*, 1996) and these general methods were developed for this study. Part of the development was to describe the relationship between the sample and the total catch and to examine the association between the vessel and the Market at its port of landing.

In order to address the study's goal the following Aims were set:

1.6 Thesis aims

There were three aims to this thesis:

1. Describe the incidental capture of benthic invertebrates in the local (ICES area VIIe) otter and pair trawl fishery. Relate this incidental capture to the landed and discarded fishes. Examine the biological diversity of the samples and assess the suitability of species to act as indicators of trawling. This Aim is described in Chapters that relate to the Sample Theme.

2. Investigate the relationship between catch composition on abiotic parameters of the trawl locations. This Aim is described in Chapters that relate to the Environment Theme
3. Evaluate the sampling method for its ability to relate the sample with the haul and the haul to the market data through the four ports of Newlyn, Looe, Plymouth and Salcombe. This Aim is described in Chapters that relate to the Haul & Market Theme.

1.6.1 Sampling objectives

In order to collect a cohesive data set to address the aims (outlined in section 1.6, page 13, above) three sampling objectives were set:

- 1 To sample from the four ports of Newlyn, Looe, Plymouth, and Salcombe.
- 2 At each port to sample once a quarter of the year for one year, (quarter 1 = January to March, quarter 2 = April to May, quarter 3 = June to August, and quarter 4 = September to December), with each trip to comprise at least two hauls.
- 3 To sample single and pair boat trawling from both Looe and Plymouth.

1.7 Rationale for boat choice

It is recognised that while otter trawling is not considered the most destructive fishing practise (Anon, 1992) it nevertheless has documented impacts (Smith *et al.*, 2000). Historically and locally it has been a very widely used method (Dickinson, 1987;Boon, 1992) and its use currently continues (MAFF/DEFRA, 1990-2001;Gray, 1995;Pawson, 1995;Course *et al.*, 1996;Lart, 2002;Pawson *et al.*, 2002) and is likely to do so for the foreseeable future.

Also, important was the structure of the southwest English Channel industry. Many local boats are owner skippered, and this represents a situation often recognised as being optimal from a safety point of view (Findlay *pers com.*). The owner-skippered boats also tend to be those most interested in conservation and the long-term future of the industry and these skippers were keen to participate in this work.

1.8 Sampling model and thesis layout

Clarke & Warwick, (2001a ,page 1-1) propose a convenient four-stage analysis which was followed here:

- 1 Represent assemblages by graphical description of the relationships between the biota in the various samples.
- 2 Discriminate sites/conditions based on their biotic composition.
- 3 Determining levels of 'stress' or disturbance, by attempting to construct biological measures from the community data which are indicative of disturbed conditions.
- 4 Linking to environmental variables.

To follow this path a conceptual model of the sample and the haul was developed as shown in Figure 1.3.

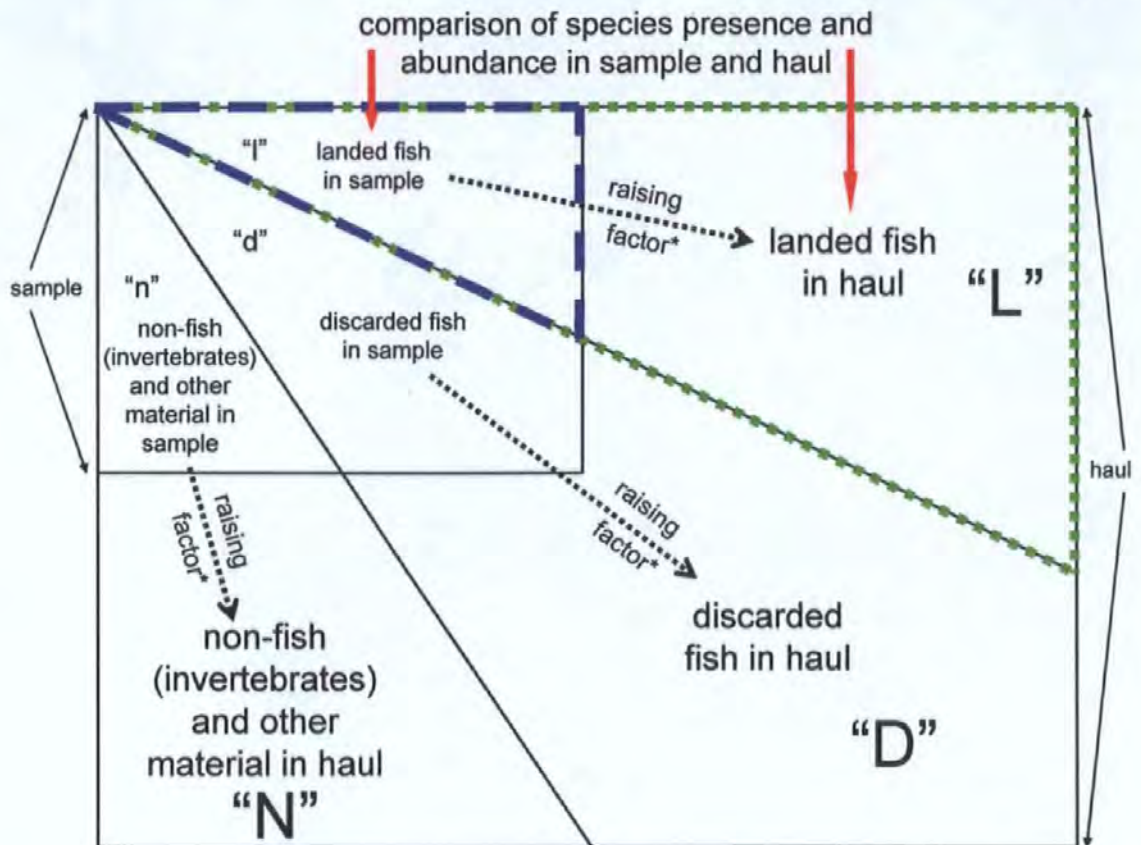


Figure 1.3. Diagrammatic representation of the sampled components and their relationship to the haul.

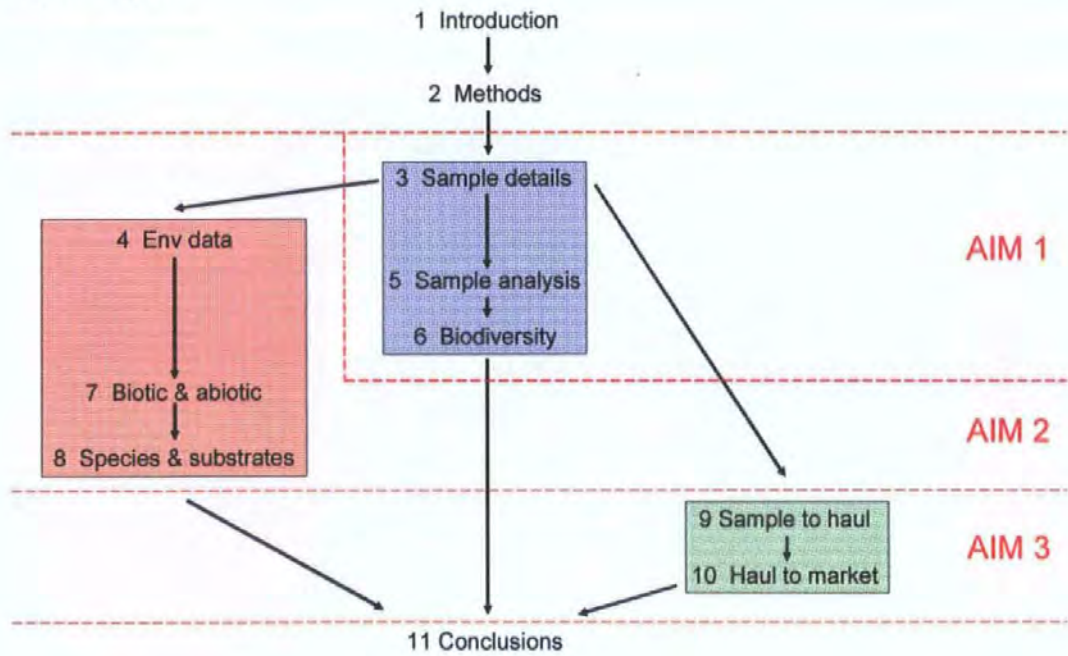
This conceptual model brings together the relationships between terms used in this study. The smaller square on Figure 1.3 represents the sample taken by a 38 kg fish basket, (Figure 2.6, page 30, below). The sample comprises three parts; 'l' is the proportion that the fishermen intend to land. Generally, this included both fish and shellfish species, 'd' represents the proportion of the sample intended to be discarded. Again this included both fish and shellfish species. Together 'l' and 'd' comprise the fishes and shellfish. 'n' represents the proportion of the haul that was made up from other non-fish or non-shellfish species that were the invertebrates and other material. Analysis of the sample is the principle theme of this thesis. The large square on Figure 1.3 represents the whole haul (Figure 2.5, page 29, below) that proportionally was divided in the same way as the sample; 'L' represents the proportion of the haul that was landed by the fishermen and this is commonly termed the landed part of the haul. 'D' represents the proportion of the haul that was discarded. Together 'L' and 'D' comprise the fishes. 'N' represents the

proportion of the haul that was made up from non-fishes that were the invertebrates and other material.

The shellfishes are really a special group of invertebrate species in that they are generally relatively large, common and edible. In some analyses (parts of Chapter 3, and most of Chapter 9 and Chapter 10) the analysis is conducted along the lines of the model presented in Figure 1.3. Other analyses (parts of Chapter 5, Chapter 6, Chapter 7, and most of Chapter 8) were more taxonomic in nature therefore the distinction between the teleost fishes (whether landed or discarded) and shellfish was required as the fact that the shellfish were landed as edible invertebrates was not important.

Figure 1.4 bring together the Aims, Themes and Chapters, and aids the following explanation of the thesis layout.

Chapter layout



Theme



Figure 1.4. Layout of Chapters according to Aims and Themes.

The activities in terms of the haul sampling, subsequent laboratory processing and initial data storage is presented in Chapter 2, 'Field and laboratory methods.' Chapter 3 describes the 'Characteristics of the sample,' which is principally concerned with describing the number and locations of the sampled hauls, though it also describes the encountered species, variation in the sample weight and its causes and how the sample composition of landed and discarded fishes and non-fishes (components of small square on Figure 1.3) varied. Whilst Chapter 3 is placed within Aim 1 on Figure 1.4, it presents data that feed into all areas of this study.

'Derivation of abiotic data', is the subject of Chapter 4. It principally describes the abiotic data used to characterise trawl locations, and their apparent pattern of similarity.

The next two Chapters describe the sample data. Chapter 5 'Spatial, temporal, disturbance and species analysis of the sample' employs graphical and multivariate analytical techniques to highlight patterns of similarity within the sample and species information. It also makes use of these data to assess the locations of the samples for their degree of anthropogenic disturbance and several interpretations of the fish community data to understand better the relationships between species. Chapter 6 'Within and between sample taxonomic diversity' assess the relatedness of the species within the samples through taxonomic distinctness measures to determine how modern definitions of biodiversity vary over space and time. It also addresses which higher order taxonomic groups are important as priorities for conservation to preserve taxonomic diversity. Together Chapter 3, (see above), Chapter 5 and Chapter 6 address Aim 1, Sample Theme (Figure 1.4).

The next two Chapters explore the relationship between the abiotic (environment) and biotic (sample) data (Aim 2). Chapter 7, 'The relationship between the samples and abiotic data' employs standard *BIO-ENV* techniques to examine the association between sites. Chapter 8 'Relating the fish species and the substrate' describes the production and

analysis of a novel technique. It examines the site:species matrices according to the species dimension. This analysis compares and contrasts the substrate preferences of fishes in this study to the published literature. Together, these two Chapters, with the data from Chapter 4 address Aim 2, (the Environment Theme).

The last two analytical Chapters scale up the sample data and together address Aim 3, Haul and Market Theme, (Figure 1.4). Chapter 9, 'Relationship between the sample and the haul based on their species composition' assesses the quality of the relationship between the landed sample ("I") and haul ("L"), and Chapter 10, 'The relationship between the haul species composition and commercial market data' measures how representative the sampled boats were to the market data of their respective ports.

Finally, Chapter 11 'Conclusions and future directions' synthesises the various threads from all the proceeding analyses.

Several Chapters have appendices, which are denoted by letters rather than numbers. Table 1.1 summarises these. This coding sequence extends to figure legends and table titles.

Table 1.1. Summary of Chapter numbers, Appendix letters and their titles.

| Chapter | | Appendix | |
|------------|--|------------|---|
| Chapter 1 | General introduction | Appendix A | Sample accuracy |
| Chapter 2 | Field and laboratory methods | Appendix B | Generated length to weight conversion data |
| Chapter 3 | Characteristics of the samples | Appendix C | Full species list |
| | | Appendix D | Total sample weight and its variation |
| Chapter 4 | Derivation of abiotic data sets | Appendix E | Test of the validity of tidal information |
| | | Appendix F | Comparison of trawl length by ArcMap and according to speed, distance and time calculations |
| Chapter 5 | Spatial, temporal, disturbance and species analysis of the sample | Appendix G | Transformations appropriate for the PRIMER analysis |
| Chapter 6 | Within and between sample taxonomic diversity | Appendix H | Development of the aggregation file |
| | | Appendix I | Branch length weighting |
| Chapter 7 | The relationship between the samples and abiotic data | | |
| Chapter 8 | Relating the fish species and the substrate | | |
| Chapter 9 | Relationship between the sample and the haul based on their species composition | Appendix J | Raising the sample weight to the haul: a choice of two methods |
| | | Appendix K | Transforming the sample and haul data |
| | | Appendix L | Raw Graphs |
| Chapter 10 | The relationship between the haul species composition and commercial market data | | |
| Chapter 11 | Conclusions and future directions | | |

Chapter 2

2 Field and laboratory methods

The composition of the trawl was determined by taking samples on board fishing vessels within the study area according to the aims (section 1.6) and objectives (section 1.6.1). This Chapter describes the methods used in sampling at sea and afterwards in the laboratory, specifically:

- Haul meta data (section 2.2.1) - details the recording scheme employed to document the sampling activities, localities and times.
- Onboard sampling (section 2.2.2) - details the onboard sampling, which fitted around the activities of the crew.
- Laboratory processing (section 2.3) - describes how the non-fish samples were conserved, sorted and subsequently measured.
- Species meta data (section 2.4) – shows how the taxonomic structure of the encountered species was constructed and recorded.

Chapter 3 describes the results that relate to these descriptions. It covers which of the sampling objectives were met, which samples could be used and which could not and their specific locations. It also examines the sample size and its variation and describes the major compositional analysis based on Figure 1.3 (page 16, above).

2.1 Sampling locations and fishing vessels

Figure 2.1 shows the study region, locations of sampled ports and extent of ICES areas.

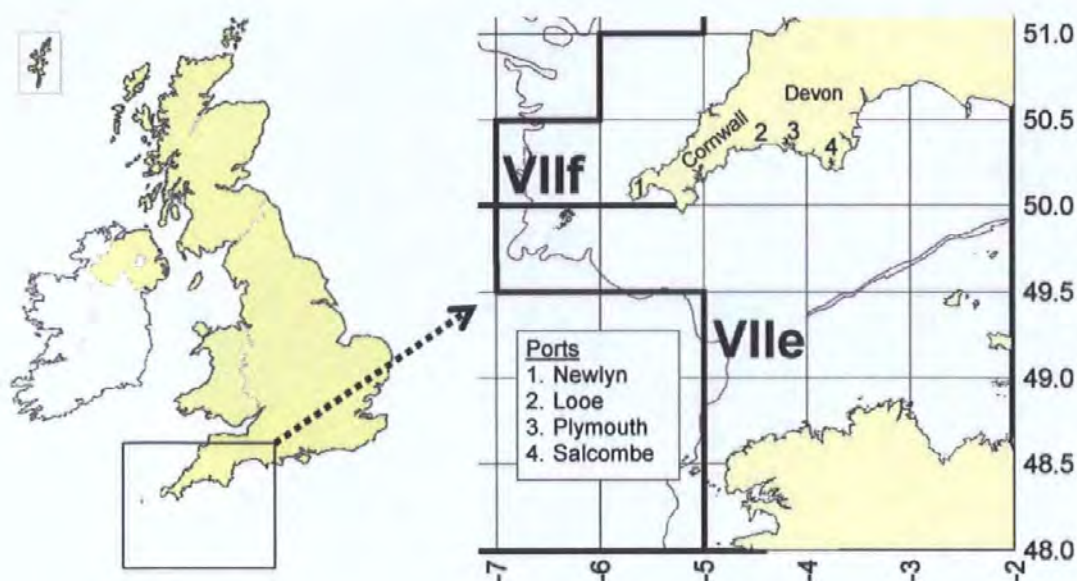


Figure 2.1. Map showing study area and location of ports.

Boon, (1992) and Gray, (1995) describe the activity and range of vessels at these ports prior to this study and the similar description by Pawson *et al.*, (2002) was concurrent in time. Sections 10.2.1.1 and 10.2.1.2 describe the throughput and nature of the ports in more detail. Chapter 4 describes the environment of the region though of particular interest is the Inshore Potting Agreement (Kaiser *et al.*, 2000; Blyth *et al.*, 2000; 2004) which is a zoned voluntary management agreement that aims to deconflict mobile and static fishing gear in the water up to ~ 15 km from Salcombe.

Whilst the port of Newlyn is within ICES area VIIIf most of the sampled fishing from this port occurred in ICES area VIIe or crossed the boundary at 50°N. The location of hauls is presented in Chapter 3, (Figure 3.1, page 47, below).

The sampling from Newlyn took place on one 21 m (70 ft) vessel of 500 Hp. This was a stern wheelhouse vessel, built from wood and had been converted to a shelter deck design. Two vessels were used for sampling each from Looe and Plymouth. Both Looe

vessels were 10 m (33 ft) 200 Hp forward wheelhouse Cygnus vessels of fibreglass construction. These were sampled independently as both single vessels and when they pair trawled together. Both vessels from Plymouth also operated as single and pair trawlers though they differed in size. The smaller was another 10 m (33 ft) 220 Hp forward wheelhouse Cygnus built from fibreglass, though the larger was 11.5 m (38 ft) 250 Hp forward wheelhouse steel vessel. Only one vessel from Salcombe was used for sampling. It was also a 10 m (33 ft) forward wheelhouse Cygnus built from fibreglass, though only had 150 Hp. Table 2.1 summarises the main details of the fishing gear based on Bridger *et al.*, (1981).

Table 2.1. Main details of single and pair trawling fishing gear according to vessels from Newlyn, Looe, Plymouth and Salcombe.

| gear | Newlyn | Looe | | Plymouth | | Salcombe |
|-------------|-------------------------------------|------------------------------------|--|------------------------------------|--|------------------------------------|
| | | single | pair | single | pair | |
| otter doors | Morge Polyvalent 500 kg | Lightweight Bison (size 6 1/2) | 100 kg weight | Vee | 100 kg weight | Custom Lexter |
| wire | 100 ftm single bridle 20 ftm splits | 120 ftm combi bridle 10 ftm splits | 200 ftm 10 mm bridle 30 ftm combi splits | 120 ftm combi bridle 10 ftm splits | 225 ftm 10 mm bridle 30 ftm combi splits | 100 ftm combi bridle 10 ftm splits |
| ground gear | 27m (90 ft) with 8 and 12" hoppers | 8 ftm (14 m) with light hoppers | 16 ftm (29 m) with 8" hoppers | 10 ftm (21 m) with 8" hoppers | 16 ftm (29 m) with 6 and 8" hoppers | 8 ftm (14 m) 6 and 8" hoppers |
| net | Pioneer | High lift ground trawl | Strachan 16 ftm pair trawl with extensions | Cosalt 290 Butterfly trawl | Strachan medium 440" fishing circle | High lift ground trawl |
| mesh (mm) | 85 | 85 | 86 | 85 | 85 | 85 |

Table 2.1 shows the overall similarity between the Looe, Plymouth and Salcombe single and Looe and Plymouth pair boats and gear. Although the gear and vessel from Newlyn was larger, the haul size across the ports was not significantly different (section 9.3.1, page 276, below).

2.2 Haul sampling

The procedure for haul sampling was developed from methods used by the Sea Fish Industry Authority (SFIA), (Course *et al.*, 1996) and Emberton *et al.*, (1995) which were expanded for this study.

2.2.1 Haul meta-data

The following information was recorded for each haul.

- Trip number. A trip was any number of days (usually between one and three days, but up to one week) spent aboard a fishing vessel.
- Sailing and landing date and port.
- Haul number. Within each trip, the hauls were consecutively numbered (though subsequently each haul (and sample) was given a unique number).
- Date and time of start (shoot) and haul, and thus the duration of the haul. Start (shoot) time was when the winch man reported he had finished paying out the gear, it was attached to the boat's tow point and the gear had begun to fish properly. Haul time was when shortening the warps began which could be 15 - 20 minutes before the haul was emptied onboard. This scheme of work is that generally adopted (Course *et al.*, 1999; Searle, *pers com.*) although Wallace & West, (2006) point out the extent to which gear continues to fish after haul back has begun. This tends to be related to depth and here depth was comparatively constant (mean and s.d. = 71.1 m, ± 11.8 , $n = 88$). Also generally hauls lasted around 4 hours (mean and s.d. = 272 min (4 h 32 min), ± 40 min, $n = 88$), therefore the different depth effect due to haul back was minimal.

- Start and haul position. The boat's position at these times was determined by vessel GPS. Additional intermediate positions were also recorded where a significant alteration of course was made, for example due to a change in the tide. The recorded positions are explained further with reference to general direction of tow.
- Depth, determined by the vessel's echosounder. An average of the shoot and haul depth was taken. In addition, the watchkeeper was asked whether there had been an alteration in depth.
- Direction of tow (related to cardinal points). This seemingly innocuous piece of information was very useful in that it helped to test the reliability of shoot and haul positions; it helped reference the tow with the tide and with speed, distance time calculations helped with plotting complex trawl paths (see Figure 2.2, below and Figure 2.3, below). The usefulness of knowing the general direction of the tow also aided determining the substrate over which the trawl passed (see Chapter 4).
- Speed of tow as an average of the vessel's speed over the ground.
- The sample composition (section 2.2.2).
- The haul composition to be landed was also recorded with the assistance of the crew, and further information about this is presented in section 9.2.1, (page 270, below). This is the basis of the haul (Chapter 9) and market analysis (Chapter 10), (Aim 3).
- Volume retained. This summary statistic was recorded as the size of the haul as numbers of six stone baskets. These data form the basis for one of the methods of raising the sample to the haul (Chapter 9), (see also Appendix J, starting on page 392, below).

The skippers were assured of data confidentiality, though all were very happy to cooperate, but most asked for their activities to be anonymously attributed.

All of the tows were plotted on Admiralty charts (Anon, 1972; 1978; 1984; 1992a; 1999) as the first stage in subsequent analysis of sediment maps (section 4.2.1.1) and tidal

maps (section 4.2.1.2). Figure 2.2 and Figure 2.3 shows the conventions used. Figure 2.2 shows a mixture of single and pair trawl tracks.

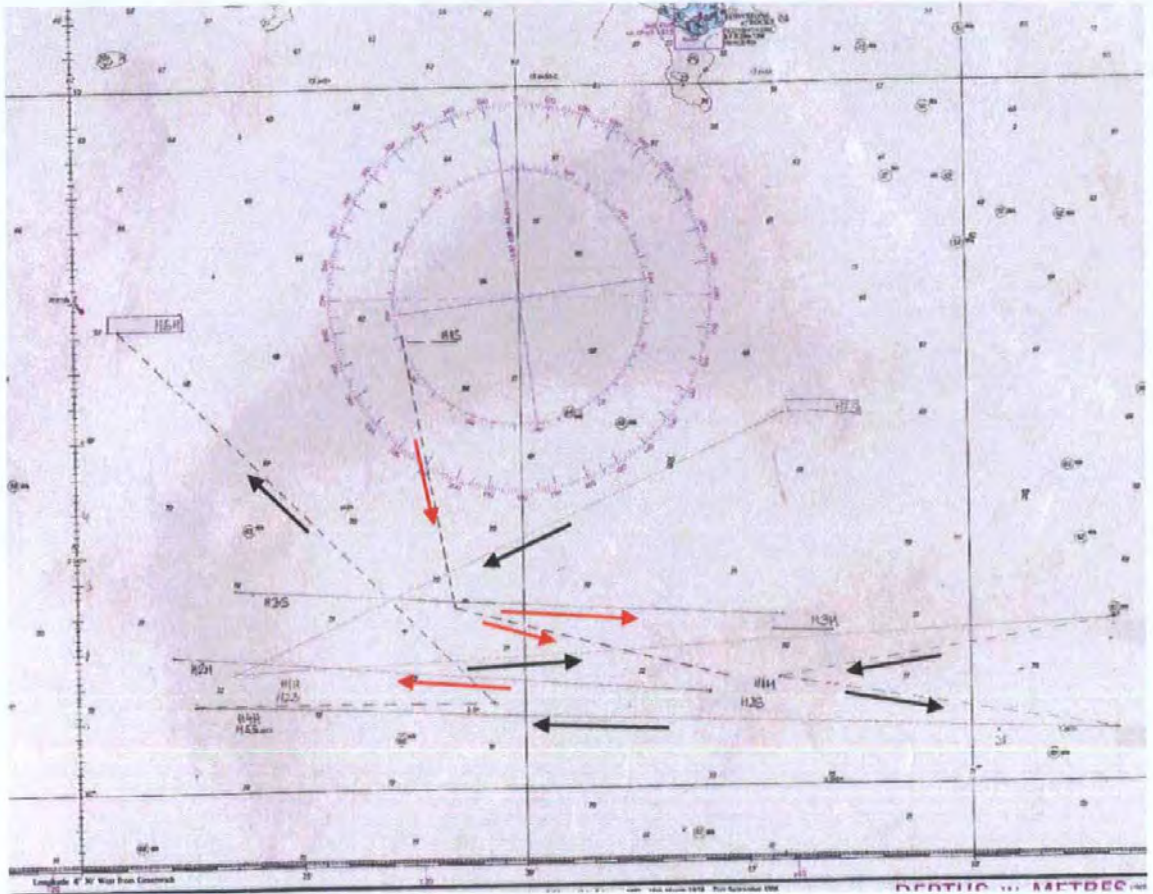


Figure 2.2. Eight trawl tracks plotted on Anon, (1984). Black lines denote a series of 5 single boat trawls and the red lines are pair boat trawl tracks. Eddystone Rocks can be seen near the north.

Some of the trawl tracks on Figure 2.2 were represented by solid lines, as there was a strong likelihood that these tracks were truly representative of the path taken and the distance between the shoot and haul positions strongly agreed with the conclusions of the speed/distance/time calculations. Dashed lines were used when the trawl tracks could not be plotted with the same degree of certainty as applied to the generally straight-line tows. Figure 2.2 and Figure 2.3 both show the usefulness in recording intermediate positions.

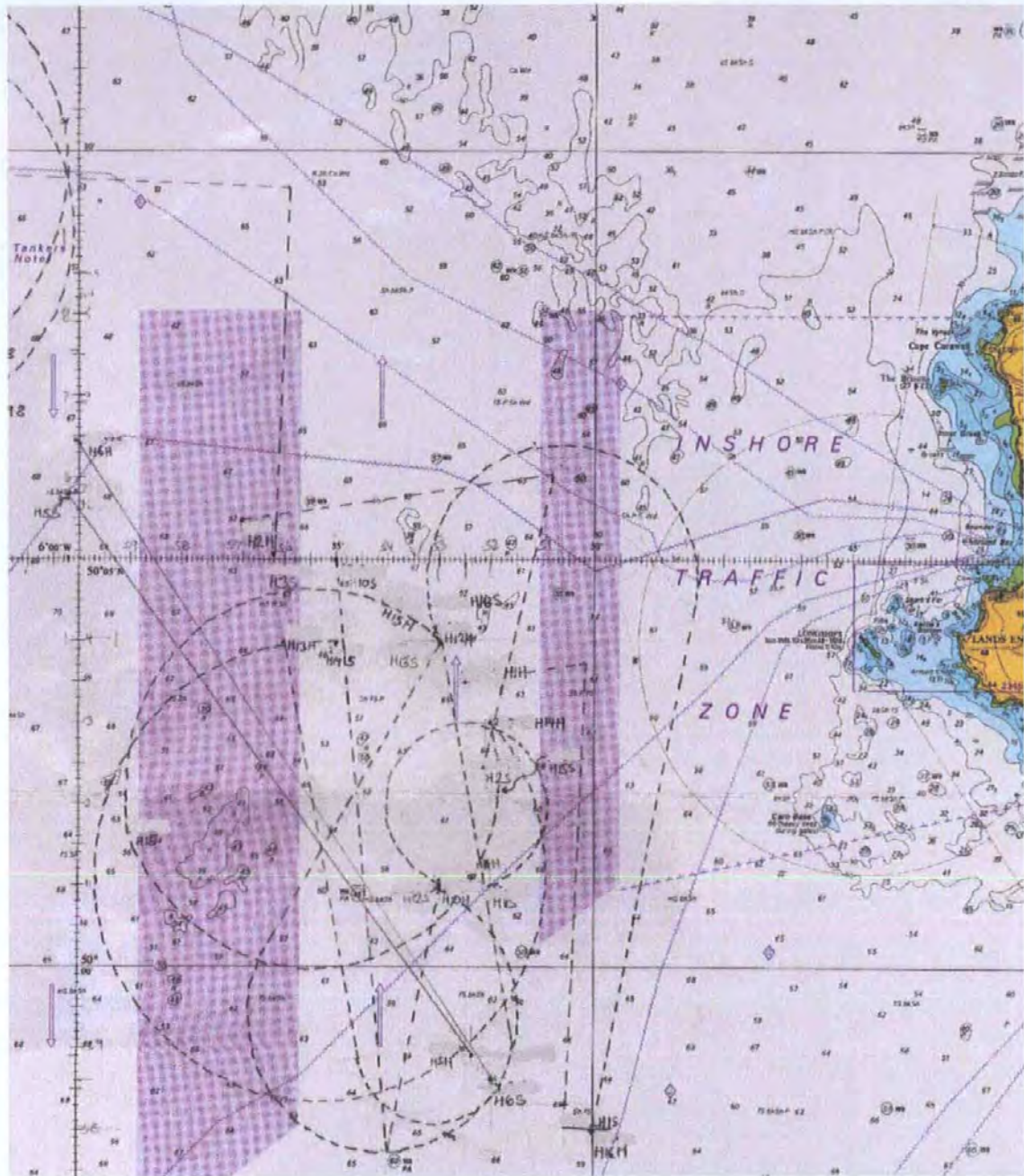


Figure 2.3. A fairly complicated plot of single boat operation plotted on Anon, (1999).

Most of the tracks on Figure 2.3 were validated with speed, distance, time calculations, and were plotted with dashed lines. When plotted in ArcMap 8.3 (ESRI, 1999) (Figure 3.1) only the shoot, intermediate and haul positions were used rather than the interpolation as shown on Figure 2.3. The curves may look a little unrealistic, though Figure 2.4 shows actual plots of boat tracks from a GPS plotter.

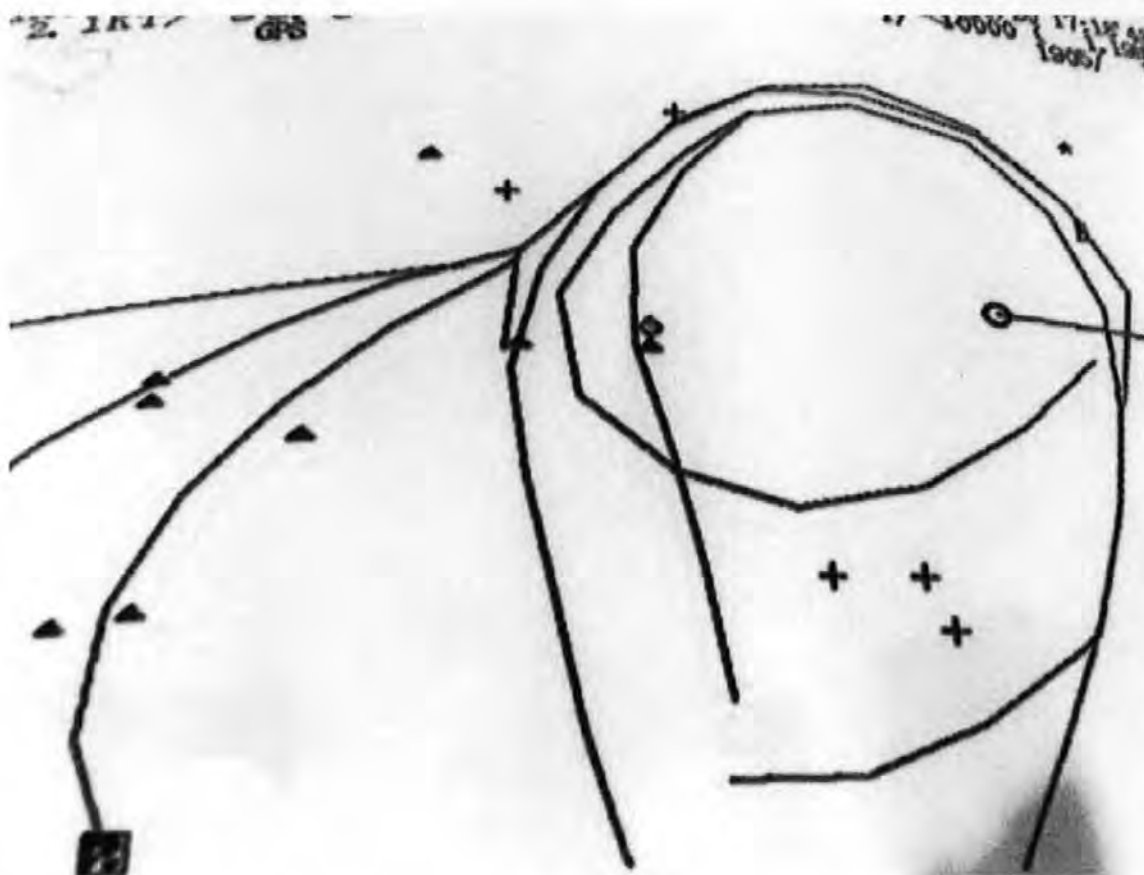


Figure 2.4. Photograph of the screen of a fishing boat's GPS plotter.

The lines on Figure 2.4 were tracks (hauls 77 and 84, see Figure F.2 and others) though the same principle applied to those from Newlyn. Sections 4.2.1.1 and 4.2.1.2 further discuss the plotting of trawl tracks in relation to deriving the sediment and tidal abiotic data set, respectively.

2.2.2 Onboard sampling procedure

Sampling fitted around the cycle of haul processing by the crew. Single boat operations were the most straightforward. Pair trawling operations usually meant moving from one vessel to the other since each usually took turns to process the haul.

The sample was taken from the fish pound though not usually until the gear was again shot away or made secure if this was the last haul of a trip (Course *et al.*, 1999).

Figure 2.5 show examples of hauls from Newlyn and Looe based vessels.



Figure 2.5. (Top). A good-sized haul from the Newlyn vessel. The white stripe in the top left corner is a 55 cm measuring board. (Bottom). A good haul on a boat from Looe (taken at night). For scale, the head of the anglerfish next to the crew's leg was ~ 40 cm across.

Prior to taking the sample, any unusually large or dangerous objects or fish were removed. Examples included car or van tires, or large rocks or pieces of coal that might

roll around dangerously or particularly large conger eels, monkfish or cod that were much too large to fit within the sample volume, and would have introduced severe bias.

The sample was taken with a typical six stone (38 kg) fish basket, (Figure 2.6).



Figure 2.6. Fish basket used for sampling the haul. The white object in the foreground is the 55 cm fish measuring board.

The internal dimensions were 0.42 m \varnothing at the top, 0.34 m \varnothing at the base and 0.35 m depth, giving a volume of 0.42 m³. A spring balance (Salter™ № 4; 100 lbs max in ½ lb increments and tared with the empty fish basket) was carried on all trips and the added length of rope between the handles allowed the approximate weight of the sample (or a part of it) to be taken. These approximate weights were compared to the calculated weights derived from length to weight conversions for each fish species and this procedure acted as a useful error check on the derived data, (see Figure A.1, Appendix A). Additionally spring balance weights were used to test the reliability of derived weight from length according to species, (see Appendix B). Also visible on Figure 2.6 are lengths of yellow cord attached at intervals up the side of the basket. These divided the basket into 6 × 1 stone (6.3 kg) portions, allowing estimation of partial values. The

marking of the fish basket proved to be a useful and fishermen-independent measure of volume and weight. Combined with the spring and quayside balance the marked fish basket was used to estimate amounts of species collected for haul composition, (see Chapter 9).

The aim in taking the sample was to collect a vertical 'virtual shovel' through the centre of the haul in the pound to mitigate size and shape bias in the sampling, (reduce the 'Brazil nut effect', Weiss, 2001). Bias caused by taking samples from different part of the fish pound was investigated by Heales *et al.*, (2000) and while no significant effect was detected amongst the fishes some differences were detected with the invertebrates.

The sample was generally collected employing a small scoop or shovel or by hand. Inevitable some species present in the haul did not also occur in the sample. Heales *et al.*, (2003) describes the requirement in sampling a relatively large proportion of the haul if the sampling is to include even moderately rare species.

Once collected, a crewmember divided the fish and shellfish parts of the sample into the landed and discarded portions. Having a crewmember divide the sample meant this was done expertly as to whether a market existed for a species at the port of landing, (for example gurnards are sold at Newlyn but not Plymouth) and also takes into account other practises such as high grading (Kingsley, 2002). Although minimum landing size have largely disappeared (Anon, 2000) the fishermen engaged in sampling observed the pre 2000 state of affairs. After processing the landed part of the sample, the discarded part of the sample was divided into fishes and non-fish components.

The landed part of the sample was weighed collectively (by spring balance) and each individual fish was measured to the cm below on a standard measuring board (see Figure 2.6). The discarded fish were measured in the same manner. These were discarded at sea rather than brought back for analysis, as in other studies, e.g. (Course *et al.*, 1996;Cotter *et al.*, 1999) as this removed the requirement to obtain a licence and

reduced the volume of material brought back to the laboratory for analysis, though greatly extended the sample processing time.

The non-fish component of the sample was weighed, and notes were taken before it was double labelled, double bagged and stored on ice in the fish room until the end of the trip. Once ashore it was transferred to the laboratory in large cool boxes. Where starfish were present in the sample they were, as far as possible, stored separately in plastic bags. This was done because they tend to disintegrate during transport, and otherwise it was impossible to determine which arm had come from which organism. Collected jellyfish (e.g. *Chrysaora hysoscella* L.) were not brought back, being impossible to store onboard. Octopuses (either *Octopus* spp. or *Eledone* spp.) where possible were returned alive to the sea. A standard weight of 750 g was used for these groups.

Emberton *et al.*, (1995) and Course *et al.*, (1996) discuss the volume of sample taken in relation to size of the haul and Lart (*pers com.*) suggested that a full single basket was a good compromise between the time needed to process the sample and the volume required for the sample to be representative. Section 9.3.2.2 shows that there were not significantly more species absent from the sample when compared to the haul for the pair trawl samples than the similar single boat samples. Also, in this study, the analysis of one sample basket was found to be a suitable sample volume in that the time required to process the sample usually matched the crew work cycle, although this was not always the case.

Commonly hauls were taken approximately every four hours and the crew required thirty minutes to an hour to process the haul. Further analysis on the proportion of the haul that was sampled is contained in Appendix J (and especially Figure J.3, page 398, below).

Collective weights and individual length data according to species were recorded directly into a waterproof surveyor's notebook. After each haul, the data were transferred into another logbook thus maintaining two sets of records.

2.2.2.1 Data storage

Fish data collected on board (both those landed and discarded) were entered into a spreadsheet. Fish lengths were converted to weights using the equation:

$$W = aL^b$$

Where:

W = weight.

L = length (as measured on board).

a = length:weight relationship and

b = exponent.

The data for a and b came from Coull *et al.*, (1989) and Lart (*pers com.*). See Table 3.3, page 51 (below) for further information and data.

2.3 Laboratory processing

Where possible the non-fish parts of the samples were processed immediately upon return to the laboratory, otherwise the samples were frozen.

When required the bags were opened and both the sample and the bags were gently rinsed over a 500 μm sieve, to dislodge and retain small items, such as pieces of *Cellaria* spp., or other small specimens. Next, individual components were laid out in large, shallow plastic trays lined with absorbent paper to remove excess water and aid comparative identification.

Preservation was restricted to material intended for a reference collection, which was kept in accordance with Smaldon & Lee, (1979).

Weight and dimension(s) of each non-fish individual specimen was recorded as follows:

2.3.1 Weight

Wet weight was recorded to ± 0.1 g, using an Acculab LT7200 and individual items < 0.1 g were disregarded. Batch weighing was used where several examples of the same small (≤ 0.1 g) species were found together thus < 0.1 g weights could be recorded by dividing the batch weight by the number of individuals.

2.3.2 Dimensions

Given the diverse shapes of invertebrates, it was necessary to take a range of measurements to describe adequately the size of the specimens. In essence, where an organism was one-dimensional its length was recorded. Two-dimensional organisms had two lengths or a length and a breadth recorded. Three-dimensional organisms were measured in three dimensions however the exact measurements depended on the type (classification) of organism. The following sections detail these and bulleted points indicate specific features that were noted or measurements that were taken.

2.3.2.1 Notes of precision

The precision with which dimensional measurements were taken depended on the organism under scrutiny. The following levels show the range encountered and explains where and why they were used. Three categories were:

- To the nearest 1 cm was used for starfish arm length and disc diameter, where a degree of distortion could be expected in the specimen.
- To the nearest 1 mm was used for hard-part measurements including sea urchin diameters, and scallop shell lengths. This level of precision was that used most commonly.
- To the nearest 0.05 mm was only used on hard-part measurements. Examples include the carapace length and breadth of crustaceans.

The size of the organism had no bearing on the precision with which it was measured. The only sacrifice was that the Vernier style callipers (checked against graph paper for accuracy) could only gape to ~ 150 mm, thus larger measurements were recorded to the nearest 1 mm using a ruler.

2.3.3 Measurements

2.3.3.1 Kingdom Animalia

2.3.3.1.1 Phylum PORIFERA, CNIDARIA, ANNELIDA

Commonly only weight was recorded for the Porifera. A single length and weight was recorded for the Cnidarians (super-class Hydrozoa) although where species grow in the form of a stolonial colony, with several Hydrocaulii distinctly emanating from the Hydrorhiza, see Hayward & Ryland, (1996 Fig 4.4, p72), the number of Hydrocaulii were counted and termed 'tillers' as in terrestrial ecology (Williams *pers com.*). Most super-class Anthozoa were recorded as weight and two lengths only (e.g. *Caryophyllia smithii* Gosse) though where a third length dimension was obvious (e.g. *Alcyonium digitatum* L.) this was also recorded. Most Annelids were recorded for length and weight, though where the species had an obvious second dimension (for example *Aphrodita aculeata* L.) this was also recorded.

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2.3.3.1.2 Phylum CHELICERATA

The marine Chelicerata (class Pycnogonida) are all small and only weight was recorded.

2.3.3.1.3 Phylum CRUSTACEA (higher)

All the crustaceans could be analysed by one general method, which is set out below.

- Identification to species level, except where damage to identifying features prevented this.
- Sex, either male or female and whether berried if female.
- Carapace breadth and carapace length to the nearest 0.05 mm.

Crothers & Crothers, (1988) advise that in species where the front projects forward well between the eyes the front becomes the rostrum. Nevertheless, the carapace length was still recorded whether or not there was a rostrum. The only difference was that for species such as *Macropodia deflexa* the carapace length was recorded as rostral length while for species such as *Necora puber* it is carapace length.

- Wet weight to the nearest 0.1g.
- The degree of completeness of the pereopods, (Cotterell, in prep).
- Nature and type of epibiotic coverage, described according to Ingle, (1996, appendix p195-212), Crothers & Crothers, (1988), and Manuel, (1988, 177).

2.3.3.1.4 Phylum MOLLUSCA

Measurement of the molluscs is best described by taking one of each of the three main classes encountered.

Class GASTROPODA

For example *Aporrhais pespelecani*, (pelicans foot shell), or *Buccinum undatum*, (common whelk), see Figure 2.7.

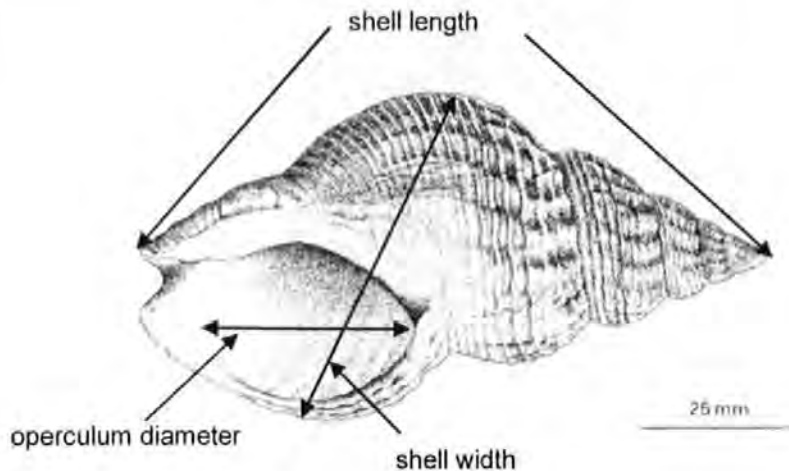


Figure 2.7. Measurements taken of *Buccinum undatum*. Shell length and width are both maxima. The operculum diameter looks rather indistinct here, though this measurement was taken on the operculum (maximum diameter on more oval examples) attached to the foot of the mantle and not the shell. Source: Hayward & Ryland, (1990b, p687).

Figure 2.7 shows how:

- Length, second and third dimensions were taken.
- Where possible both mantle and shell weights were taken.

For small species such as *Crepidula fornicata* and *Trivia arctica* only the weight, shell length and width were measured, (as individuals of these species are small).

- The nature and type of any epibiotic coverage was described in a similar fashion to that of the crustaceans (see page 36, above) and Hayward & Ryland, (1996, Fig 10.3 p492) was used to describe their location.

Class PELECYPODA, the bivalves

Hayward & Ryland, (1996, p573) was used to orientate the specimen.

- Shell length was taken as the dimension from the hinge to the opposite (ventral) side and the shell width was taken as the maximum dimension at right angles to this as shown in Figure 2.8.

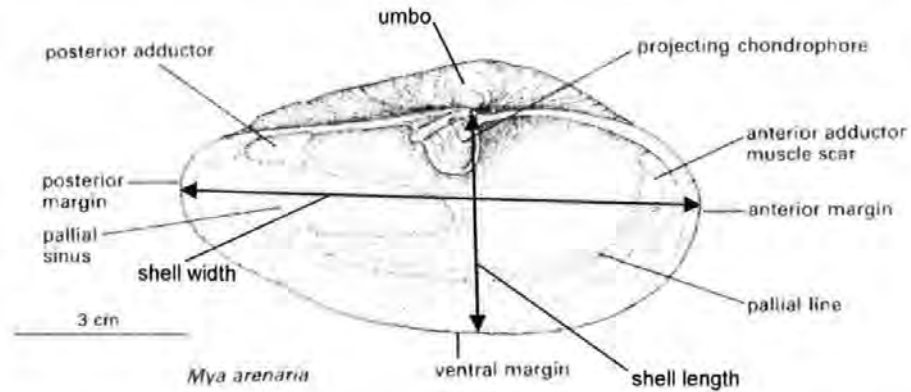


Figure 2.8. Measurements taken of bivalve molluscs. Taken and adapted from Hayward & Ryland, (1990b, p733).

- The nature and type of any epibiotic coverage was described in a similar fashion to that of the crustaceans (see page 36, above) and Figure 2.8 was used to describe their location.

Class CEPHALOPODA, the squids and cuttlefishes

- Mantle length was recorded for all squid and cuttlefish.

2.3.3.1.5 Phylum BRYOZOA

In the description of the bryozoan, the form of the specimen was used to define which measurements were taken. For example within the class Gymnolaemata, order Cheilostomatida, and family Hippoporinidae examples of *Pentapora fascialis* had 3 length measurements and weight of the colony recorded while examples of the family Cellariidae, (*Cellaria* sp) had only their weight taken, due to the fragility of the latter.

Examples of the family Flustridae (e.g. *Flustra foliacea*) had a single length measurement and their weight recorded.

2.3.3.1.6 Phylum ECHINODERMATA

Echinoderms are morphologically varied therefore, each major type required different methods of measurement. Below this is detailed according to families and common species; with the classification taken from Howson & Picton, (1997), and further, clarifying, amendments from Hayward & Ryland, (1996). Their ease of repeatable measurement enabled many dimensions to be recorded and they were important to this study as echinoderms are large, benthic and relatively slow moving.

Class Asteroidea

Family Asteriidae, the starfish, (e.g. *Asterias rubens* L.).

The description of starfish was complex because of their use by other researchers (Jenkins *et al.*, 2001; Ramsay *et al.*, 2001a; 2001b; Rogers *et al.*, 2001) as measures of trawling intensity. Starfish also tended to be both abundant and a significant component of the non-fish part of the sample, and thus were of particular interest.

- Weight was recorded and the diameter of the central disk was measured to the nearest cm.

Next, each arm was measured. The possible completeness categories were:

- Separate arm.
- Central disk, (likely to be from a specimen that had been totally smashed apart).
- Central disc and one arm up to central disc with all arms intact i.e. the lowest unit capable of being counted as a starfish up to a whole specimen.

The first two categories were not as useful as the third. The third category was especially useful, as from this it was possible to compare the numbers of intact specimens to those

damaged in quantifiable manner. Intact or nearly complete specimen could also more easily be examined for previous arm loss and regeneration.

Marthasterias glacialis was analysed identically to *A. rubens*, as were members of the order Paxillosida, family Astropectinidae. Order Paxillosida, family Luidiidae were also analysed the same except that *Luidia ciliaris* has seven arms, as were specimens from order Valvatida, family Poraniidae, (e.g. *Porania pulvillus*) and family Goniasteridae (e.g. *Hippasteria phrygiana*). Specimens of order Valvatida family Solasteridae (e.g. *Crossaster papposus*) were only measured according to maximum diameter because these are regular and do not appear to be particularly susceptible to damage; therefore measuring every arm (as for *A. rubens*) was unnecessary.

Class Ophiuroidea, the brittle stars

- All the Ophiuroidea were analysed the same as for the description of the family Asteriidae.

Class Holothurioidea, the sea cucumbers

The Holothurians (e.g. *Holothuria forskali*) were individually bagged due to their tendency to spoil other items with which they may come into contact.

- They were measured according to their oral – aboral length (to the nearest cm) and weighed (to the nearest g).

Class Echinoidea, the sea urchins

These are considered separately as regular or irregular echinoids, (Hyman, 1955; Lawrence, 1978).

Order Echinoida, the regular echinoids

The following measurements were taken:

- Echinoid length. This is analogous to oral-aboral length in the holothurians, and as such is actually the height of the echinoid, when in its usual attitude.
- Echinoid width (measured at the widest part).
- The oral test diameter.

When recording weight it was important to ensure the specimen was fully thawed if previously frozen.

Order Spatangoida, the irregular echinoids

These are the family Spatangidae (Hayward & Ryland, 1996) or the order Spatangoida (Howson & Picton, 1997). The commonest examples are the heart urchins (e.g. *Spatangus purpureus* O.F. Müller). The following measurements were taken:

- Echinoid length. Again, this is analogous to oral-aboral length in the holothurians, and as such is actually the height of the echinoid, when in its usual attitude.
- Major and minor axis lengths were also taken to describe the irregular nature of the animal.
- Oral test diameter.
- Weight was recorded as for the regular Echinoids.

2.3.3.2 Kingdom Plantae

2.3.3.2.1 Phylum CHLOROPHYCOTA, CHROMOPHYCOTA, RHODOPHYCOTA and ANGIOSPERMAE

Specimens of these groups were recorded as weight and length. Encrusting organisms were also noted. Only *Zostera marina* (L.) was included as an Angiosperm (see below).

2.3.3.3 Group Anthropogenica, Geologica and other Plantae

Anthropogenica relates to all human derived material. Examples of these include fishing litter (line, bits of netting etc) and general litter (drink cartons, plastic packaging, shoes, car tires and pieces of coal and clinker). Geologica relates to substrate items, such as stones. Other Plantae were generally leaves washed into the sea. Weight and appropriate length measurements were taken of all these items. Additionally encrusting epibionts were also recorded.

2.3.4 Data storage

Data about the invertebrates and other (non-fish) material was also stored in an Excel spreadsheet with each row recording the information for one item. This approach allowed application of data filters, forms or pivot tables within Excel™, or enabled easy export of the data to Access™ or PRIMER-E (Clarke & Warwick, 2001a) and was based on those features described in the measurement of invertebrates from haul sampling, and laboratory processing, (pages 35 to 42, above).

2.4 Species meta-data

The species meta-data describes the taxonomic classification of the encountered species. The relevance of this was to enable the taxonomic relationship between different species to be determined. This forms the basis of the analysis in Chapter 6, though also runs through all analyses involving species, genera, family, order or classes of encountered

species. Table 2.2 shows records of two species to illustrate the development of the species meta-data.

Table 2.2. Species meta-data.

| descriptor | | example1 | | example2 | |
|----------------------|-------|-----------------------------|--------|--------------------------------|--------|
| <i>genus</i> | | <i>Liocarcinus</i> | | <i>Marthasterias</i> | |
| <i>species</i> | | <i>holsatus</i> | | <i>glacialis</i> | |
| <i>genus species</i> | | <i>Liocarcinus holsatus</i> | | <i>Marthasterias glacialis</i> | |
| taxon-ID | | S26700 | | ZB2000 | |
| taxon-name | | holsatus | | glacialis | |
| taxon-level | | 18 | | 18 | |
| parent | | S26660 | | ZB1990 | |
| taxon | | taxon | | taxon | |
| name | level | name | # | Name | # |
| kingdom | 1 | | | | |
| phylum | 2 | CRUSTACEA (higher) | S1 | ECHINODERMATA | ZB0 |
| sub-phylum | 3 | | | | |
| super-class | 4 | | | | |
| class | 5 | EUMALACOSTRACA | S350 | ASTEROIDEA | ZB310 |
| sub-class | 6 | EUCARIDA | S21180 | | |
| super-order | 7 | | | | |
| extra-order | 8a | | | | |
| order | 8 | DECAPODA | S21440 | FORCIPULATIDA | ZB1870 |
| sub-order | 9 | PLEOCYEMATA | S21680 | | |
| infra-order | 10 | BRACHYURA | S25110 | | |
| section | 11 | BRACHYRHYNCHA | S26500 | | |
| super-family | 12 | PORTUNOIDEA | S26510 | | |
| family | 13 | Portunidae | S26520 | Asteriidae | ZB1880 |
| sub-family | 14 | Polybiinae | S26590 | | |
| tribe | 15 | | | | |
| <i>genus</i> | 16 | <i>Liocarcinus</i> | S26660 | <i>Marthasterias</i> | ZB1990 |
| sub-genus | 17 | | | | |
| extra-species | 18a | | | | |
| <i>species</i> | 18 | <i>holsatus</i> | S26700 | <i>glacialis</i> | ZB2000 |
| sub-species | 19 | | | | |
| variety | 20 | | | | |
| [spare] | 21 | | | | |
| synonym | 22 | | | | |

The classification was developed from Howson & Picton, (1997) and Picton & Howson, (1999). The later publication contains four electronic versions of the Species Directory though relevant here was the Access97™ file "SpeciesA.mdb" and the SPDIRE table in particular. This table contains 14,874 taxonomic records and each record consists of four data: Taxon-ID, taxon-name, taxon-level and parent. The process of how the classification was developed is illustrated with the example of *Liocarcinus holsatus*

shown in Table 2.2. The taxon-name *holsatus* (taxon-ID S26700) exists at a taxon-level of 18, (species). Taxon-ID has as a parent a taxon number of S26660, which exists at a taxon level of 16 (genus). Taxon-ID S26660 relates to a taxon name of *Liocarcinus*. Taxon-ID S26660, (*Liocarcinus*) has as a parent taxon-ID S26590, (Polybiinae) which exists at a taxon-level of 14, (sub-family). Taxon-ID S26590 has as a parent taxon-ID S26520 (Portunidae) which exists at a taxon-level of 13 (family). Thus, it was possible to construct a database query that would construct the classification of any taxon name (from its number) and link up each taxon-ID with its parent. This created a species to phylum classification tree containing 8,561 species, (but which could also be truncated at any of the 14,874 points) and which was entirely based on Picton & Howson, (1999).

The query was constructed in such a way as to skip empty taxon levels whilst maintaining the pathway and deposit taxon-names and taxon-IDs at the correct taxon-level, and as shown by the two examples in Table 2.2 both the number of present names and their locations can be varied. The generated classification formed the basis of the aggregation file for the biodiversity of samples analysis in Chapter 6 (starting on page 155, below).

For this study two species needed to be added; *Liocarcinus vernalis* (Risso), (Ingle & Clark, 1998) for which the species *L. vernalis* was given a taxon-ID of S26735. The second species that needed to be added was rather surprisingly *Zostera marina* L. The classification for this species was acquired from Picton (*pers com.*) and the suggested taxon-ID for *L. vernalis* was taken up in return.

Chapter 3

3 Characteristics of the samples

This Chapter presents general results of the sample collection. As shown on Figure 1.4 (page 17, above) this Chapter is within the Sample Theme and covers Aim 1 however, many of the areas feed into later analyses, specifically:

- Patterns within and between samples according to port and type of trawling, (Chapter 5) and the taxonomic biodiversity (Chapter 6) of the samples, (Aim 1, Sample Theme).
- Relationship between the samples and environmental (or abiotic) factors (Chapter 7 and Chapter 8), (Aim 2, Environment Theme).
- Relationship between the sample and the haul data (Chapter 9), (first presented in the conceptual diagram of Figure 1.3, on page 16 (above) and the relationship between these sampled boats and their respective markets (Chapter 10), (Aim 3, Haul & Market Theme).

The first section describes meta-data relating to the location and number (section 3.1) of sampling.

The next three sections relate to the species. Section 3.2 (with particular links to Appendix C) presents the encountered species. It shows those classed as landed or discarded and which were amalgamated together in the haul data (the subject of Chapter 9). Section 3.3 shows the most dominant species overall and according to port and type

of trawling. Section 3.4 presents an accumulation curve of all the species encountered with sample number to help determine the extent of the sampling effort (Willott, 2001).

When collecting the sample its total weight inevitably varied. Section 3.5 investigates this variability and addresses whether, and to what extent it constituted bias. Finally, section 3.6 examines the degree to which the landed and discarded fishes and non-fish part of the sample (Figure 1.3, page 16, above) varied across all the samples, according to port and type of trawling and the degree to which other factors contributed to the variation.

3.1 Location and number of sampled hauls

Figure 3.1 shows the location of all the hauls according to port and type of trawling.

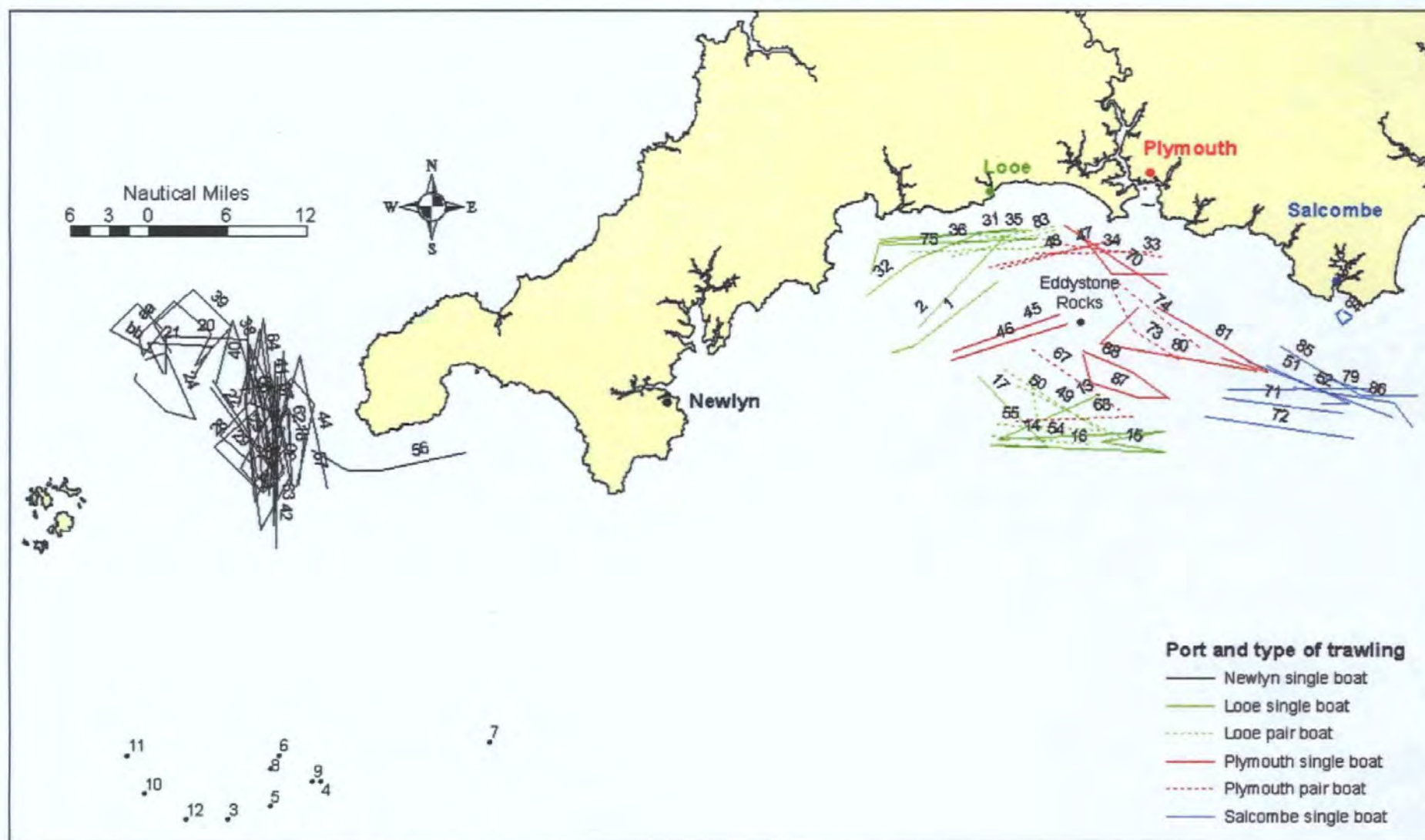


Figure 3.1. Colour coded location of all hauls according to port and type of trawling.

The Newlyn hauls on Figure 3.1 denoted by letters ("aa" and "bb") were those that did not have accompanying samples, and are not included in the analysis. Only haul position was recorded for the Newlyn trip during Q2, '98 (see Table 3.2 on page 49, below). These hauls are shown by point symbols rather than as tracks on Figure 3.1.

The colour coding of trawl track according to port and type of trawling, as shown on Figure 3.1 continues throughout the thesis.

The full data set comprised 92 samples from 26 trips to sea, (see Table 3.1).

Table 3.1. Number of hauls by port and type of trawling.

| port | # of hauls | | |
|----------|------------------|-----------|-------|
| | type of trawling | | total |
| | single boat | pair boat | |
| Newlyn | 46 | 0 | 46 |
| Looe | 11 | 9 | 20 |
| Plymouth | 8 | 8 | 16 |
| Salcombe | 10 | 0 | 10 |
| total | 75 | 17 | 92 |

Eighty-eight of the 92 hauls as described in Table 3.1 were usable in the analyses. Those not usable were hauls 7 and 8 from Newlyn on 29 August 1998 because of safety considerations (an electrical problem). Haul 11 on the same trip was not considered usable because the gear came fast after two and a half hours, and was found to be very badly damaged on hauling. Finally, very rough weather prevented sampling of haul 5 from Newlyn on 28 July 1999.

The 88 hauls from which samples were taken were numbered sequentially (see page 24, above) according to the order through time they were taken and along with the dates and numbers of usable samples are shown in Table 3.2. This sequential numbering was the key to the haul numbering throughout the study; on maps (Figure 3.1, page 47, above), MDS plots (Figure 5.3, page 116 and Figure 5.4, page 118 below), and plots of taxonomic distinctness (Figure 6.1, page 167 and Figure 6.2, page 169, below).

Table 3.2. Number of hauls by port and type of trawling (N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling) according to year and quarters of the year; quarter 1 = January to March, quarter 2 = April to May, quarter 3 = June to August, and quarter 4 = September to December. Dates are the date on which the trip started. Also shown (below each trip details) are the sequential haul numbers.

| port | type | year and quarter with date and number of hauls | | | | | | | | | | | |
|------|------|--|----|----------|----|-------|---|----------|---|----------|----|----------|---|
| | | 1998 | | | | | | 1999 | | | | | |
| | | 2 | 3 | 4 | | | | 1 | 2 | 3 | 4 | 2000 | |
| | | date | # | date | # | date | # | date | # | date | # | date | # |
| N | S | 24-May | 10 | 29-Aug | 13 | | | 5-May | 8 | 26-Jul | 1 | | |
| | | 3 to 12 | | 18 to 30 | | | | 37 to 44 | | 28-Jul | 10 | | |
| L | S | 21-Apr | 2 | 24-Jul | 5 | 1-Oct | 2 | 25-Feb | 2 | | | | |
| | | 1,2 | | 13 to 17 | | 31,32 | | 35, 36 | | | | | |
| L | P | | | | | | | 23-Jun | 2 | 7-Jul | 3 | 21-Oct | 2 |
| | | | | | | | | 49,50 | | 53,54,55 | | 75,76 | |
| P | S | | | | | | | 25-May | 2 | 3-Sep | 2 | 17-Nov | 2 |
| | | | | | | | | 45,46 | | 69,70 | | 80,81 | |
| P | P | | | | | | | 10-Feb | 2 | 7-Jun | 2 | 5-Aug | 2 |
| | | | | | | | | 33,34 | | 47,48 | | 67,68 | |
| S | S | | | | | | | 24-Jun | 2 | 15-Sep | 2 | 29-Oct | 3 |
| | | | | | | | | 51,52 | | 71,72 | | 77,78,79 | |
| | | | | | | | | | | | | 20-Jan | 1 |
| | | | | | | | | | | | | 21-Jan | 2 |
| | | | | | | | | | | | | 84,85,86 | |

Table 3.2 shows that the first trip to Salcombe of 2000, (20 January 2000) only sampled one haul. This was due to the gear becoming stuck fast and damaged during the first tow. The damage was substantial forcing the boat to return to port to make repairs. The sampled haul was taken during the afternoon. In order to meet objective 2 (section 1.6.1) the following day's fishing was also sampled. All three of these hauls were used in the analysis. A similar situation occurred for the hauls from Newlyn during the third quarter of 1999, though in this instance it was bad weather that forced the boat to return to port, (26 July 1999 - setting out again on 28 July).

3.2 Species encountered

3.2.1 All species

The total species list is shown in Appendix C, (Table C.1, page 348 and Table C.2, page 349, below). The groups in these tables are presented according to the taxon identification code (Howson & Picton, 1997; Picton & Howson, 1999) and show the varying resolution (usually species) to which the taxonomy was classified. Left to right on these tables are the fine to coarse (species to kingdom) classification as illustrated by the examples shown in Table 2.2, (page 43, above).

3.2.2 Landed and discarded fishes (including the shellfish)

Table 3.3 shows 66 fish and shellfish species encountered in the landed or discarded part of the sample, with scientific and common names, and the taxon identification code according to Howson & Picton, (1997) and Picton & Howson, (1999).

Table 3.3. Fish and shellfish species encountered showing whether considered a landed or discarded (or both) species, and whether removed from the haul before processing. The list is sorted according to sample species code. Shellfish species are lightly highlighted.

| where found | | | species code† | | | | | length : weight relationship | | | gutt weight ratio† |
|-------------|--------|-----------|---------------|--------|-------------------|--------------------------|--|---|---------------|--------|--------------------------|
| haul | landed | discarded | taxon ID | sample | haul | genus† | species† | common name | "a" † | "b" † | |
| • | | • | ZG620 | ANC | | <i>Engraulis</i> | <i>encrasicolus</i> | anchovy | 0.0065 | 2.981 | 1 |
| | | • | ZG890 | ARG | | <i>Argentina</i> | <i>sphyraena</i> | argentine | 0.0053 | 3.05 | 1 |
| | | • | ZG2180 | BIB | BIB | <i>Gadus</i> | <i>luscus</i> | pout, whiting (pouting) | 0.0038 | 3.3665 | 1 |
| | | • | ZG8630 | BLL | BLL | <i>Scophthalmus</i> | <i>rhombus</i> | brill | 0.0055 | 3.3047 | 1.05 |
| | | • | ZF1350 | BLR | RAY | <i>Raja</i> | <i>brachyura</i> | blonde ray | 0.0218 | 2.955 | 1.12 |
| | | • | ZG4730 | BSE | BSE | <i>Dicentrarchus</i> | <i>labrax</i> | bass | 0.0074 | 3.0963 | 1 |
| | | • | ZG1730 | COD | COD | <i>Gadus</i> | <i>morhua</i> | cod | 0.007 | 3.087 | 1.17 |
| | | • | ZG220 | CON | | <i>Conger</i> | <i>conger</i> | conger | 0.001 | 3.45 | 1 |
| | | • | S26460 | CRE | CRE | <i>Cancer</i> | <i>pagurus</i> | edible crab | 0.08593 | 3.117 | 1 |
| | | • | W23930 | CTL | CTL | <i>Sepia</i> | <i>officinalis</i> | cuttlefish | 0.47 | 2.73 | 1 |
| | | • | ZF1430 | CUR | RAY | <i>Raja</i> | <i>naevus</i> | cuckoo ray | 0.00089 | 3.486 | 1.13 |
| | | • | ZG8910 | DAB | DAB | <i>Limanda</i> | <i>limanda</i> | dab | 0.00545 | 3.195 | 1.07 |
| | | • | ZG6990 | DET | | <i>Callionymus</i> | spp. | dragonet | 0.003 | 3.2639 | 1 |
| | | • | ZG8990 | FLE | FLE | <i>Platichthys</i> | <i>flesus</i> | flounder | 0.0087 | 3.0978 | 1.08 |
| | | • | ZF410 | GSD | | <i>Scyliorhinus</i> | <i>stellaris</i> | greater spotted dogfish / bullhuss. | 0.0035 | 3 | 1 |
| | | • | ZG4080 | GUG | GUX | <i>Eutrigla</i> | <i>gurnardus</i> | gurnard (grey) | 0.0062 | 3.1003 | 1 |
| | | • | ZG4040 | GUL | GUX | <i>Aspitrigla</i> | <i>obscura</i> | gurnard (long-finned) | 0.0045 | 3.228 | 1 |
| | | • | ZG4210 | GUS | GUX | <i>Trigloporus</i> | <i>lastoviza</i> | gurnard (streaked) | 0.0045 | 3.228 | 1 |
| | | • | ZG4160 | GUT | GUX | <i>Trigla</i> | <i>lucerna</i> | tub gurnard | 0.008 | 3.061 | 1 |
| | • | | • | ZG4030 | GUX | GUX | <i>Aspitrigla</i> | <i>cuculus</i> | gurnard (red) | 0.0045 | 3.228 |
| | | • | ZG1820 | HAD | HAD | <i>Melanogrammus</i> | <i>aeglefinus</i> | haddock | 0.015 | 2.8268 | 1.16 |
| | | • | ZG490 | HER | HER | <i>Clupea</i> | <i>harengus</i> | herring | 0.0059 | 3.0904 | 1 |
| | | • | ZG2240 | HKE | HKE | <i>Merluccius</i> | <i>merluccius</i> | hake | 0.0047 | 3.099 | 1.16 |
| | | • | ZG5080 | HOM | HOM | <i>Trachurus</i> | <i>trachurus</i> | scad, horse mackerel | 0.0034 | 3.2943 | 1 |
| | | • | ZG3160 | JOD | JOD | <i>Zeus</i> | <i>faber</i> | John Dory | 0.0229 | 2.9343 | 1 |
| | | • | ZG8950 | LEM | LEM | <i>Microstomus</i> | <i>kitt</i> | lemon sole | 0.00756 | 3.142 | 1.04 |
| | | • | ZG1960 | LIN | LIN | <i>Molva</i> | <i>molva</i> | ling | 0.00407 | 3.07 | 1.15 |
| | | • | ZF400 | LSD | LSD | <i>Scyliorhinus</i> | <i>canicula</i> | lesser spotted dogfish | 0.0035 | 3 | 1 |
| | | • | ZG8000 | MAC | MAC | <i>Scomber</i> | <i>scombrus</i> | Atlantic mackerel | 0.003 | 3.29 | 1 |
| | | • | ZG8500 | MEG | MEG | <i>Lepidorhombus</i> | <i>whiffiagonis</i> | megrim | 0.00245 | 3.321 | 1.05 |
| | | • | ZG1350 | MOB | MON | <i>Lophius</i> | <i>budegassa</i> | black-bellied angler | 0.0257 | 2.8866 | 3 |
| | | • | ZG1360 | MON | MON | <i>Lophius</i> | <i>piscatorius</i> | monkfish / anglerfish | 0.0153 | 2.9979 | 3 |
| | | • | ZG5760 | MUG | | <i>Mugilidae</i> | spp. | grey mullets | 0.0148 | 2.9034 | 1 |
| | | • | ZG5680 | MUR | MUR | <i>Mullus</i> | <i>surmuletus</i> | red mullet | 0.0047 | 3.3088 | 1.13 |
| | | • | W25160 | OCT | | <i>Octopus / Eledone</i> | spp. | octopus | 0.04 | 3 | 1 |
| | | • | ZG2190 | PCO | | <i>Trisopterus</i> | <i>minutus</i> | poor cod | 0.0092 | 3.0265 | 1 |
| | | • | ZG530 | PIL | PIL | <i>Sardinia</i> | <i>pilchardus</i> | pilchard (sardine) | 0.00213 | 3.4746 | 1 |
| | | • | ZG9030 | PLE | PLE | <i>Pleuronectes</i> | <i>platessa</i> | plaice | 0.0089 | 3.053 | 1.07 |
| | | • | ZG4480 | POG | | <i>Agonus</i> | <i>cataphractus</i> | pogge | 0.0196 | 2.6139 | 1 |
| | • | ZG2090 | POK | | <i>Pollachius</i> | <i>virens</i> | blackjack, saithe, coalfish, coley, drummer | 0.0099 | 2.99 | 1.19 | |
| • | | • | ZG2080 | POL | POL | <i>Pollachius</i> | <i>pollachius</i> | Pollack | 0.0099 | 2.99 | 1.14 |
| | | • | ZG8730 | SCA | none | <i>Arnoglossus</i> | <i>laterna</i> | scaldfish | 0.008 | 3 | 1 |
| | | • | ZG8720 | SCI | | <i>Arnoglossus</i> | <i>imperialis</i> | imperial scaldfish | 0.008 | 3 | 1 |
| | | • | ZG18050 | SCQ | | <i>Aequipecten</i> | <i>opercularis</i> | queen scallop | 0.174 | 3 | 1 |
| | | • | S25530 | SCR | | <i>Maja</i> | <i>squinado</i> | spider crab | 0.554 | 2.886 | 1 |
| | | • | W18090 | SCX | SCX | <i>Pecten</i> | <i>maximus</i> | scallop | 0.174 | 3 | 1 |
| | | • | ZG6860 | SDL | | <i>Ammodytes</i> | <i>tobianus</i> | lesser sand eel | 0.00097 | 3.32 | 1 |
| | | • | ZF1410 | SER | RAY | <i>Raja</i> | <i>microocellata</i> | small-eyed ray | 0.0099 | 3.2051 | 1.13 |
| | | • | ZG430 | SHD | SHD | <i>Alosa</i> | <i>sp</i> | shad | 0.0096 | 2.981 | 1 |
| | | • | ZG830 | SME | | <i>Osmerus</i> | <i>eperlanus</i> | smelt | 0.07 | 2.9694 | 1 |
| | | • | ZF550 | SMH | | <i>Mustelus</i> | <i>mustelus</i> | smoothhound | 0.004 | 3 | 1 |
| | | • | ZG9290 | SOL | | <i>Solea</i> | <i>solea</i> | Dover sole | 0.00762 | 3.068 | 1.05 |
| | | • | ZF1420 | SPO | SOL | <i>Raja</i> | <i>montagui</i> | spotted ray | 0.0027 | 3.23 | 1.13 |
| | | • | ZG570 | SPR | | <i>Sprattus</i> | <i>sprattus</i> | sprats | 0.00194 | 3.4746 | 1 |
| | | • | W24300 | SQC | SQC | <i>Loligo</i> | <i>sp</i> | squid (unspecified) | 0.041 | 3 | 1 |
| | | • | W24310 | SQC(F) | SQC | <i>Loligo</i> | <i>forbesii</i> | squid (commercial) | 0.041 | 3 | 1 |
| | | • | W24320 | SQC(V) | SQC | <i>Loligo</i> | <i>vulgaris</i> | squid (commercial) | 0.041 | 3 | 1 |
| | | • | W24350 | SQF‡ | | <i>Alloteuthis</i> ‡ | <i>sp</i> | squid (non-commercial) | 0.04 | 3 | 1 |
| | | • | ZF560 | SSH | | <i>Mustelus</i> | <i>asterias</i> | starry smooth hound | 0.002 | 3.1164 | 1 |
| | | • | ZF1460 | STR | RAY | <i>Raja</i> | <i>radiata</i> | starry skate (<i>Amblyraja</i> <i>radiata</i>) on FishBase | 0.0409 | 2.8965 | 1 |
| • | | • | ZF1360 | THR | RAY | <i>Raja</i> | <i>clavata</i> | thornback ray | 0.0187 | 3.0062 | 1 |
| | | • | ZF1470 | UDR | RAY | <i>Raja</i> | <i>undulata</i> | undulate ray | 0.0099 | 3.2051 | 1.13 |
| | | • | ZG1900 | WHB | WHG | <i>Micromesistius</i> | <i>poutassou</i> | blue whiting | 0.0075 | 3.027 | 1 |
| | | • | ZG1860 | WHG | WHG | <i>Merlangius</i> | <i>merlangus</i> | whiting | 0.00556 | 3.104 | 1.13 |
| | | • | ZG5860 | WRA | WRA | <i>unspecified</i> | <i>unspecified</i> | wrasses | 0.0048 | 3.3175 | 1 |
| | | • | ZG3210 | ZUL | | <i>Capros</i> | <i>aper</i> | zulu (boarfish) | 0.22 | 1.97 | 1 |

† See Appendix C (Table C.1, page 348 and Table C.2, page 349, below) for higher classification levels. 'a' and 'b' values and the gutted weight ratio are from Coull *et al.*, (1989) and Lart (*pers com.*) and are shown to the precision provided.

‡ *Alloteuthis sp* (SQF) was included here (though this species was always discarded) as it was measured at sea and later converted to weight. It is highlighted as a non-fish species, (see Table 3.4, page 54 and Table 3.5, page 56, below).

The first three columns in Table 3.3 detail the fate (landed or discarded) of each species. Two species (conger, *Conger conger* and saithe *Pollachius virens*) were found in the haul but were absent from the samples (therefore are absent from Table 3.4 and Table 3.5. Large size was the reason for not sampling conger as described in section 2.2.2 (see Figure 2.5, page 29, above). Saithe was not sampled simply because it did not occur in the sampled volumes. Indeed saithe was quite a rare fish species, being the third most rare across the whole of the haul weight (these species are included Table 3.3 as they were analysed in Chapter 10 (when relating the haul data with the market throughput).

Column four shown the taxon ID according to Picton & Howson, (1999). Column five shows the codes for each species, arranged in alphabetical order of the generally three-letter species codes. These codes were largely derived from those employed by The SeaFish Industry Authority (e.g. as used by Course *et al.*, 1996) These are meant to be self explanatory, though they are not scientific terms, and care needs to be taken to ensure there is no confusion between species and operators; between this study and others. The species codes on landing data (column six) shows the codes assigned to species in the haul composition. It can be seen that many of these are the same as for column five, but importantly they show which species were combined together by the fishermen and are treated together for analysis. Examples of this practice were common for the gurnards, squids, and rays, and less commonly for monkfish, and whiting, where occasionally a black-bellied monkfish or blue whiting respectively was included in the haul. Further examination of these categories is presented in Chapter 9 and Chapter 10.

The scaldfish has "none" for its haul code because while it did occur in a sample designated to be landed these fish were discarded by crews. The next three columns describe the classification (as genus and species) and common name(s) of the species.

The last three columns detail the length:weight relationship, exponent and gutted weight ratio. Most of these data were acquired from Coull *et al.*, (1989) or Lart (*pers. com*). These values did not appear to generate reliable weight from length data for the

dragonet (*Callionymus sp*) via the batch weighting of species the conversion values were not available for the starry smooth hound (*Mustelus asterias*). Appendix B describes how these data were acquired. The 8 shellfish species were included in Table 3.3 as when these occurred in the landed part of the sample they were measured at sea and these data were converted to weight. Without these shellfishes, there were 54 fish species.

3.3 Species composition in the sample

3.3.1 Species composition across all samples

Table 3.4 shows the rank-order of species across all samples by weight.

Table 3.4. The rank-order of species from all samples, showing their individual weight contribution (g), and individual (% 2 d.p.) and cumulative contribution, (% 2 d.p.) for all species. Lines demarcate those species that cumulatively contribute to 95 % and the most dominant 60 species. Species that occurred only in the non-fish part of the sample are strongly highlighted and shellfish species are lightly highlighted in yellow. Items described in section 2.3.3.3, 'Group Anthropogenica, Geologica and other Plantae' are highlighted in blue. Some genus names (marked *) have been shortened for clarity.

| # | species | wt | % | c % | # | species | wt | % | c % | # | species | wt | % | c % | # | species | wt | % | c % |
|----|--------------------------------|-----------|-------|-------|----|----------------------------------|---------|------|-------|-----|--------------------------------|------|------|--------|-----|----------------------------------|-----|------|--------|
| 1 | <i>Aspitrigla cuculus</i> | 408,854.6 | 13.95 | 13.95 | 49 | <i>Melanogram* aeglefinus</i> | 2,167.0 | 0.07 | 99.10 | 97 | <i>Engraulis encrasicolus</i> | 86.3 | 0.00 | 99.97 | 145 | <i>Halarachnion ligulatum</i> | 2.6 | 0.00 | 100.00 |
| 2 | <i>Merlangius merlangus</i> | 366,308.2 | 12.50 | 26.45 | 50 | <i>Clupea harengus</i> | 1,737.5 | 0.06 | 99.16 | 98 | <i>Corystes cassivelaunus</i> | 68.0 | 0.00 | 99.97 | 146 | <i>Lafoea dumosa</i> | 2.6 | 0.00 | 100.00 |
| 3 | <i>Trisopterus luscus</i> | 231,652.3 | 7.90 | 34.35 | 51 | <i>Aspitrigla obscura</i> | 1,513.9 | 0.05 | 99.21 | 99 | <i>Flustra foliacea</i> | 67.3 | 0.00 | 99.97 | 147 | <i>Obelia dichotoma</i> | 2.5 | 0.00 | 100.00 |
| 4 | <i>Gadus morhua</i> | 189,020.4 | 6.45 | 40.80 | 52 | <i>Aequipecten opercularis</i> | 1,455.6 | 0.05 | 99.26 | 100 | <i>Nemertesia antennina</i> | 63.8 | 0.00 | 99.97 | 148 | <i>Polysiphonia elongata</i> | 2.2 | 0.00 | 100.00 |
| 5 | <i>Zeus faber</i> | 178,091.6 | 6.08 | 46.87 | 53 | <i>Scyliorhinus stellaris</i> | 1,396.2 | 0.05 | 99.31 | 101 | <i>Ophiura ophiura</i> | 63.8 | 0.00 | 99.98 | 149 | <i>Macropodia linaresi</i> | 1.9 | 0.00 | 100.00 |
| 6 | <i>Loligo vulgaris</i> | 174,266.5 | 5.95 | 52.82 | 54 | <i>Luidia ciliaris</i> | 1,296.2 | 0.04 | 99.35 | 102 | bone | 62.7 | 0.00 | 99.98 | 150 | <i>Obelia sp</i> | 1.9 | 0.00 | 100.00 |
| 7 | <i>Microstomus kitt</i> | 174,159.5 | 5.94 | 58.76 | 55 | litter | 1,269.8 | 0.04 | 99.40 | 103 | <i>Echinus sp</i> | 53.6 | 0.00 | 99.98 | 151 | <i>Abietinaria abietina</i> | 1.7 | 0.00 | 100.00 |
| 8 | <i>Scyliorhinus canicula</i> | 126,225.4 | 4.31 | 63.07 | 56 | Labridae | 1,017.9 | 0.03 | 99.43 | 104 | <i>Fucus serratus</i> | 45.3 | 0.00 | 99.98 | 152 | <i>Anomia ephippium</i> | 1.7 | 0.00 | 100.00 |
| 9 | <i>Loligo sp</i> | 91,660.7 | 3.13 | 66.19 | 57 | coal | 1,000.9 | 0.03 | 99.47 | 105 | <i>Liocarcinus sp</i> | 37.6 | 0.00 | 99.98 | 153 | <i>Diphasia pinaster</i> | 1.6 | 0.00 | 100.00 |
| 10 | <i>Pleuronectes platessa</i> | 88,659.5 | 3.02 | 69.22 | 58 | <i>Cellaria sp</i> | 961.5 | 0.03 | 99.50 | 106 | <i>Pentapora fascialis</i> | 31.0 | 0.00 | 99.99 | 154 | <i>Caryophyllia smithii</i> | 1.5 | 0.00 | 100.00 |
| 11 | <i>Trachurus trachurus</i> | 83,298.4 | 2.84 | 72.06 | 59 | <i>Echinus elegans</i> | 933.3 | 0.03 | 99.53 | 107 | <i>Acanthocardia echinata</i> | 30.3 | 0.00 | 99.99 | 155 | <i>Abietinaria filicula</i> | 1.3 | 0.00 | 100.00 |
| 12 | <i>Marthasterias glacialis</i> | 76,562.1 | 2.61 | 74.67 | 60 | <i>Sardina pilchardus</i> | 931.6 | 0.03 | 99.56 | 108 | <i>Botryllus schlosseri</i> | 24.7 | 0.00 | 99.99 | 156 | <i>Mastocarpus stellata</i> | 1.3 | 0.00 | 100.00 |
| 13 | <i>Loligo forbesii</i> | 70,038.3 | 2.39 | 77.06 | 61 | <i>Buccinum undatum</i> | 817.3 | 0.03 | 99.59 | 109 | <i>Atrina fragilis</i> | 23.2 | 0.00 | 99.99 | 157 | <i>Sertularella gayi</i> | 1.3 | 0.00 | 100.00 |
| 14 | <i>Scomber scombrus</i> | 61,670.2 | 2.10 | 79.17 | 62 | <i>Amoglossus laterna</i> | 734.6 | 0.03 | 99.62 | 110 | <i>Ophiura affinis</i> | 22.4 | 0.00 | 99.99 | 158 | <i>Ectocarpus siliculosus</i> | 1.2 | 0.00 | 100.00 |
| 15 | <i>Raja brachyura</i> | 59,459.1 | 2.03 | 81.19 | 63 | <i>Sprattus sprattus</i> | 719.1 | 0.02 | 99.64 | 111 | <i>Nemertesia ramosa</i> | 22.0 | 0.00 | 99.99 | 159 | <i>Delesseria sanguinea</i> | 1.1 | 0.00 | 100.00 |
| 16 | <i>Limanda limanda</i> | 58,952.0 | 2.01 | 83.21 | 64 | <i>Astropecten irregularis</i> | 716.2 | 0.02 | 99.66 | 112 | <i>Luidia sp</i> | 21.4 | 0.00 | 99.99 | 160 | <i>Galathea dispersa</i> | 1.1 | 0.00 | 100.00 |
| 17 | <i>Raja clavata</i> | 52,531.9 | 1.79 | 85.00 | 65 | <i>Trigloporus lastoviza</i> | 715.5 | 0.02 | 99.69 | 113 | <i>Sertularella polyzonias</i> | 18.8 | 0.00 | 99.99 | 161 | <i>Halurus equisetifolius</i> | 1.0 | 0.00 | 100.00 |
| 18 | <i>Lophius piscatorius</i> | 48,119.3 | 1.64 | 86.64 | 66 | <i>Liocarcinus marmoreus</i> | 567.3 | 0.02 | 99.71 | 114 | <i>Eunicella verrucosa</i> | 17.2 | 0.00 | 99.99 | 162 | <i>Kirchenpaueria pinnata</i> | 0.9 | 0.00 | 100.00 |
| 19 | <i>Lepid* whiffiagonis</i> | 31,394.9 | 1.07 | 87.71 | 67 | <i>Porania pulvillus</i> | 553.6 | 0.02 | 99.73 | 115 | <i>Anseropoda placenta</i> | 15.4 | 0.00 | 99.99 | 163 | <i>Membranipora membranacea</i> | 0.9 | 0.00 | 100.00 |
| 20 | <i>Raja naevus</i> | 27,777.8 | 0.95 | 88.66 | 68 | stone | 497.9 | 0.02 | 99.74 | 116 | <i>Ascophyllum nodosum</i> | 14.1 | 0.00 | 99.99 | 164 | <i>Halecium beanli</i> | 0.8 | 0.00 | 100.00 |
| 21 | <i>Raja radiata</i> | 23,536.6 | 0.80 | 89.46 | 69 | <i>Amoglossus imperialis</i> | 494.8 | 0.02 | 99.76 | 117 | <i>Halecium halecium</i> | 13.0 | 0.00 | 99.99 | 165 | <i>Palliolium tigrinum</i> | 0.8 | 0.00 | 100.00 |
| 22 | <i>Sepia officinalis</i> | 23,060.1 | 0.79 | 90.25 | 70 | <i>Alcyonium digitatum</i> | 467.0 | 0.02 | 99.78 | 118 | <i>Macropodia tenuirostris</i> | 12.9 | 0.00 | 99.99 | 166 | <i>Callophyllis laciniata</i> | 0.5 | 0.00 | 100.00 |
| 23 | <i>Merluccius merluccius</i> | 22,676.1 | 0.77 | 91.02 | 71 | <i>Micromesistius poutassou</i> | 464.3 | 0.02 | 99.79 | 119 | <i>Aporrhais pespelecani</i> | 12.3 | 0.00 | 99.99 | 167 | <i>Fucus ceranoides</i> | 0.5 | 0.00 | 100.00 |
| 24 | <i>Eutrigla gurnardus</i> | 21,380.4 | 0.73 | 91.75 | 72 | <i>Echinus acutus</i> | 435.5 | 0.01 | 99.81 | 120 | leaf | 12.0 | 0.00 | 99.99 | 168 | <i>Rhizocaulus verticillatus</i> | 0.5 | 0.00 | 100.00 |
| 25 | <i>Platichthys flesus</i> | 21,045.2 | 0.72 | 92.47 | 73 | <i>Glycymeris glycymeris</i> | 389.3 | 0.01 | 99.82 | 121 | <i>Macropodia deflexa</i> | 10.6 | 0.00 | 99.99 | 169 | <i>Achaeus cranchii</i> | 0.4 | 0.00 | 100.00 |
| 26 | <i>Trisopterus minutus</i> | 20,641.6 | 0.70 | 93.17 | 74 | <i>Raja montagui</i> | 372.0 | 0.01 | 99.83 | 122 | <i>Polyclinum aurantium</i> | 10.6 | 0.00 | 99.99 | 170 | <i>Galathea strigosa</i> | 0.4 | 0.00 | 100.00 |
| 27 | <i>Pollachius pollachius</i> | 19,086.3 | 0.65 | 93.82 | 75 | <i>Alloteuthis subulata</i> | 332.1 | 0.01 | 99.85 | 123 | <i>Himantalia elongata</i> | 9.0 | 0.00 | 99.99 | 171 | <i>Gelidium crinale</i> | 0.4 | 0.00 | 100.00 |
| 28 | <i>Cancer pagurus</i> | 16,158.8 | 0.55 | 94.38 | 76 | <i>Liocarcinus corrugatus</i> | 328.5 | 0.01 | 99.86 | 124 | <i>Pagurus prideaux</i> | 8.8 | 0.00 | 100.00 | 172 | <i>Macropodia rostrata</i> | 0.4 | 0.00 | 100.00 |
| 29 | <i>Raja microcellata</i> | 14,986.9 | 0.51 | 94.89 | 77 | <i>Alosa sp</i> | 322.8 | 0.01 | 99.87 | 125 | <i>Crepidula fornicata</i> | 7.8 | 0.00 | 100.00 | 173 | <i>Sertularella tenella</i> | 0.4 | 0.00 | 100.00 |
| 30 | <i>Callionymus sp</i> | 14,143.4 | 0.48 | 95.37 | 78 | <i>Crossaster papposus</i> | 269.1 | 0.01 | 99.88 | 126 | <i>Akera bullata</i> | 7.5 | 0.00 | 100.00 | 174 | <i>Amphisbetia operculata</i> | 0.3 | 0.00 | 100.00 |
| 31 | <i>Scophthalmus rhombus</i> | 13,281.4 | 0.45 | 95.82 | 79 | <i>Aphrodita aculeata</i> | 233.6 | 0.01 | 99.88 | 127 | <i>Sertularia cupressina</i> | 7.4 | 0.00 | 100.00 | 175 | <i>Obelia bidentata</i> | 0.3 | 0.00 | 100.00 |
| 32 | <i>Asterias rubens</i> | 13,277.0 | 0.45 | 96.27 | 80 | <i>Liocarcinus vernalis</i> | 201.4 | 0.01 | 99.89 | 128 | <i>Calliblepharis ciliata</i> | 7.0 | 0.00 | 100.00 | 176 | <i>Polysiphonia nigra</i> | 0.3 | 0.00 | 100.00 |
| 33 | <i>Echinus esculentus</i> | 10,942.9 | 0.37 | 96.65 | 81 | <i>Pagurus bernhardus</i> | 194.9 | 0.01 | 99.90 | 129 | <i>Pisidia longicornis</i> | 6.5 | 0.00 | 100.00 | 177 | <i>Securiflustra securifrons</i> | 0.3 | 0.00 | 100.00 |
| 34 | <i>Mustelus asterias</i> | 10,722.9 | 0.37 | 97.01 | 82 | <i>Spatangus purpureus</i> | 193.8 | 0.01 | 99.90 | 130 | <i>Ammodytes tobianus</i> | 6.2 | 0.00 | 100.00 | 178 | <i>Trivia arctica</i> | 0.3 | 0.00 | 100.00 |
| 35 | <i>Dicentrarchus labrax</i> | 9,021.5 | 0.31 | 97.32 | 83 | <i>Argentina sphyraena</i> | 188.9 | 0.01 | 99.91 | 131 | <i>Stelligera stuposa</i> | 5.9 | 0.00 | 100.00 | 179 | <i>Ulva lactuca</i> | 0.3 | 0.00 | 100.00 |
| 36 | <i>Mullus surmuletus</i> | 6,903.5 | 0.24 | 97.56 | 84 | DECAPODA | 167.3 | 0.01 | 99.92 | 132 | <i>S. canicula (eggcase)</i> | 5.6 | 0.00 | 100.00 | 180 | <i>Zostera marina</i> | 0.3 | 0.00 | 100.00 |
| 37 | <i>Pecten maximus</i> | 6,686.8 | 0.23 | 97.79 | 85 | <i>Mugil sp</i> | 150.5 | 0.01 | 99.92 | 133 | <i>Scrupocellaria sp</i> | 5.5 | 0.00 | 100.00 | 181 | <i>Diphasia rosacea</i> | 0.3 | 0.00 | 100.00 |
| 38 | <i>Trigla lucerna</i> | 5,135.8 | 0.18 | 97.96 | 86 | <i>Chaetopterus varlopedatus</i> | 146.4 | 0.00 | 99.93 | 134 | <i>Ophiura sp</i> | 5.1 | 0.00 | 100.00 | 182 | <i>Diphasia alata</i> | 0.2 | 0.00 | 100.00 |
| 39 | <i>Maja squinado</i> | 4,883.4 | 0.17 | 98.13 | 87 | <i>Osmerus eperlanus</i> | 142.2 | 0.00 | 99.93 | 135 | <i>Palmaria palmata</i> | 4.8 | 0.00 | 100.00 | 183 | <i>Heterosiphonia plumosa</i> | 0.2 | 0.00 | 100.00 |
| 40 | <i>Molva molva</i> | 4,137.9 | 0.14 | 98.27 | 88 | <i>Agonus cataphractus</i> | 129.5 | 0.00 | 99.94 | 136 | <i>Diphasia attenuata</i> | 4.4 | 0.00 | 100.00 | 184 | <i>Perinereis cultrifera</i> | 0.2 | 0.00 | 100.00 |
| 41 | <i>Liocarcinus depurator</i> | 3,898.0 | 0.13 | 98.40 | 89 | <i>Holothuria forskali</i> | 123.8 | 0.00 | 99.94 | 137 | <i>Obelia longissima</i> | 4.1 | 0.00 | 100.00 | 185 | <i>Pterocladia capillacea</i> | 0.2 | 0.00 | 100.00 |
| 42 | <i>Liocarcinus holsatus</i> | 3,387.5 | 0.12 | 98.52 | 90 | <i>Hippasteria phrygiana</i> | 114.9 | 0.00 | 99.94 | 138 | <i>Inachus leptochirus</i> | 3.9 | 0.00 | 100.00 | 186 | <i>Actinia equina</i> | 0.1 | 0.00 | 100.00 |
| 43 | <i>Raja undulata</i> | 3,023.2 | 0.10 | 98.62 | 91 | <i>Inachus dorsettensis</i> | 108.7 | 0.00 | 99.95 | 139 | <i>Liocarcinus pusillus</i> | 3.7 | 0.00 | 100.00 | 187 | <i>Aglaophenia kirchenpaueri</i> | 0.1 | 0.00 | 100.00 |
| 44 | <i>Lophius budegassa</i> | 2,574.3 | 0.09 | 98.71 | 92 | <i>Capros aper</i> | 103.8 | 0.00 | 99.95 | 140 | <i>Hydrallmania falcata</i> | 3.6 | 0.00 | 100.00 | 188 | <i>Enteromorpha sp</i> | 0.1 | 0.00 | 100.00 |
| 45 | <i>Necora puber</i> | 2,459.3 | 0.08 | 98.79 | 93 | <i>Rossia macrosoma</i> | 100.4 | 0.00 | 99.96 | 141 | <i>Lytocarpia myriophyllum</i> | 3.3 | 0.00 | 100.00 | 189 | <i>Monothea obliqua</i> | 0.1 | 0.00 | 100.00 |
| 46 | <i>Solea solea</i> | 2,417.3 | 0.08 | 98.87 | 94 | PORIFERA | 100.0 | 0.00 | 99.96 | 142 | <i>Galathea intermedia</i> | 3.0 | 0.00 | 100.00 | 190 | <i>Pycnogonum littorale</i> | 0.1 | 0.00 | 100.00 |
| 47 | <i>Octopodidae</i> | 2,250.0 | 0.08 | 98.95 | 95 | <i>Loliginidae</i> | 99.2 | 0.00 | 99.96 | 143 | <i>Eudendrium ramosum</i> | 3.0 | 0.00 | 100.00 | 191 | <i>Tamarisca tamarisca</i> | 0.1 | 0.00 | 100.00 |
| 48 | <i>Chrysora hysoscella</i> | 2,250.0 | 0.08 | 99.03 | 96 | <i>Polybius henslowii</i> | 95.8 | 0.00 | 99.97 | 144 | <i>Chondrus crispus</i> | 2.8 | 0.00 | 100.00 | | | | | |

Table 3.4 shows that the most abundant fish species in the sample were the red gurnard followed by whiting, bib, cod, John Dory, European squid, lemon sole, lesser spotted dogfish, unspecified (usually damaged) squid then plaice. These 10 species or groups comprised nearly 70 % of the sample.

Table 3.4 also shows that across all the samples only one non-fish species (*M. glacialis*, rank 12) occurred in the top 30 which made up > 95 % of the sample. A further two species within the top 30, *Loligo vulgaris* and *L. forbesii* (rank 6 and 13 respectively) were shellfishes. *Loligo sp.* (rank 9) was where the identification could not be carried to species level.

The prominence of *M. glacialis* in Table 3.4 was due to its large size. The mean weight of the fishes was 275 g across all the samples although the average weight of complete *M. glacialis* across all of the samples was 505 g and including damaged specimen, this was 201 g.

3.3.2 Species composition according to port and type of trawling

Table 3.5 shows the rank-order by weight of species in the sample by port and type of trawling.

Table 3.5. The rank-order of species by weight from all samples according to port and type of trawling, and showing their individual (% 1 d.p.) and cumulative contribution, (% 0 d.p.) for the top 70 species. Lines demarcate those species that cumulatively contribute to 95 % and the most dominant 60 species. Species that occurred only in the non-fish part of the sample are strongly highlighted and shellfish species are lightly highlighted in yellow. Items described in section 2.3.3.3, 'Group Anthropogenica, Geologica and other Plantae' are highlighted in blue. Some genus names (marked *) have been shortened for clarity.

| | | | | | | | | | | | | | | | | | | |
|----|--------------------------------|-----|-----|-------------------------------|-----|-----|--------------------------------|-----|-----|-------------------------------|-----|-----|--------------------------------|-----|-----|----------------------------------|-----|-----|
| 50 | <i>Liocarcinus depurator</i> | 0.0 | 100 | litter | 0.0 | 100 | <i>Ophiura ophiura</i> | 0.0 | 100 | litter | 0.0 | 100 | <i>Liocarcinus corrugatus</i> | 0.0 | 100 | <i>Liocarcinus corrugatus</i> | 0.0 | 100 |
| 51 | litter | 0.0 | 100 | <i>Spatangus purpureus</i> | 0.0 | 100 | <i>Aphrodita aculeata</i> | 0.0 | 100 | <i>Liocarcinus vernalis</i> | 0.0 | 100 | <i>Agonus cataphractus</i> | 0.0 | 100 | <i>Astropecten irregularis</i> | 0.0 | 100 |
| 52 | <i>Solea solea</i> | 0.0 | 100 | <i>Chaetop* variopedatus</i> | 0.0 | 100 | <i>Alloteuthis subulata</i> | 0.0 | 100 | <i>Echinus elegans</i> | 0.0 | 100 | <i>Liocarcinus vernalis</i> | 0.0 | 100 | <i>Inachus dorsettensis</i> | 0.0 | 100 |
| 53 | <i>Raja montagui</i> | 0.0 | 100 | <i>Porania pulvillus</i> | 0.0 | 100 | <i>Chaetop* variopedatus</i> | 0.0 | 100 | <i>Glycymeris glycymeris</i> | 0.0 | 100 | <i>Luidia ciliaris</i> | 0.0 | 100 | <i>Corystes cassivelaunus</i> | 0.0 | 100 |
| 54 | <i>Buccinum undatum</i> | 0.0 | 100 | PORIFERA | 0.0 | 100 | <i>Capros aper</i> | 0.0 | 100 | <i>Pagurus bernhardus</i> | 0.0 | 100 | <i>Astropecten irregularis</i> | 0.0 | 100 | DECAPODA | 0.0 | 100 |
| 55 | <i>Glycymeris glycymeris</i> | 0.0 | 100 | <i>Alcyonium digitatum</i> | 0.0 | 100 | stone | 0.0 | 100 | <i>Aphrodita aculeata</i> | 0.0 | 100 | <i>Ophiura ophiura</i> | 0.0 | 100 | <i>Acanthocardia echinata</i> | 0.0 | 100 |
| 56 | <i>Alloteuthis subulata</i> | 0.0 | 100 | DECAPODA | 0.0 | 100 | <i>Liocarcinus vernalis</i> | 0.0 | 100 | <i>Inachus dorsettensis</i> | 0.0 | 100 | <i>Nemertesia antennina</i> | 0.0 | 100 | <i>Liocarcinus sp</i> | 0.0 | 100 |
| 57 | <i>Crossaster papposus</i> | 0.0 | 100 | <i>Agonus cataphractus</i> | 0.0 | 100 | <i>Ascophyllum nodosum</i> | 0.0 | 100 | <i>Pecten maximus</i> | 0.0 | 100 | DECAPODA | 0.0 | 100 | <i>Nemertesia antennina</i> | 0.0 | 100 |
| 58 | <i>Argentina sphyraena</i> | 0.0 | 100 | <i>Liocarcinus vernalis</i> | 0.0 | 100 | <i>Pagurus bernhardus</i> | 0.0 | 100 | <i>Chaetop* variopedatus</i> | 0.0 | 100 | <i>Corystes cassivelaunus</i> | 0.0 | 100 | <i>Aporrhais pespelecani</i> | 0.0 | 100 |
| 59 | <i>Liocarcinus corrugatus</i> | 0.0 | 100 | <i>Hippasteria phrygiana</i> | 0.0 | 100 | <i>Sertularella polyzonias</i> | 0.0 | 100 | <i>Corystes cassivelaunus</i> | 0.0 | 100 | <i>Liocarcinus marmoreus</i> | 0.0 | 100 | <i>Agonus cataphractus</i> | 0.0 | 100 |
| 60 | <i>Amoglossus imperialis</i> | 0.0 | 100 | <i>Amoglossus imperialis</i> | 0.0 | 100 | <i>Nemertesia ramosa</i> | 0.0 | 100 | <i>Alcyonium digitatum</i> | 0.0 | 100 | <i>Inachus dorsettensis</i> | 0.0 | 100 | <i>Alloteuthis subulata</i> | 0.0 | 100 |
| 61 | <i>Osmerus eperlanus</i> | 0.0 | 100 | <i>Holothuria forskali</i> | 0.0 | 100 | <i>Inachus dorsettensis</i> | 0.0 | 100 | PORIFERA | 0.0 | 100 | Loliginidae | 0.0 | 100 | leaf | 0.0 | 100 |
| 62 | <i>Rossia macrosoma</i> | 0.0 | 100 | <i>Pagurus bernhardus</i> | 0.0 | 100 | <i>Macropodia tenuirostris</i> | 0.0 | 100 | <i>Atrina fragilis</i> | 0.0 | 100 | <i>Flustra foliacea</i> | 0.0 | 100 | <i>Ophiura affinis</i> | 0.0 | 100 |
| 63 | <i>Aequipecten opercularis</i> | 0.0 | 100 | <i>Glycymeris glycymeris</i> | 0.0 | 100 | <i>Himanthalia elongata</i> | 0.0 | 100 | <i>Sprattus sprattus</i> | 0.0 | 100 | <i>Sertularella polyzonias</i> | 0.0 | 100 | <i>Akera bullata</i> | 0.0 | 100 |
| 64 | <i>Spatangus purpureus</i> | 0.0 | 100 | <i>Aphrodita aculeata</i> | 0.0 | 100 | <i>Fucus serratus</i> | 0.0 | 100 | <i>Ophiura ophiura</i> | 0.0 | 100 | <i>Diphasia attenuata</i> | 0.0 | 100 | <i>Crepidula fornicata</i> | 0.0 | 100 |
| 65 | <i>Limanda limanda</i> | 0.0 | 100 | <i>Inachus dorsettensis</i> | 0.0 | 100 | <i>Nemertesia antennina</i> | 0.0 | 100 | <i>Alloteuthis subulata</i> | 0.0 | 100 | <i>Macropodia deflexa</i> | 0.0 | 100 | <i>Calliblepharis ciliata</i> | 0.0 | 100 |
| 66 | Loliginidae | 0.0 | 100 | <i>Liocarcinus corrugatus</i> | 0.0 | 100 | <i>Stelligera stuposa</i> | 0.0 | 100 | <i>Halecium halecium</i> | 0.0 | 100 | <i>Nemertesia ramosa</i> | 0.0 | 100 | <i>Ammodytes tobianus</i> | 0.0 | 100 |
| 67 | <i>Liocarcinus marmoreus</i> | 0.0 | 100 | <i>Cellaria sp</i> | 0.0 | 100 | <i>Ophiura affinis</i> | 0.0 | 100 | Loliginidae | 0.0 | 100 | <i>Obelia longissima</i> | 0.0 | 100 | <i>Palmaria palmata</i> | 0.0 | 100 |
| 68 | <i>Holothuria forskali</i> | 0.0 | 100 | <i>Capros aper</i> | 0.0 | 100 | <i>Ophiura sp</i> | 0.0 | 100 | <i>Pagurus prideaux</i> | 0.0 | 100 | <i>Stelligera stuposa</i> | 0.0 | 100 | <i>Liocarcinus pusillus</i> | 0.0 | 100 |
| 69 | <i>Capros aper</i> | 0.0 | 100 | <i>Nemertesia antennina</i> | 0.0 | 100 | <i>Eunicella verrucosa</i> | 0.0 | 100 | <i>Nemertesia ramosa</i> | 0.0 | 100 | <i>Halecium halecium</i> | 0.0 | 100 | <i>Macropodia deflexa</i> | 0.0 | 100 |
| 70 | <i>Echinus sp</i> | 0.0 | 100 | <i>Acanthocardia echinata</i> | 0.0 | 100 | <i>Scrupocellaria sp</i> | 0.0 | 100 | <i>Flustra foliacea</i> | 0.0 | 100 | <i>Hydrallmania falcata</i> | 0.0 | 100 | <i>Chaetopterus variopedatus</i> | 0.0 | 100 |

Table 3.5. The rank-order of species by weight from all samples according to port and type of trawling, and showing their individual (% 1 d.p.) and cumulative contribution, (% 0 d.p.) for the top 70 species. Lines demarcate those species that cumulatively contribute to 95 % and the most dominant 60 species. Species that occurred only in the non-fish part of the sample are strongly highlighted and shellfish species are lightly highlighted in yellow. Items described in section 2.3.3.3, 'Group Anthropogenica, Geologica and other Plantae' are highlighted in blue. Some genus names (marked *) have been shortened for clarity.

| Newlyn | | | Looe single | | | Looe pair | | | Plymouth single | | | Plymouth pair | | | Salcombe | | |
|--------------------------|------|-----|-------------------------|------|-----|-------------------------|------|-----|-------------------------|------|-----|----------------------------|------|-----|-------------------------|------|-----|
| species | % | c% | species | % | c% | species | % | c% | species | % | c% | species | % | c% | species | % | c% |
| 1Aspitrigla cuculus | 21.9 | 22 | Merlangius merlangus | 16.3 | 16 | Merlangius merlangus | 41.0 | 41 | Trisopterus luscus | 11.3 | 11 | Merlangius merlangus | 24.9 | 25 | Merlangius merlangus | 14.7 | 15 |
| 2Gadus morhua | 12.6 | 34 | Aspitrigla cuculus | 11.9 | 28 | Loligo vulgaris | 10.6 | 52 | Merlangius merlangus | 10.8 | 22 | Aspitrigla cuculus | 8.5 | 33 | Loligo vulgaris | 11.9 | 27 |
| 3Zeus faber | 12.1 | 47 | Trisopterus luscus | 11.4 | 40 | Microstomus kitt | 7.2 | 59 | Scomber scombrus | 8.3 | 30 | Loligo vulgaris | 6.3 | 40 | Trisopterus luscus | 11.8 | 38 |
| 4Trisopterus luscus | 6.5 | 53 | Loligo vulgaris | 9.7 | 49 | Trisopterus luscus | 5.2 | 64 | Pleuronectes platessa | 6.9 | 37 | Limanda limanda | 5.6 | 45 | Scyliorhinus canicula | 10.9 | 49 |
| 5Loligo sp | 6.2 | 59 | Microstomus kitt | 8.6 | 58 | Aspitrigla cuculus | 4.8 | 69 | Microstomus kitt | 6.0 | 43 | Pleuronectes platessa | 5.5 | 51 | Raja brachyura | 9.9 | 59 |
| 6Microstomus kitt | 5.5 | 65 | Limanda limanda | 5.6 | 64 | Pleuronectes platessa | 4.0 | 73 | Aspitrigla cuculus | 5.9 | 49 | Trisopterus luscus | 5.0 | 56 | Aspitrigla cuculus | 6.9 | 66 |
| 7Marthasterias glacialis | 4.8 | 70 | Scomber scombrus | 4.9 | 68 | Scyliorhinus canicula | 3.0 | 76 | Scyliorhinus canicula | 5.1 | 54 | Microstomus kitt | 4.5 | 60 | Loligo forbesii | 5.8 | 72 |
| 8Trachurus trachurus | 3.8 | 73 | Scyliorhinus canicula | 4.1 | 73 | Trisopterus minutus | 2.2 | 78 | Raja clavata | 5.1 | 59 | Scomber scombrus | 4.4 | 65 | Pleuronectes platessa | 5.7 | 77 |
| 9Loligo vulgaris | 2.8 | 76 | Pleuronectes platessa | 4.0 | 77 | Limanda limanda | 2.2 | 80 | Limanda limanda | 4.1 | 63 | Scyliorhinus canicula | 4.1 | 69 | Microstomus kitt | 4.7 | 82 |
| 10Scyliorhinus canicula | 2.8 | 79 | Trachurus trachurus | 2.6 | 79 | Loligo sp | 2.2 | 82 | Lophius piscatorius | 3.5 | 67 | Lophius piscatorius | 3.8 | 73 | Raja microocellata | 3.4 | 86 |
| 11Loligo forbesii | 2.5 | 81 | Raja brachyura | 1.8 | 81 | Gadus morhua | 2.0 | 85 | Gadus morhua | 3.4 | 70 | Sepia officinalis | 3.6 | 76 | Platichthys flesus | 2.2 | 88 |
| 12Lepid* whiffiagonis | 1.9 | 83 | Loligo forbesii | 1.5 | 83 | Callionymus sp | 1.8 | 86 | Mustelus asterias | 3.2 | 74 | Trachurus trachurus | 3.3 | 80 | Cancer pagurus | 1.5 | 89 |
| 13Lophius piscatorius | 1.9 | 85 | Raja clavata | 1.5 | 84 | Zeus faber | 1.7 | 88 | Sepia officinalis | 2.9 | 76 | Loligo forbesii | 2.4 | 82 | Zeus faber | 1.2 | 90 |
| 14Raja clavata | 1.8 | 87 | Zeus faber | 1.5 | 85 | Scomber scombrus | 1.5 | 90 | Raja brachyura | 2.7 | 79 | Zeus faber | 2.2 | 84 | Trachurus trachurus | 1.0 | 91 |
| 15Raja radiata | 1.8 | 89 | Marthasterias glacialis | 1.4 | 87 | Platichthys flesus | 1.5 | 91 | Loligo vulgaris | 2.5 | 82 | Raja clavata | 2.0 | 86 | Loligo sp | 1.0 | 92 |
| 16Raja naevus | 1.5 | 90 | Gadus morhua | 1.2 | 88 | Trachurus trachurus | 1.4 | 92 | Pollachius pollachius | 2.2 | 84 | Gadus morhua | 1.9 | 88 | Trisopterus minutus | 1.0 | 93 |
| 17Merluccius merluccius | 1.1 | 91 | Eutrigla gurnardus | 1.2 | 89 | Loligo forbesii | 1.0 | 93 | Trachurus trachurus | 2.2 | 86 | Eutrigla gurnardus | 1.8 | 90 | Raja clavata | 0.8 | 94 |
| 18Merlangius merlangus | 1.0 | 93 | Raja microocellata | 0.8 | 90 | Merluccius merluccius | 0.8 | 94 | Dicentrarchus labrax | 1.9 | 88 | Raja brachyura | 1.7 | 91 | Sepia officinalis | 0.7 | 95 |
| 19Scophthalmus rhombus | 1.0 | 94 | Platichthys flesus | 0.8 | 91 | Raja brachyura | 0.7 | 95 | Raja naevus | 1.4 | 89 | Platichthys flesus | 1.6 | 93 | Eutrigla gurnardus | 0.5 | 95 |
| 20Pollachius pollachius | 0.9 | 94 | Raja undulata | 0.7 | 92 | Lepid* whiffiagonis | 0.7 | 96 | Trisopterus minutus | 1.2 | 91 | Marthasterias glacialis | 1.3 | 94 | Limanda limanda | 0.5 | 96 |
| 21Echinus esculentus | 0.7 | 95 | Dicentrarchus labrax | 0.7 | 92 | Trigla lucerna | 0.5 | 96 | Callionymus sp | 1.1 | 92 | Merluccius merluccius | 1.0 | 95 | Callionymus sp | 0.4 | 96 |
| 22Eutrigla gurnardus | 0.6 | 96 | Lophius budegassa | 0.7 | 93 | Raja naevus | 0.5 | 97 | Marthasterias glacialis | 1.0 | 93 | Trisopterus minutus | 0.8 | 96 | Lepid* whiffiagonis | 0.4 | 97 |
| 23Cancer pagurus | 0.5 | 96 | Cancer pagurus | 0.6 | 94 | Eutrigla gurnardus | 0.5 | 97 | Cancer pagurus | 0.7 | 93 | Lepidorhombus whiffiagonis | 0.5 | 97 | Molva molva | 0.4 | 97 |
| 24Asterias rubens | 0.5 | 97 | Callionymus sp | 0.6 | 94 | Liocarcinus depurator | 0.4 | 97 | Merluccius merluccius | 0.7 | 94 | Asterias rubens | 0.5 | 97 | Asterias rubens | 0.3 | 97 |
| 25Pecten maximus | 0.3 | 97 | Raja naevus | 0.5 | 95 | Mullus surmuletus | 0.4 | 98 | Asterias rubens | 0.7 | 95 | Sardina pilchardus | 0.3 | 97 | Raja naevus | 0.3 | 98 |
| 26Maja squinado | 0.3 | 97 | Asterias rubens | 0.5 | 95 | Dicentrarchus labrax | 0.3 | 98 | Octopodidae | 0.5 | 95 | Trigla lucerna | 0.3 | 98 | Marthasterias glacialis | 0.3 | 98 |
| 27Pleuronectes platessa | 0.3 | 98 | Pollachius pollachius | 0.4 | 96 | Marthasterias glacialis | 0.3 | 98 | Lepid* whiffiagonis | 0.5 | 96 | Callionymus sp | 0.2 | 98 | Aequipecten opercularis | 0.3 | 98 |
| 28Raja brachyura | 0.2 | 98 | Mullus surmuletus | 0.4 | 96 | Sprattus sprattus | 0.2 | 99 | Mullus surmuletus | 0.5 | 96 | Mullus surmuletus | 0.2 | 98 | Lophius piscatorius | 0.3 | 98 |
| 29Trisopterus minutus | 0.2 | 98 | Trisopterus minutus | 0.4 | 96 | Asterias rubens | 0.2 | 99 | Melanogram* aeglefinus | 0.4 | 97 | Octopodidae | 0.2 | 98 | Liocarcinus holsatus | 0.2 | 99 |
| 30Mullus surmuletus | 0.2 | 98 | Pecten maximus | 0.4 | 97 | Molva molva | 0.1 | 99 | Platichthys flesus | 0.3 | 97 | Chrysaora hysoscella | 0.2 | 99 | Pecten maximus | 0.1 | 99 |
| 31Mustelus asterias | 0.1 | 98 | Lophius piscatorius | 0.3 | 97 | Luidia ciliaris | 0.1 | 99 | Solea solea | 0.3 | 97 | Liocarcinus depurator | 0.2 | 99 | Echinus esculentus | 0.1 | 99 |
| 32Trigla lucerna | 0.1 | 98 | Liocarcinus depurator | 0.3 | 97 | Clupea harengus | 0.1 | 99 | coal | 0.3 | 97 | Liocarcinus holsatus | 0.2 | 99 | Solea solea | 0.1 | 99 |
| 33Molva molva | 0.1 | 99 | Echinus esculentus | 0.3 | 98 | Alosa sp | 0.1 | 99 | Chrysaora hysoscella | 0.3 | 98 | Buccinum undatum | 0.2 | 99 | Maja squinado | 0.1 | 99 |
| 34Aspitrigla obscura | 0.1 | 99 | Liocarcinus holsatus | 0.2 | 98 | Arnoglossus imperialis | 0.1 | 99 | Trigla lucerna | 0.3 | 98 | Echinus esculentus | 0.1 | 99 | stone | 0.1 | 99 |
| 35Clupea harengus | 0.1 | 99 | Lepid* whiffiagonis | 0.2 | 98 | Liocarcinus holsatus | 0.1 | 99 | Cellaria sp | 0.2 | 98 | Loligo sp | 0.1 | 99 | litter | 0.1 | 99 |
| 36Scyliorhinus stellaris | 0.1 | 99 | Molva molva | 0.2 | 98 | Echinus esculentus | 0.1 | 100 | Eutrigla gurnardus | 0.2 | 98 | Pecten maximus | 0.1 | 100 | Alcyonium digitatum | 0.1 | 99 |
| 37Necora puber | 0.1 | 99 | Merluccius merluccius | 0.2 | 99 | Solea solea | 0.1 | 100 | Liocarcinus holsatus | 0.2 | 99 | Raja naevus | 0.1 | 100 | Merluccius merluccius | 0.1 | 99 |
| 38Scomber scombrus | 0.1 | 99 | Solea solea | 0.1 | 99 | litter | 0.1 | 100 | Loligo forbesii | 0.2 | 99 | Micromesistius poutassou | 0.1 | 100 | Trigloporus lastoviza | 0.1 | 100 |
| 39Labridae | 0.1 | 99 | Necora puber | 0.1 | 99 | Cellaria sp | 0.0 | 100 | Echinus esculentus | 0.2 | 99 | Arnoglossus laterna | 0.0 | 100 | Raja undulata | 0.1 | 100 |
| 40Melanogram* aeglefinus | 0.1 | 99 | Sepia officinalis | 0.1 | 99 | Engraulis encrasicolus | 0.0 | 100 | Liocarcinus depurator | 0.1 | 99 | stone | 0.0 | 100 | Necora puber | 0.1 | 100 |
| 41Chrysaora hysoscella | 0.1 | 99 | Astropecten irregularis | 0.1 | 99 | Necora puber | 0.0 | 100 | Zeus faber | 0.1 | 99 | Aequipecten opercularis | 0.0 | 100 | Liocarcinus marmoreus | 0.1 | 100 |
| 42Luidia ciliaris | 0.1 | 99 | Trigla lucerna | 0.1 | 99 | Astropecten irregularis | 0.0 | 100 | Loligo sp | 0.1 | 99 | litter | 0.0 | 100 | Mugil sp | 0.0 | 100 |
| 43Callionymus sp | 0.1 | 99 | Maja squinado | 0.1 | 99 | Liocarcinus corrugatus | 0.0 | 100 | Necora puber | 0.1 | 99 | Cellaria sp | 0.0 | 100 | Liocarcinus depurator | 0.0 | 100 |
| 44Liocarcinus holsatus | 0.0 | 99 | Loligo sp | 0.1 | 99 | Pecten maximus | 0.0 | 100 | Trigloporus lastoviza | 0.1 | 99 | Echinus elegans | 0.0 | 100 | Polybius henslowii | 0.0 | 100 |
| 45Arnoglossus laterna | 0.0 | 100 | Echinus elegans | 0.1 | 99 | Arnoglossus laterna | 0.0 | 100 | Micromesist* poutassou | 0.1 | 100 | Crossaster papposus | 0.0 | 100 | Cellaria sp | 0.0 | 100 |
| 46Echinus elegans | 0.0 | 100 | coal | 0.1 | 99 | Liocarcinus marmoreus | 0.0 | 100 | Molva molva | 0.1 | 100 | Alloteuthis subulata | 0.0 | 100 | Porania pulvillus | 0.0 | 100 |
| 47Sepia officinalis | 0.0 | 100 | Liocarcinus marmoreus | 0.1 | 99 | DECAPODA | 0.0 | 100 | Astropecten irregularis | 0.1 | 100 | Necora puber | 0.0 | 100 | Aphrodita aculeata | 0.0 | 100 |
| 48Echinus acutus | 0.0 | 100 | Aequipecten opercularis | 0.1 | 100 | Sepia officinalis | 0.0 | 100 | Luidia ciliaris | 0.0 | 100 | Solea solea | 0.0 | 100 | Flustra foliacea | 0.0 | 100 |
| 49Porania pulvillus | 0.0 | 100 | Trigloporus lastoviza | 0.1 | 100 | Alcyonium digitatum | 0.0 | 100 | Aequipecten opercularis | 0.0 | 100 | Pagurus bernhardus | 0.0 | 100 | Fucus serratus | 0.0 | 100 |
| 50Liocarcinus depurator | 0.0 | 100 | litter | 0.0 | 100 | Ophiura ophiura | 0.0 | 100 | litter | 0.0 | 100 | Liocarcinus corrugatus | 0.0 | 100 | Liocarcinus corrugatus | 0.0 | 100 |
| 51litter | 0.0 | 100 | Spatangus purpureus | | | | | | | | | | | | | | |

Table 3.5 illustrates similar dominant species to Table 3.4 across all hauls based on port and type of trawling. In terms of the fish species, the first notable feature was the marked similarity between the most abundant fish species sampled from Looe and Plymouth and to a lesser extent Salcombe and the difference between these samples and those from Newlyn. The Newlyn boat principally targeted John Dory. This species ranked third in the samples (taken during the second and third quarters of the year) though it is a high value, non-pressure stock species and the skipper of this boat made an economic decision to fish where he expected this species to be found. The pattern of exploitation during the sampling from Newlyn was coincidental with where this species was commonly caught (Dunn, 2001). John Dory was not similarly targeted by the boats from other ports and while present was seen as a valuable species that was incidentally caught, not a target.

The most abundant species in the Newlyn samples was the red gurnard. Until relatively recently this species was discarded, though forward thinking skippers are landing this species as more modern markets (with international links) are selling gurnards. Principally this species is for foreign consumption though there is an increasing trend for the larger gurnards, especially, to be sold into the domestic restaurant trade. All the gurnard species have a varied diet (Blanc & Hureau, 1979; Hureau, 1986; Bauchot, 1987; Fischer *et al.*, 1990; Richards & Saksena, 1990) though the red gurnard is the most active predator (Wheeler, 1978). Crabs make up a large proportion of its food and it is an important predator of other scavenging species, (Wheeler, 1978). The lowest rank this species attained was sixth in the single boat samples from Plymouth.

Cod ranked second in abundance from the Newlyn samples, much higher than from any other port. This species is an important mainstay of the Newlyn boat. Cod's abundance decreased to the east of the study area. The fourth highest-ranking species from Newlyn was bib, which was generally discarded. This species was consistently abundant in all of the samples and represents a greatly under used resource. While its flesh is soft and spoils quickly (Wheeler, 1978) it can be turned into fish meal.

The squid ranked fifth, ninth and eleventh from Newlyn. The Newlyn trips largely missed the main squid season though this was early in 1998 peaking in September and October (MAFF/DEFRA, 1990-2001). Some samples from other ports coincided well with the squid season while others did not though this was lost in Table 3.5.

Lemon sole were consistently in the top ten of the samples by port and type of trawling. Peak abundances occur in the spring in both the sample and market data (MAFF/DEFRA, 1990-2001) though this species can be found at almost any time of the year, especially further offshore (Hawke *pers com.*). Lemon sole are a mainstay for the local fishing industry; boats pairing for whiting during the early part of the year often fish independently for lemon sole later.

Whiting was the most abundant fish sampled from Looe, Salcombe, Plymouth pair boat trawls and second only to bib from Plymouth single boat samples, while whiting only ranked eighteenth from Newlyn. Both dogfish and horse mackerel occur in all of the samples by port and type of trawling and except in the Newlyn samples dogfish were more abundant than horse mackerel.

In terms of the non-fish part of the sample, the highest ranked species was *M. glacialis* from Newlyn, which contributed 4.8 % of the total sample. Only from Newlyn does *Echinus esculentus* feature in the top cumulative 95 % rank, as species 21, and contributed 0.7 % of the total weight of the sample. In the single boat hauls from both Looe and Plymouth *M. glacialis* and *A. rubens* featured in the list with the former contributing more (1.4 to 0.5 from Looe and 1.0 and 0.7 % from Plymouth). Neither of these species ranked very highly in the Salcombe samples (both contributing only 0.3 %). These two species did not feature in the top cumulative 95 % (*M. glacialis* 0.3 and *A. rubens* 0.2 %) from Looe pair trawled hauls, and only *M. glacialis* features in the top cumulative 95 % from Plymouth pair trawled samples, (*M. glacialis* 1.3 %) though *A. rubens* falls just out of the list contributing 0.5 %. This seems to suggest that large (or

common) invertebrate species were actually less likely to be dominant in pair trawled hauls, see section 3.6 and Table 3.6 (page 64, below).

3.4 Accumulation of species

Species accumulation curves were calculated from the PRIMER-E (Clarke & Warwick, 2001a) *species-area plot*, where area was converted to sequential hauls. Species accumulation curves (Figure 3.2) were calculated for the full sample, also the landed and discarded fishes, and the non-fish material.

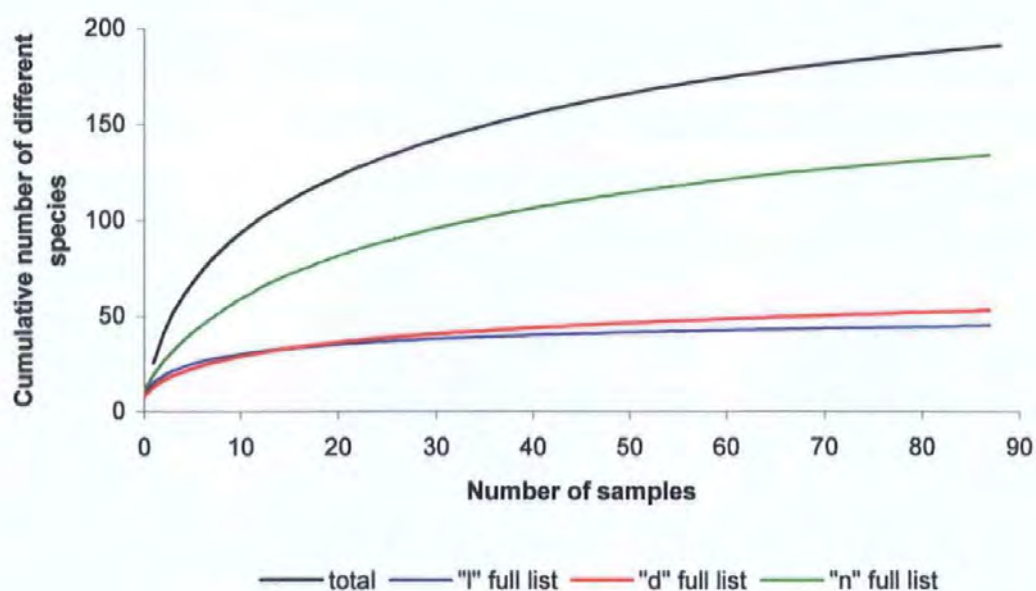


Figure 3.2. Species-accumulation curves, across the full number of samples ($n = 88$). Total is the full sample and component parts of the sample (based on Figure 1.3, page 16, above) are shown in colour coordinated lines.

The curves in Figure 3.2 were generated using 999 random permutations to produce smoothed lines. While it is apparent that the curve for the total sample does not fully flatten to an asymptote it was the number of non-fish species responsible for the continuing increase in number of different species encountered. In contrast, the

asymptote was closely approached for the fish species to be landed and, to a lesser extent, the discarded fishes due to the occasional encountering of quite rare fish, (such as Argentine, *Argentina sphyraena*, and blue whiting *Micromesistius poutassou*).

Whilst it might be tempting to extrapolate the number of species encountered to determine those species expected in, for example, the northern (UK) part of ICES area VIIe, Foggo *et al.*, (2003) show how variable and uncertain this exercise can be. Nevertheless, the shape of the line for all species in Figure 3.2 does not appear to be especially steep when compared to the slopes found in other studies (Gage, 1975; Rumohr *et al.*, 2001; Ugland *et al.*, 2003) which employed other sampling methods (core sampling and van Veen grabs respectively). This suggests that the sampling techniques in this study were as robust in this respect as those employed by others. Considerably fewer new species were encountered above ~ sample 40 which was in general agreement with Rumohr *et al.*, (2001 Fig. 6.) and Ugland *et al.*, (2003 Fig 1 a and b).

The purpose of describing the species accumulation curves as shown in Figure 3.2 was not to carry further the ideas of area sampled and species richness to community diversity indices (Thompson & Withers, 2003; Thompson *et al.*, 2003) as these methods do not hold where the sampled area is either not constant or cannot be accurately ascertained and compensated for. Instead, Figure 3.2 illustrated that the accumulation of species was approaching an asymptote. Common diversity indices cannot be applied to trawl data of this sort though there are methods that are robust to changing sample size and these are examined in considerable detail in Chapter 6.

3.5 Total sample weight and its variation

As described by the conceptual model (Figure 1.3, page 16, above) and as set out in the 'Haul sampling' (section 2.2) the basic sampling unit was the contents of one 38 kg (6

stone) fish basket. While it was always attempted to fill the basket inevitably the derived sample weight varied. Figure 3.3 shows as a frequency histogram the total sample weight by haul derived from length to weight converted data. The average sample weight (\pm s.d.) across all the hauls was 33.3 kg, (\pm 5.1 kg, $n = 88$).

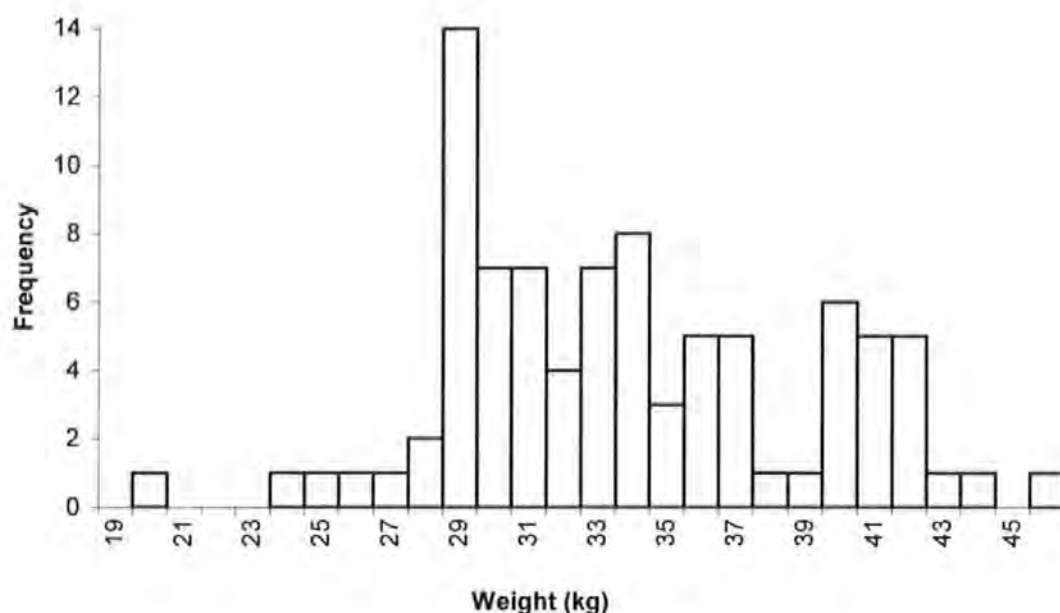


Figure 3.3. Frequency histogram of total derived sample weight (g) for all samples ($n = 88$). The dashed line denotes the nominal basket weight.

Figure 3.3 shows no samples weighed less than a half full basket (< 19 kg). There were seven samples (8 %) in the third quartile (19 to < 29 kg); and the majority (sixty-one, or 69 %) in the fourth quartile, (29 to < 39 kg); and twenty in the fifth quartile (39 to 48 kg) and no samples were heavier than this, (the maximum weight was ~ 45.3 kg).

It was important to determine whether the variability in the sample weight was caused by a bias in the sampling. The accuracy with which the specimens in the samples were determined from their length measurement is presented in Appendix A, which shows that the length to weight derived weights were highly related to the spring balance weights:

$$y = 1.030x - 87.029, R^2 = 0.9791$$

where

y = Calculated weight and

x = spring balance weight

Sources of variability in the total sample weight by a variety of factors are examined in Appendix D. The most relevant of these was the difference according to port and type of trawling though the only significant difference was between the Newlyn and Plymouth pair samples. Section D.3.5 showed that the most likely reason for the variability in total sample weight was related to the packing of items in the sample. The samples from Newlyn comprised the greatest number of the largest fish by species (according to both length and weight) and Salcombe the smallest with Looe and Plymouth fitting along the trend.

3.6 Landed and discarded fishes, and non-fish (invertebrate) components of the samples

Figure 3.4 shows the average and 95% confidence intervals (chosen to allow comparison with other data sets; Dytham, 1999, p49) of the landed “l”, and discarded “d” fishes (including shellfishes) and invertebrates and other material “n” across all hauls.

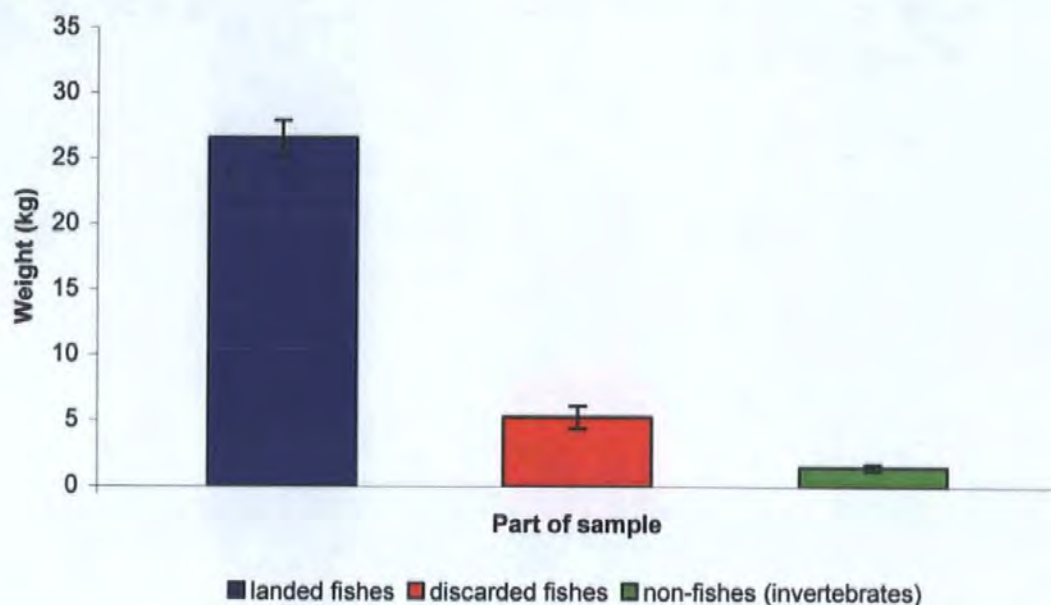


Figure 3.4. Average and 95% confidence intervals for the three parts of the sample; landed “l” and discarded “d” fishes and shellfish, and non-fishes (invertebrates) and other material “n” in the sample.

It is apparent from Figure 3.4 that most (79.8 %) of the sample were landed fish; that discarded fish was a very much smaller component (15.8 %) and the invertebrates and other non-fish material was generally a very small component (4.4 %). Overall, there was little variation in these proportions.

Table 3.6 examines the influence of sampling variables on the components of the samples through GLM analysis.

Table 3.6. Full factor GLM for components of the sample by weight (g) as dependent variables tested against: wind = wind speed (knots) encountered, dur = duration of tow (mins), dep = depth of haul (m), speed = speed of tow (ms^{-1}), vol-bas = haul size as number of baskets of fish, trip # = sequential trip aboard that particular boat, sample # = sequential sample number (1 to 88), port & type = port of operation and type of trawling (pair or single boat), d/n/t = time of haul (day/night/twilight), q = quarter of the year, and interactions. Time of haul (day/night/twilight), port (of sailing), ty = type of trawling (pair or single boat) and interactions. Note that covariances are not dealt with as interactions, and that the interaction of port & type * d/n/t * q returned zero d.f. To aid clarity associations that were significant at the 5 % level are highlighted.

| source | df | dependent variables | | | | | |
|-------------------------|----|---------------------|---------|-----------|---------|----------|---------|
| | | landed | | discarded | | non-fish | |
| | | F value | P value | F value | P value | F value | P value |
| corrected model | 37 | 3.793 | < 0.001 | 6.696 | < 0.001 | 1.804 | 0.026 |
| intercept | 1 | 0.273 | 0.604 | 17.625 | < 0.001 | 0.567 | 0.455 |
| wind | 1 | 0.794 | 0.377 | 0.572 | 0.453 | 0.036 | 0.851 |
| dur | 1 | 3.167 | 0.081 | 0.203 | 0.654 | 0.371 | 0.545 |
| dep | 1 | 8.055 | 0.007 | 22.116 | < 0.001 | 2.713 | 0.106 |
| speed | 1 | 0.003 | 0.954 | 0.149 | 0.701 | 0.297 | 0.588 |
| vol-bas | 1 | 0.090 | 0.766 | 2.478 | 0.122 | 3.135 | 0.083 |
| trip # | 1 | 0.880 | 0.353 | 3.028 | 0.088 | 0.068 | 0.796 |
| sample # | 1 | 2.799 | 0.101 | 0.114 | 0.737 | 0.047 | 0.829 |
| port & type | 5 | 3.212 | 0.014 | 4.784 | 0.001 | 0.492 | 0.781 |
| d/n/t | 2 | 0.750 | 0.478 | 1.483 | 0.237 | 0.480 | 0.622 |
| q | 3 | 3.579 | 0.020 | 5.119 | 0.004 | 0.892 | 0.409 |
| port & type * d/n/t | 3 | 0.741 | 0.533 | 2.246 | 0.094 | 0.101 | 0.959 |
| port & type * q | 12 | 4.789 | < 0.001 | 10.508 | < 0.001 | 0.507 | 0.900 |
| d/n/t * q | 4 | 2.438 | 0.059 | 1.633 | 0.181 | 1.059 | 0.387 |
| port & type * d/n/t * q | 0 | * | * | * | * | * | * |
| error | 50 | | | | | | |
| total | 88 | | | | | | |
| corrected total | 87 | | | | | | |

The results shown by Table 3.6 well described the variability in the GLM; R^2 (landed) = 0.737; R^2 (discarded) = 0.832; R^2 (invertebrates etc.) = 0.572, however the model is only strictly valid in terms of the Levene's test for equality of error variance for the discarded component (P = 0.428) with the other values being P (landed) = 0.002, and P (invertebrates etc) = 0.018. This is examined next; nevertheless, Table 3.6 shows significant associations with depth, port and type of trawling and quarter of the year and interactions involving the last two, but only for the landed and discarded fishes. The general similarity of these patterns does lend credibility to the model for the landed part of the sample.

None of the sampling variables had any significant influence on non-fish weights. In addition, sampling variables that had influence on landed weights also had a

significant influence on discarded weights. These two results suggest that the weights of landed and discarded fish were inversely correlated. To test this, the Spearman's rank-order correlation of the landed and discarded part of the sample was calculated. The resultant negative correlation was highly significant ($r_s = -0.364$, $n = 88$, $P < 0.001$). This test was chosen because while landed weights did approximate a normal distribution according to the Anderson Darling (A-D test, Dytham, 1999, p72); ($A^2 = 0.415$, $n = 88$, $P = 0.328$) though the weight of the discarded fishes did not, ($A^2 = 4.314$, $n = 88$, $P < 0.001$).

The significant relationship between depth and the weight of the landed and discarded parts of the sample (though not with the invertebrates and other material) is explained by the Newlyn samples being generally deeper (see Figure 4.8, page 95, below) and smaller in weight (see Table D.2, page 352, below).

Another significant relationship shown in the GLM of Table 3.6 (above) was between the weight of the landed and discarded fishes with port and type of trawling. This relationship is of particular interest in describing the characteristics and ecosystem influences of the southwest English Channel trawl fishery, and is examined in detail in following Chapters.

Figure 3.5 shows the sample weight according to landed, discarded and non-fish components by port and type of trawling.

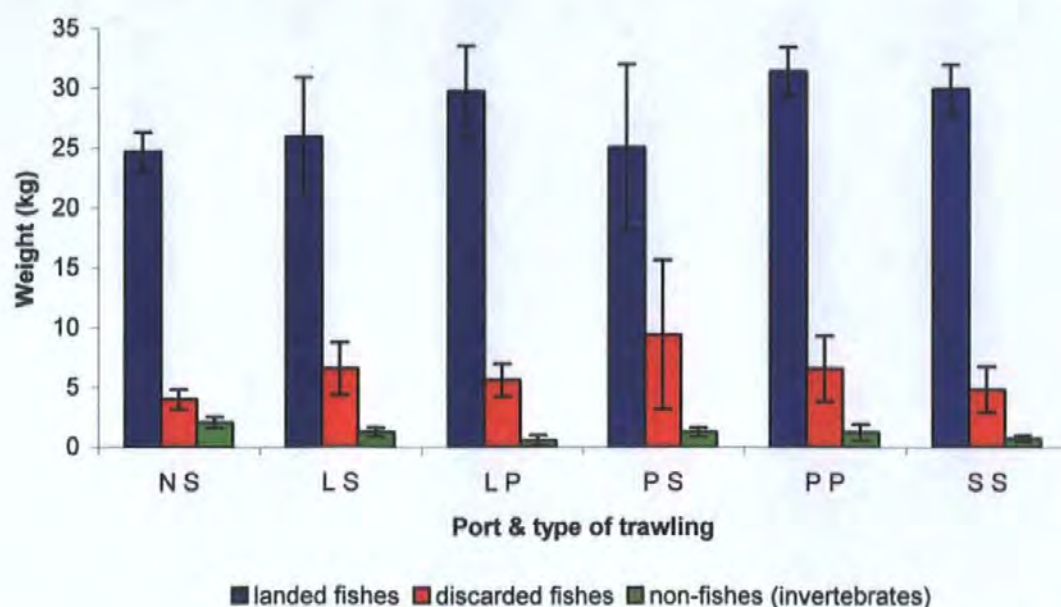


Figure 3.5. Average weight (kg) and 95 % confidence intervals of landed “l” and discarded “d” fishes and non-fishes (invertebrates) and other material “n” according to port, N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe and type of trawling -S = single boat trawling, -P = pair boat trawling.

Figure 3.5 reinforces the inverse proportionality of landed and discarded weight. The Newlyn samples were smaller overall (Table D.2, page 352, below). It is also interesting to observe that on average the Looe and Plymouth pair trawled samples contained more landed, less discarded fishes, and less invertebrates and other material by weight (or as a proportion of the sample) when compared to the equivalent single boat samples as shown in Table 3.7.

Table 3.7. Weight (kg) and proportion of landed, discarded and non-fish (invertebrate) components of the sample by single and pair boat samples for Looe and Plymouth.

| trawl | weight (kg) | | | proportion | | |
|--------|-------------|-----------|-------------------------|------------|-----------|-------------------------|
| | landed | discarded | non-fish (invertebrate) | landed | discarded | non-fish (invertebrate) |
| single | 25.5 | 7.7 | 1.2 | 0.727 | 0.238 | 0.035 |
| pair | 30.5 | 6.0 | 0.9 | 0.815 | 0.163 | 0.022 |

The raw data behind the averages in Table 3.7 consistently did not approximate normal distributions according to the A-D test and only the above described trend for the non-fish (invertebrate) was significant (according to one-tailed Man-Whitney tests), as shown

in Table 3.8.

Table 3.8. Results of two-tailed Man-Whitney test for the weight and proportion of the components of the single and pair boat samples according to the hypotheses described above.

| component | hypothesis | weight | | proportion | |
|-------------------------|---------------|--------|-------|------------|-------|
| | | W | P | W | P |
| landed | pair > single | 302 | 0.060 | 327 | 0.224 |
| discarded | pair < single | 352 | 0.500 | 367 | 0.317 |
| non-fish (invertebrate) | pair < single | 407 | 0.041 | 419 | 0.010 |

Although these trends were not universally significant they suggest that pair trawling was more selective, or that the pair trawling was conducted in structurally more simple and therefore less species rich areas, and as shown on page 58 (above) pair trawl samples contained fewer large invertebrates which may indicate an ecosystem effect of fishing (Jennings, 2005). Ideas around these themes are further explored when examining the composition and biodiversity of the sample, (Chapter 6).

The GLM shown in Table 3.6 (above) also indicated a significant relationship between landed and discarded weights with the sample and the quarter of the year in which the samples were taken. This temporal variability will be explored in subsequent Chapters (particularly Chapter 5 and Chapter 6) particularly with reference to the Newlyn samples as these were collected during equivalent times of subsequent years in similar areas (Figure 3.1, page 47, above).

Chapter 4

4 Derivation of abiotic data sets

4.1 Introduction

This Chapter explains the derivation of abiotic datasets to describe each trawl location, and for use in later analyses relating the sample datasets to the environment. It is also important to understand the major influences on the environment and analysis was undertaken to determine to what extent this was evident for the locations sampled.

The two most important derived abiotic data sets concerned:

- 1 How the **sediment information** was related to the trawl tracks. This was considered of prime importance due to the influence of the substrates on the biota and *vice versa* (Gray, 1974; Snelgrove & Butman, 1994), and
- 2 How the **tidal strength** varied. The data of interest here were not the tidal strength at the time of trawling but instead the maximum tidal strength expected at the location of trawling. Again, this was considered important because of the influence of the tide on both substrates and biota (as shown by Rees *et al.*, (1999) Figure 3c).

This section additionally describes a third data set,

- 3 How the **wind speed** data was acquired. This information describes the conditions found while sampling, as a proxy for sea state and its influence on sampling, in terms of the practicalities of working at sea.

This section also describes how the timing of the haul was converted to a factor, describing,

- 4 How **time** was converted to the factors of day, night and twilight. The purpose of this was because while time is not a particularly amenable piece of information whether a haul was collected during the day, night or twilight is important.

This information was needed for investigations into the relationship between the sample and the substrate and other environmental factors (covered in Chapter 7 and Chapter 8).

The contents of this chapter were also used to describe internal and external effects.

- Internal effects detail potential artefacts of the sampling such as examining whether the wind speed or time of day affected the validity of the sample volume. In general, internal effects were unwelcome and where present point to features of the sampling that should be improved.
- External effects detail potential causative properties between the sample data and derived abiotic factors. External effects point to interesting relationships between the biotic and abiotic data set.

Section 4.2.1 shows how each of the four data groups were derived. A redundancy analysis (section 4.2.2) describes whether any of the subsets within all the groups display features that were sufficiently similar so that one may be substituted for another without losing information. This approach simplifies subsequent analyses, and "...makes the resulting PCA plot easier to interpret," (Quinn & Keough, 2002, p444). Also retaining redundant variables introduces bias in the form of undue weighting.

Section 4.3 describes the final set of parameters selected and their individual attributes and section 4.3.3 (page 89, below) draws together these across all sample locations.

4.2 Methods

4.2.1 Derivation of datasets

4.2.1.1 Sediment information

Trawl tracks were overlaid on 1:250,000 Sea Bed Sediments charts prepared by the British Geological Survey, (BGS). In order to determine the sea bed sediment types covered by each trawl the following charts were used: Haig Fras (50° to 51°N, 006° to 008°W), (Anon, (1986); Land's End (50° to 51°N, 004° to 006°W) Anon, (1987); Portland (50° to 51°N, 002° to 004°W), Anon, (1983b); Scilly (49° to 50°N, 006° to 008°W), Anon, (1982); and Lizard (49° to 50°N, 004° to 006°W), Anon, (1983a). Various technologies were used in generating these charts. The following text was taken and adapted from the chart legends to describe their construction. "The sediment divisions were based on particle size analysis of Shipek Grab samples supplemented by analysis of the topmost parts of shallow cores where these were available. Divisions between sediment types were determined by separately contouring the gravel percentage and the sand:mud ratio. The combination of the two sets of contours defined the fields of the various sediment types and these boundaries were modified where appropriate to take into account bathymetric and sidescan sonar data." The basis of the classification was the triangular diagram at the top of Figure 4.1.

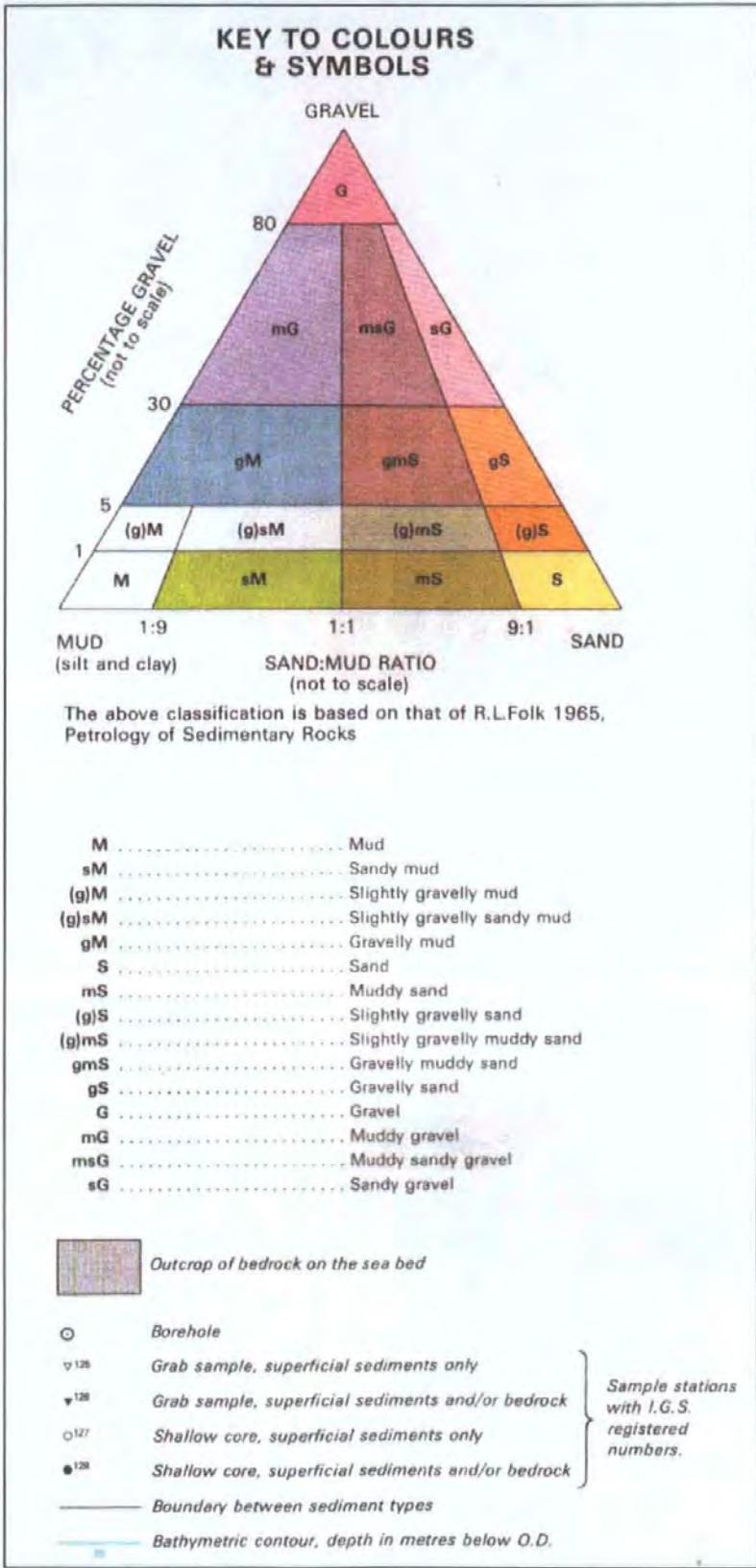


Figure 4.1. Legend from British Geological Survey 1:250,000 series showing sea bed sediments. This particular legend was taken from Anon, (1983b) and only those substrate types on this chart were coloured in the legend.

See Folk, (1954; 1965; 1980) for more information on the textual classification in Figure 4.1. Figure 4.4, (page 79, below) shows the substrates encountered in the study area. In

addition to the soft sediments described on Figure 4.1, there were areas of hard substrate within the study area. These are portrayed in grey on the BGS chart (see to the west and east of the Salcombe Estuary on Figure 4.4 (below). They are described on Figure 4.1 as “Outcrop[s] of bedrock on the sea bed with only very thin patchy sediment cover.

When overlaying the trawl tracks onto the BGS charts and working out which of the 16 sediment types were present, it was not possible to examine the relative proportion of each type passed over with each trawl. This was because the boundaries between sediment types were created by interpolation and contouring (as described on page 70, above) and as such are approximates. Instead, they were described on a simple presence/absence basis, whereby if a trawl track passed over a particular sediment type then this was regarded as a presence. This method was supported by Fennessy, (*pers com.*); as in tennis, a line (boundary) was considered ‘in’.

In order to calculate the substrates passed over when sampling the Newlyn trips during Q2 '98 (for which only the haul position was known) trawl tracks were determined from direction, speed and duration of tow as described in section 2.2.1.

4.2.1.2 Tidal information

Tidal strength information as maximum tidal strength was generated from a customised run of the VICTOR model (George, *pers com.*). This model was constructed around a grid between 51° 04' and 49° 40' N and 006° 30.0 and 002° 56.4 W. The model generated 13,912 tidal vectors spaced at 0°00.20' of latitude and 0°01.20' of longitude, which corresponds to a spacing of 1,492 m. Each point included three pieces of data, a position as eastings and northings in OSGB36 datum and the (directionless) value of the maximum tidal strength at the location in knots. The magnitude was converted into ms^{-1} and the positional data was read into ArcMap 8.3 (ESRI, 1999) and converted into decimal degrees (WGS84 datum) to correspond with the trawl tracks, (Abbott and Jones *pers com.*).

The trawl tracks were superimposed onto the maximum tidal strength mosaic model by creating a layer in ArcMap 8.3 (ESRI, 1999) comprising their start, haul and intermediate positions (as described on page 25, and Figure 2.2, page 26, and Figure 2.3, page 27, above). Once overlaid each track was interrogated at its start (shoot position), every 1,500 m along its length (which was approximately the resolution of the tidal model) and at its end (haul position), as is shown in Figure 4.3.

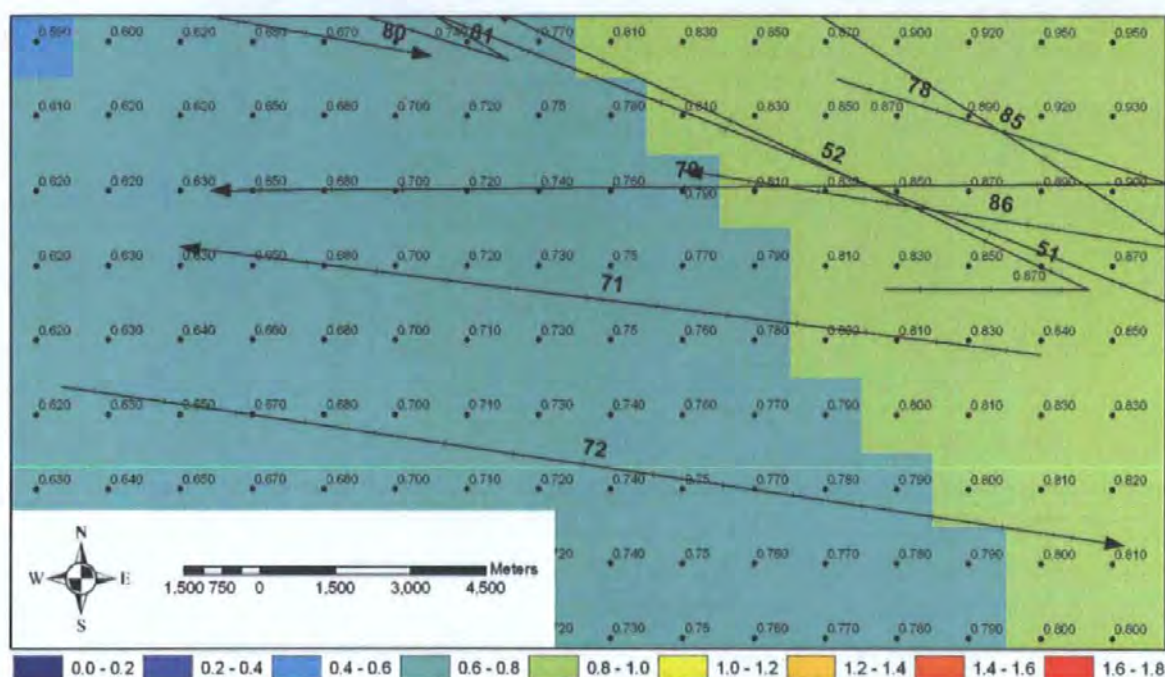


Figure 4.3. Details of example trawl tracks against a backdrop of maximum tidal strength. Tick marks on the trawl lines show the start and haul position and distances of 1,500 m along their lengths. The arrow shows the direction of the tow.

Figure 4.3 shows that haul 71 was begun in an area of higher tidal maxima than it finished. The reverse was the case for haul 72. This GIS analysis allowed the maximum, minimum, average and range of maximum tidal strength values to be generated for each haul.

4.2.1.2.1 Analysis of trawl track length

The creation of the ArcMap trawl tracklayer enabled the comparison of the trawl track length by GIS and according to speed, distance and time. This is presented in Appendix F.

4.2.1.3 Wind speed

Wind speed data was collected from NOAA, (Anon, 2002). This source provided two types of data. Mean wind speeds (knots) were the average across the whole of the day and maximum sustained wind speed, which was the highest level maintained for a period of ten minutes continuously. The former data were used since fishing often took place across much of the day and the record for a ten-minute period did not influence the cancellation of, or alteration to a trip.

4.2.1.4 Day/night/twilight from time

While the time the sampling took place was a function of fishing rather than directly an environmental factor, it was nevertheless important to determine to what extent it was responsible for shaping the pattern in the sample for both ecological and operational reasons.

The time at which the hauls were started and finished was noted, as described in Chapter 2. Casey & Myers, (1998) suggest that without prior knowledge it is difficult to tell whether a haul was taken during the day or at night, although there are known size and species relationships (Benoit & Swain, 2002). Time is not in itself a very amenable piece of information to analyse as a factor, though whether an operation took place during the day or at night is far more relevant. Whether hauls were considered as occurring during the day or night was determined from an evaluation copy of TideWizard 1.3.2, (Anon, 2003). The software was configured to include daylight parameters and British Summer Time. All calculations were taken from the port of Plymouth. D = a daytime haul. N = a nighttime haul. T = a twilight haul based on the following conventions:

- Hauls were classed as day or night if their entirety was during the day or night.
- If dawn occurred during the first third of the duration then the haul was a daytime one.
- If dusk occurred during the first third of the duration then the haul was a nighttime one.

- If dawn occurred during the last third of the duration then the haul was a nighttime one.
- If dusk occurred during the last third of the duration then the haul was a daytime one.
- Hauls were considered twilight when either dawn or dusk occurred during the middle third of the haul's duration.

4.2.2 Redundancy analysis

The results (section 4.3.1) present each of the derived abiotic data sets in isolation. Prior to examining these together, redundant variables (or those that can be substituted without loss of information) were removed. The analysis was performed by generating a *Draftsman Plot* in PRIMER-E (Clarke & Warwick, 2001a) and validated by examination of the correlation coefficients between non-presence/absence datasets. Where there was a high correlation between factors then one can be substituted for the other(s) without effective loss of information. Clarke & Gorley, (2001, p54) advocate that a correlation coefficient $r > 0.95$ is used to indicate valid examples of redundancy, though this is only a guide. Lower correlation coefficient values between factors describe interactions that show little or no internal trend and these factors should be retained.

Presence/absence data cannot be examined via draftsman plots. Instead, it was possible to examine the correlation coefficients between various substrates according to their presence in the samples and apply the same rule as described above as necessary. It was not relevant to include the D/N/T factor into the redundancy analysis. Instead, its influence in describing the composition of the samples (through an ANOSIM) was used to determine how useful it was in further analyses. See section 5.2.1 for a description of the sample dataset.

4.2.3 Analysing trends in derived abiotic datasets

In order to assess patterns of similarity with the abiotic data sets a matrix of the 88 sites by the remaining derived abiotic variables was constructed, which contained both the presence/absence and non-presence/absence type data. The matrix was analysed for patterns relating to port and type of trawling, to correspond with similar analyses based on sample composition in Chapter 3, Chapter 5 and Chapter 6, and combined in Chapter 7. It was analysed via normalised, and correlation based Principal Component Analysis (PCA) using Minitab, (Minitab, 2000) although the plots were generated in PRIMER-E (Clarke & Warwick, 2001a).

In addition to the PCA the overall separation into port and type of trawling of the abiotic data was summarised by a one-way ANOSIM (PRIMER-E, Clarke & Warwick, 2001a), based on the suite of data after the redundancy analysis. The similarity matrix underlying the ANOSIM was created using normalised Euclidian distances from untransformed, standardised abiotic data.

4.3 Results

4.3.1 Derived datasets

4.3.1.1 Sediment Information

Each of the BGS charts carries a note on sediment type and thickness. The following text was made up from combining and rewording (for clarity) all of these notes, thus it forms a general description of the area in total. 'Typically the sea bed sediments consist of rock and mineral detritus derived from the bedrock on the sea bed and adjacent land areas. The thickness of superficial sediments over most of the areas covered by the five BGS sheets used here is < 1 m overlaying comparatively smooth bedrock. Thicker sediments occur as

sand banks and ridges, which are subjected to strong tidal currents, which as a result fashion their shape. Bedrock is exposed mainly in areas scoured by strong tidal currents and also in areas of high topographic relief.' For each track, the presence of each of the 16 sediment classes was determined by spatial overlay on BGS charts as described earlier. Individual groups were the combinations of all different substrate groups passed over by the trawl. Major substrate types are the unqualified substrates (without modification).

It was not possible to illustrate the passage of the trawl tracks over the sediment on the actual charts used (Anon, 1982; 1983a; 1983b; 1986; 1987) due to their scale. Instead, (for illustrative purposes) the trawl tracks were plotted onto a geo-referenced chart of the whole study area (Figure 4.4). The geo-referencing (ESRI, 1999) was made onto an extract of the 1:1,000,000 scale sediment map (NERC, 1987) and the four geo-referencing 'tic' points were the mouth of Little Petherick Creek, Padstow, Land's End, Lizard Point and Start Point and the substrate chart (Figure 4.4) does not differ qualitatively from a mosaic of (Anon, 1982; 1983a; 1983b; 1986; 1987).

Table 4.1 shows the data as both individual groups and major substrate types (according to individual hauls) and these are arranged according to port and type of trawling as shown in Table 3.2, (page 49, above). Individual groups are the combinations of all different substrate groups passed over by the trawl; as an example the first haul from Newlyn passed over gravely sand, gravel and sandy gravel thus is described as gS.G.sG. Major substrate types are the unqualified substrates. The same haul from Newlyn passed over a sandy and two gravely substrates thus is described as SG.

Table 4.1. Major substrate types and particular substrates which comprise them according to individual hauls and port and type of trawling, N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling.

| port & type | haul | year and quarter | | | | | | | | | | | | 2000 | | | | | | | | | |
|-------------|-----------------|------------------|----|-----------------|------------|------|-----------------|------------|-----|-----------------|------------|-------------|-----------------|-------------|--------------|-----------------|------------|-----------|----|-----------|-------------|---|----|
| | | 1998 | | | | 1999 | | | | 2000 | | | | | | | | | | | | | |
| | | 2 | | 3 | | 4 | | 1 | | 2 | | 3 | | 4 | | 1 | | | | | | | |
| # | major sub types | substrates | # | major sub types | substrates | # | major sub types | substrates | # | major sub types | substrates | # | major sub types | substrates | # | major sub types | substrates | | | | | | |
| NS | 1 | 03 | SG | gS.G.sG | 18 | SG | | | | | 37 | SG | (g)S.gS.G.Sg | 56 | SR | S.(g)S.R | | | | | | | |
| | 1 | | | | | | | | | | | | 57 | SGR | (g)S.gS.sG.R | | | | | | | | |
| | 2 | 04 | SG | gS.sG | 19 | SG | gS.G.sG | | | 38 | SG | gS.G.sG | 58 | SG | gS.G.sG | | | | | | | | |
| | 3 | 05 | SG | gS.sG | 20 | SG | gS.sG | | | 39 | S | (g)S.gS | 59 | SG | gS.G.sG | | | | | | | | |
| | 4 | 06 | SG | gS.G.sG | 21 | SG | gS.sG | | | 40 | SGR | gS.G.sG.R | 60 | SG | gS.G.sG | | | | | | | | |
| | 5 | 07 | SG | gS.G.Sg | 22 | S | (g)S.gS | | | 41 | SGR | gS.G.sG.R | | | | | | | | | | | |
| | 6 | 08 | SG | gS.G.sG | 23 | S | (g)S.Gs | | | 42 | SG | (g)S.gS.Sg | 61 | SG | gS.sG | | | | | | | | |
| | 7 | 09 | SG | gS.G.sG | | | | | | 43 | SG | gS.sG | 62 | SG | gS.G.sG | | | | | | | | |
| | 8 | 10 | SG | gS.sG | | | | | | 44 | SGR | (g)S.G.sG.R | 63 | SG | (g)S.gS.sG | | | | | | | | |
| | 9 | 11 | S | (g)S.gS | 24 | SG | gS.msG.sG | | | | | | 64 | SGR | gS.G.sG.R | | | | | | | | |
| | 10 | 12 | S | (g)S.gS | 25 | SG | (g)S.gS.Sg | | | | | | 65 | SG | gS.sG | | | | | | | | |
| | 11 | | | | | | | | | | | | 66 | SG | gS.G.sG | | | | | | | | |
| | 12 | | | | 26 | SG | (g)S.gS.sG | | | | | | | | | | | | | | | | |
| | 13 | | | | 27 | SG | (g)S.gS.sG | | | | | | | | | | | | | | | | |
| | 14 | | | | 28 | SG | (g)S.gS.sG | | | | | | | | | | | | | | | | |
| | 15 | | | | 29 | SG | gS.sG | | | | | | | | | | | | | | | | |
| | 16 | | | | 30 | SGR | (g)S.gS.G.sG.R | | | | | | | | | | | | | | | | |
| LS | 1 | 01 | S | S.gS | 13 | S | S.(g)S | 31 | SGR | S.(g)S.sG.R | 35 | SGR | S.(g)S.sG.R | | | | | | | | | | |
| | 2 | 02 | SG | S.gS.sG | 14 | S | S.(g)S | 32 | S | S.(g)S | 36 | SGR | S.sG.R | | | | | | | | | | |
| | 3 | | | | 15 | S | S.(g)S.gS | | | | | | | | | | | | | | | | |
| | 4 | | | | 16 | S | (g)S.gS | | | | | | | | | | | | | | | | |
| | 5 | | | | 17 | S | S.(g)S.gS | | | | | | | | | | | | | | | | |
| LP | 1 | | | | | | | | | 49 | S | S.(g)S | 53 | S | S.(g)S | 75 | SG | S.gS.sG | 82 | SG | S.Sg | | |
| | 2 | | | | | | | | | 50 | S | S.(g)S | 54 | S | S.(g)S | 76 | SG | S.Sg | 83 | SG | S.Sg | | |
| | 3 | | | | | | | | | | | 55 | S | (g)S | | | | | | | | | |
| PS | 1 | | | | | | | | | 45 | SG | S.gS.sG | 69 | SGR | S.mS.gS.sG.R | 80 | S | S.(g)S | 87 | S | S | | |
| | 2 | | | | | | | | | 46 | SG | S.gS.sG | 70 | SG | S.mS.gS.sG | 81 | S | S.(g)S.gS | 88 | S | S | | |
| PP | 1 | | | | | | | | | 33 | SGR | mS.gS.sG.R | 47 | SG | mS.gS.sG | 67 | S | S | 73 | S | S | | |
| | 2 | | | | | | | | | 34 | SG | mS.gS.sG | 48 | SG | mS.gS.sG | 68 | S | S.(g)S | 74 | S | S | | |
| SS | 1 | | | | | | | | | | | 51 | S | (g)S.gmS.gS | 71 | S | S.(g)S.gS | 77 | S | gS | 84 | S | gS |
| | 1 | | | | | | | | | | | | | | | | | | 85 | SR | S.(g)S.gS.R | | |
| | 2 | | | | | | | | | 52 | S | (g)S.gmS.gS | 72 | S | S.(g)S | 78 | S | (g)S.Gs | 86 | S | S.(g)S.gS | | |
| | 3 | | | | | | | | | | | | | | | | | 79 | S | S.(g)S.gS | | | |

Figure 4.4 and Table 4.1 show that the majority of the Newlyn derived trawls were over gravely sand and sandy gravel, though there were many occasions where additional substrates, including rock, were encountered. The majority of the Plymouth, Looe and Salcombe hauls featured sand, though closer inshore the trawls extended into patches of gravely sand, sandy gravel as well as other mixed substrate types and again included rock.

4.3.1.2 Tidal Information

Figure 4.5 shows directionless maximum tidal strength values generated by the VICTOR model classified into 0.2 ms^{-1} bins (but not further smoothed) and colour coded for clarity, with the labelled trawl tracks superimposed.

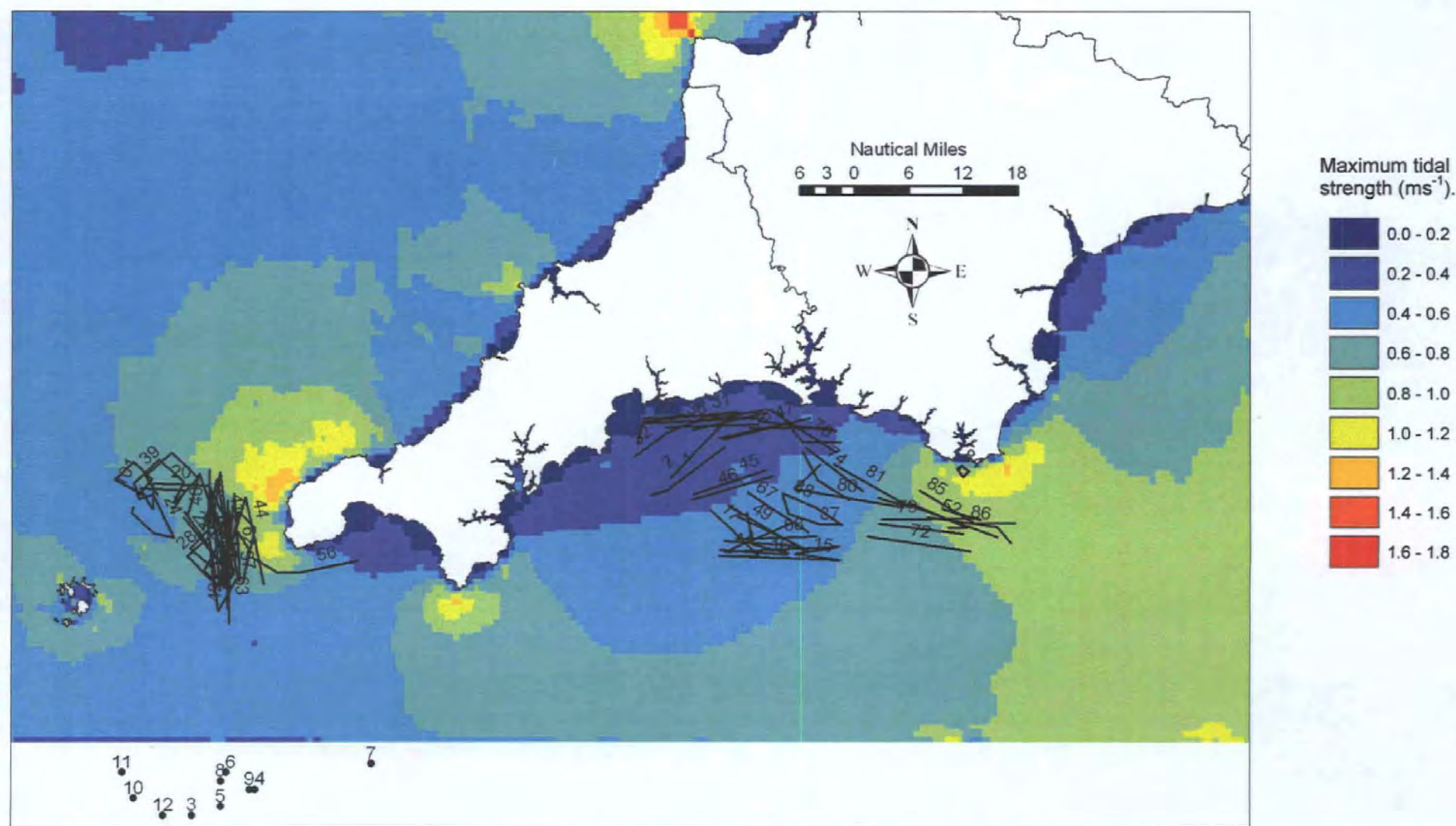


Figure 4.5. Full extent of the VICTOR model (as colour-coded and smoothed values) of maximum tidal strength (ms^{-1}), with trawl tracks superimposed.

Figure 4.5 shows that the lowest values of maximum tidal strength were found close inshore along the north coast of the UK southwest peninsula and throughout the largest bays along the south coast. Higher magnitudes were found further offshore with peak values around Trevoze Head near Padstow, The Wra Stone, near Cape Cornwall, and off The Lizard and Start Point. The greatest values of all were around Hartland Point near Bideford.

Table 4.2 shows the average maximum tidal strength (\pm range) along each trawl track. The tracks on Table 4.2 are arranged according to port and type of trawling (as Table 4.1, page 80, and Table 3.2, page 49, above). Table 4.2 also shows the average by trip.

Table 4.2. Average maximum tidal strength (ms^{-1}) by individual hauls and according to port and type of trawling, N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling, (\pm = range of data).

| port & type | haul | year and quarter | | | | | | | |
|-------------|---------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|------|
| | | 1998 | | | 1999 | | | | 2000 |
| | | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 |
| N S | 1 | 03 0.52 | 18 0.75 \pm 0.19 | | | 37 0.72 \pm 0.16 | 56 0.75 \pm 0.23 | | |
| | 1 | | | | | | 57 0.70 \pm 0.04 | | |
| | 2 | 04 0.52 | 19 0.75 \pm 0.18 | | | 38 0.69 \pm 0.15 | 58 0.73 \pm 0.14 | | |
| | 3 | 05 0.52 | 20 0.68 \pm 0.20 | | | 39 0.67 \pm 0.14 | 59 0.74 \pm 0.13 | | |
| | 4 | 06 0.52 | 21 0.62 \pm 0.12 | | | 40 0.73 \pm 0.17 | 60 0.71 \pm 0.10 | | |
| | 5 | 07 0.52 | 22 0.65 \pm 0.12 | | | 41 0.77 \pm 0.22 | | | |
| | 6 | 08 0.52 | 23 0.65 \pm 0.12 | | | 42 0.62 \pm 0.23 | 61 0.61 \pm 0.19 | | |
| | 7 | 09 0.52 | | | | 43 0.66 \pm 0.17 | 62 0.79 \pm 0.10 | | |
| | 8 | 10 0.52 | | | | 44 0.85 \pm 0.30 | 63 0.59 \pm 0.25 | | |
| | 9 | 11 0.52 | 24 0.56 \pm 0.10 | | | | 64 0.74 \pm 0.18 | | |
| | 10 | 12 0.52 | 25 0.65 \pm 0.15 | | | | 65 0.64 \pm 0.16 | | |
| | 11 | | | | | | 66 0.68 \pm 0.09 | | |
| | 12 | | 26 0.65 \pm 0.18 | | | | | | |
| | 13 | | 27 0.66 \pm 0.16 | | | | | | |
| | 14 | | 28 0.68 \pm 0.20 | | | | | | |
| | 15 | | 29 0.70 \pm 0.15 | | | | | | |
| | 16 | | 30 0.79 \pm 0.31 | | | | | | |
| average | | 0.52 | 0.68 \pm 0.17 | | | 0.71 \pm 0.19 | 0.69 \pm 0.19 | | |
| L S | 1 | 01 0.33 \pm 0.04 | 13 0.48 \pm 0.01 | 31 0.23 \pm 0.08 | 35 0.24 \pm 0.08 | | | | |
| | 2 | 02 0.29 \pm 0.04 | 14 0.53 \pm 0.10 | 32 0.25 \pm 0.05 | 36 0.25 \pm 0.09 | | | | |
| | 3 | | 15 0.56 \pm 0.05 | | | | | | |
| | 4 | | 16 0.53 \pm 0.11 | | | | | | |
| | 5 | | 17 0.47 \pm 0.10 | | | | | | |
| average | | 0.31 \pm 0.04 | 0.51 \pm 0.07 | 0.24 \pm 0.07 | 0.25 \pm 0.09 | | | | |
| L P | 1 | | | | 49 0.48 \pm 0.13 | 53 0.49 \pm 0.10 | 75 0.27 \pm 0.07 | 82 0.27 \pm 0.04 | |
| | 2 | | | | 50 0.49 \pm 0.11 | 54 0.50 \pm 0.05 | 76 0.26 \pm 0.08 | 83 0.27 \pm 0.03 | |
| | 3 | | | | | 55 0.50 \pm 0.07 | | | |
| average | | | | | 0.48 \pm 0.12 | 0.49 \pm 0.07 | 0.26 \pm 0.07 | 0.27 \pm 0.04 | |
| P S | 1 | | | | 45 0.37 \pm 0.04 | 69 0.37 \pm 0.18 | 80 0.52 \pm 0.30 | 87 0.51 \pm 0.11 | |
| | 2 | | | | 46 0.38 \pm 0.03 | 70 0.36 \pm 0.19 | 81 0.61 \pm 0.32 | 88 0.51 \pm 0.10 | |
| | average | | | | 0.38 \pm 0.04 | 0.37 \pm 0.19 | 0.57 \pm 0.31 | 0.51 \pm 0.11 | |
| P P | 1 | | | | 33 0.35 \pm 0.10 | 47 0.33 \pm 0.10 | 67 0.47 \pm 0.12 | 73 0.46 \pm 0.15 | |
| | 2 | | | | 34 0.35 \pm 0.07 | 48 0.33 \pm 0.10 | 68 0.50 \pm 0.07 | 74 0.45 \pm 0.16 | |
| | average | | | | 0.35 \pm 0.09 | 0.33 \pm 0.10 | 0.49 \pm 0.10 | 0.46 \pm 0.16 | |
| S S | 1 | | | | 51 0.83 \pm 0.13 | 71 0.74 \pm 0.21 | 77 0.89 \pm 0.31 | 84 0.90 \pm 0.31 | |
| | 1 | | | | | | | 85 0.88 \pm 0.10 | |
| | 2 | | | | 52 0.82 \pm 0.16 | 72 0.73 \pm 0.19 | 78 0.89 \pm 0.07 | 86 0.85 \pm 0.10 | |
| | 3 | | | | | | 79 0.78 \pm 0.27 | | |
| average | | | | | 0.83 \pm 0.15 | 0.74 \pm 0.20 | 0.85 \pm 0.22 | 0.87 \pm 0.17 | |

The values on Table 4.2 were not those encountered when the samples were taken; instead they were those maxima expected from the locations of the sampling. The range values give an indication of the heterogeneity of the trawls in terms of their locations. The Looe and Plymouth single and pair trawls were from areas which generally have similar values of maximum tidal strength (rarely $> 0.5 \text{ ms}^{-1}$, and had relatively low variability as expressed in their range. The two exceptions to these situations were hauls 80 and 81 (Plymouth single boat samples taken during 17/11/1999). These also had larger variability as expressed in their range. This was due to their proximity to the strong tidal stream area towards Salcombe (see Figure 4.5, page 82, above and Figure F.2, page 368, below). All the Salcombe hauls were in quite high tidal stream areas and had larger ranges. The Newlyn samples (which were between those from Looe or Plymouth and Salcombe in magnitude) were also relatively similar in terms of average maxima (given their similarity of location) except those during Q2 '98 which were more geographically distant. These values were also derived differently and do not have ranges as only their haul positions were recorded during their collection.

4.3.1.3 Wind speed

Table 4.3 shows how the wind speed varied across the sampling period.

Table 4.3. Average wind speed (ms^{-1} , \pm range where applicable) according to port and type of trawling and year and quarter of the year.

| port and type | year and quarter | | | | | | | | average |
|---------------|------------------|-----------|---|------|-----------|-----------|----|-----------|---------|
| | 1998 | | | 1999 | | | | 2000 | |
| | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | |
| NS | 7 \pm 2 | 7 \pm 6 | | | 9 \pm 2 | 7 \pm 6 | | | 7 |
| LS | 13 | 5 \pm 1 | 9 | 7 | | | | | 8 |
| LP | | | | | 4 | 7 | 13 | 3 | 7 |
| PS | | | | | 6 | 2 | 5 | 10 | 6 |
| PP | | | | 9 | 7 | 7 | 4 | | 7 |
| SS | | | | | 4 | 10 | 9 | 5 \pm 1 | 7 |
| average | 8 | 6 | 9 | 8 | 7 | 7 | 8 | 6 | 7 |

Table 4.3 shows that on average the wind conditions were quite constant across the sampling period, though expected longitudinal variation was evident (higher averages in quarters 1 and 4), although according to port and type of trawling there was very little difference overall.

4.3.1.4 Day/night/twilight from time

Table 4.4 shows how the hauls were arranged based on the time of shoot and haul converted to the factor of day, night and twilight.

Table 4.4. Numbers of day (D), twilight (T) and night (N) hauls from which usable samples were collected according to port and type of trawling and year and quarter of the year.

| port and type | D/N/T | year and quarter | | | | | | | | total |
|---------------------|-------|------------------|----|---|------|----|----|---|------|-------|
| | | 1998 | | | 1999 | | | | 2000 | |
| | | 2 | 3 | 4 | 1 | 2 | 3 | 4 | | |
| N S | D | 4 | 8 | | | 5 | 8 | | | 25 |
| | T | 3 | 1 | | | 2 | 1 | | | 7 |
| | N | 3 | 4 | | | 1 | 2 | | | 10 |
| L S | D | 2 | 3 | 1 | 1 | | | | | 7 |
| | T | | 1 | 1 | 1 | | | | | 3 |
| | N | | 1 | | | | | | | 1 |
| L P | D | | | | | 2 | 3 | 2 | 2 | 9 |
| | T | | | | | | | | | 0 |
| | N | | | | | | | | | 0 |
| P S | D | | | | | 2 | 2 | 2 | 2 | 8 |
| | T | | | | | | | | | 0 |
| | N | | | | | | | | | 0 |
| P P | D | | | | | 2 | 2 | 2 | | 6 |
| | T | | | | | | | | | 0 |
| | N | | | | 2 | | | | | 2 |
| S S | D | | | | | 2 | 2 | 2 | 3 | 9 |
| | T | | | | | | | 1 | | 1 |
| | N | | | | | | | | | 0 |
| total | | 12 | 18 | 2 | 4 | 16 | 20 | 9 | 7 | 88 |

Table 4.4 shows that sampling from Newlyn generated an appreciable number (24 %) of nighttime hauls and quite a few (17 %) twilight hauls. Amongst the other ports and types of trawling few nighttime hauls were sampled.

4.3.2 Redundancy analysis

Table 4.5 shows the correlation coefficients of the presence/absence based substrate data across each haul.

Table 4.5. Correlation coefficients (r) between substrates as presence/absence data. S = sand, mS = muddy sand, (g)S = slightly gravelly sand, gmS = gravelly, muddy sand, gS = gravelly sand, G = gravel, msG = muddy, sandy gravel, sG = sandy gravel, and R = rock. The mean value = - 0.034. Blue highlighted values are ± 1 standard deviation of the mean. Yellow highlighted values are ± 2 standard deviations of the mean.

| | | | | | | | | |
|------|---------|---------|---------|---------|---------|---------|---------|---------|
| S | - 0.042 | 0.150 | - 0.127 | - 0.632 | - 0.422 | - 0.089 | - 0.436 | 0.044 |
| mS | | - 0.253 | - 0.041 | 0.166 | - 0.137 | - 0.029 | 0.225 | 0.141 |
| (g)S | | | 0.163 | - 0.195 | - 0.304 | - 0.100 | - 0.520 | 0.061 |
| gmS | | | | 0.093 | - 0.077 | - 0.016 | - 0.183 | - 0.063 |
| gS | | | | | 0.247 | 0.066 | 0.373 | - 0.105 |
| G | | | | | | - 0.054 | 0.422 | 0.186 |
| msG | | | | | | | 0.089 | - 0.045 |
| sG | | | | | | | | 0.213 |
| | mS | (g)S | gmS | gS | G | msG | sG | R |

No correlation values between the substrates approach the point ($\sim > 0.950$) where duplication (and therefore redundancy) was apparent, so all sediment variables were retained. The largest values on Table 4.5 were negative correlations; these were between gravelly sand and sand ($r = - 0.632$) and sandy gravel and slightly gravelly sand ($r = - 0.520$).

The most commonly co-occurring substrate types have a degree of gravel in them, for example sandy gravel and gravel ($r = 0.422$); sandy gravel and gravelly sand ($r = 0.373$); and gravel and gravelly sand ($r = 0.247$).

Table 4.6 shows the correlation coefficients (r) produced from the draftsman plot for the non presence/absence data.

Table 4.6. Correlation coefficients (r) of non-presence / absence abiotic data. Data are: wind = wind speed (ms^{-1}); av max.t.s. = average maximum tidal strength, min max.t.s. = minimum maximum tidal strength, max max.t.s. = maximum maximum tidal strength, and range m.t.s. = range of average maximum tidal strength (ms^{-1}); and depth (m). Correlations ≥ 0.900 are highlighted. See text for*.

| | | | | | |
|--------------|--------|-------------|--------------|-----------------|-------------------|
| av max.t.s. | -0.071 | | | | |
| min max.t.s. | -0.105 | 0.966 | | | |
| max max.t.s. | -0.048 | 0.976 | 0.897* | | |
| range m.t.s. | 0.080 | 0.444 | 0.211 | 0.621 | |
| depth | -0.014 | 0.263 | 0.227 | 0.320 | 0.307 |
| | wind | av max.t.s. | min max.t.s. | max max.t.s. | range max.t.s. |

The high correlation values in Table 4.6 (above the $r = 0.95$ threshold) suggest that the inclusion of the absolute maximum, and minimum tidal strengths as abiotic measures were duplications. This was confirmed by the fact that the correlation was also high ($r = 0.897$) between the absolute minima and maxima for each haul. The correlation coefficients were not particularly high for the measures of tide and the ranges of maximum tidal strength along the trawl track, ($r = 0.621$ between range and absolute maxima, and $r = 0.211$ between range and absolute minima) suggesting that the measure of range cannot be substituted for another and it should be retained. Depth could not be substituted for another measure and was retained, though its influence as a measure of the geographical distribution of the trawl track will be explored later, (see Figure 4.8, page 95 below).

Table 4.6 showed that the wind strength correlated without pattern to the other measures ($r \text{ mean} \pm \text{s.d.} = -0.032 \pm 0.035$). Also, this measure was a function of the collection of the data rather than a feature of the environment therefore it was removed before further analysis.

Table 4.7 shows the results of the ANOSIM on the full sample according to time of trawling.

Table 4.7. ANOSIM as pair-wise *R*-values for all the full sample data according to day (D), night (N) and twilight (T) timing of the haul. Not significantly different pair-wise associations are highlighted. Global *R* = 0.190.

| | | |
|---|---------|-------|
| D | 0.046 | |
| N | - 0.040 | 0.046 |
| | T | D |

According to its global *R* value time of trawling was overall not at all a good descriptor for the full sample and Table 4.7 shows that the full samples were not separable by D/N/T, and all the combinations between the factors were not significantly different.

A quarter of the samples from Newlyn were nighttime, though these samples too could not reliably be distinguished by D/N/T, as shown in Table 4.8.

Table 4.8. ANOSIM as pair-wise *R*-values for the Newlyn full sample data according to day (D), night (N) and twilight (T) timing of the haul. Not significantly different pair-wise associations are highlighted. Global *R* = 0.132.

| | | |
|---|---------|-------|
| D | 0.046 | |
| N | - 0.040 | 0.046 |
| | T | D |

Despite this outcome the most different time grouping (day and night) were not significantly similar although this could have been due to the low global *R*-value.

4.3.3 Trends in derived environmental datasets

Section 4.3.2 showed that the abiotic measures of absolute maximum, and minimum tidal strengths were redundant and that wind strength had little influence on the data. Section 4.3.2 also showed that the factor of D/N/T was not a good descriptor of the sample. The finalised abiotic datasets were:

- Continuous data; average and range of average maximum tidal strength (ms⁻¹), depth (m).

- Presence/absence data; substrate, S = sand, mS = muddy sand, (g)S = slightly gravely sand, gmS = gravely, muddy sand, gS = gravely sand, G = gravel, msG = muddy, sandy gravel, sG = sandy gravel, and R = rock.

Figure 4.6 shows the PCA plot based on the finalised abiotic datasets.

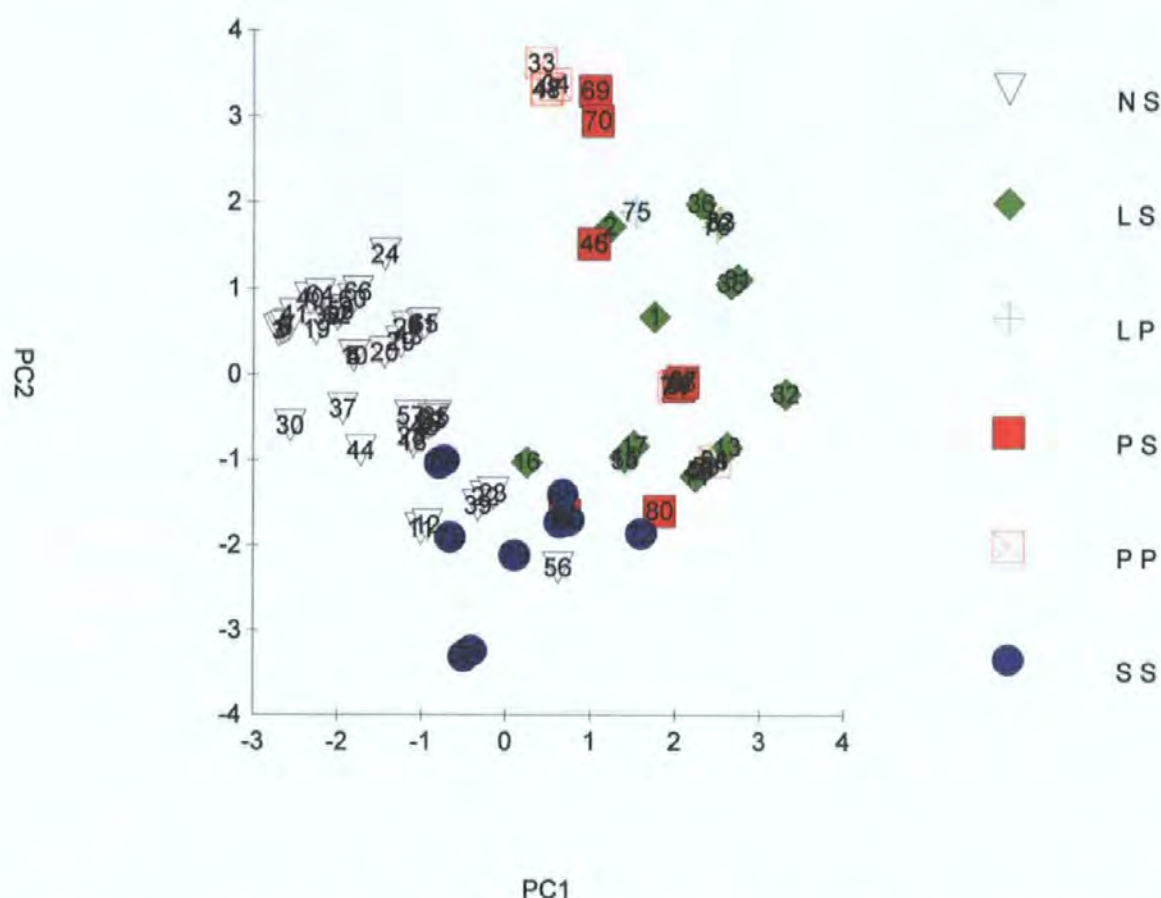


Figure 4.6. Normalised (correlation-based) PCA plot of abiotic data (according to port and type of trawling, N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling) based on the finalised datasets (described on page 89, above).

The 'arch' on Figure 4.6 was very pronounced suggesting that concentrating only on those factors directly related to the environment has stretched out the samples along their gradient of variables (despite this PCA being conducted on standardised and normalised data. Part of the reason for this was due to 9 out of the 12 abiotic variables being substrate related. While all the data were standardised the dominance of the presence/absence substrate information is apparent.

The Newlyn abiotic datasets exist towards one end of the range. Next along the continuum generally were the Salcombe samples and at the other end were the Looe and Plymouth samples. Despite 9 out of the 12 abiotic samples being related to substrate the influence of tide is consistent with this pattern.

Table 4.9 describes the separation of the finalised abiotic datasets described on page 89 (above) according to port and type of trawling.

Table 4.9. ANOSIM as pair-wise *R*-values based on the finalised abiotic data (described on page 89, above) untransformed, standardised data environmental data according to port and type of trawling, N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling. The similarity matrix was created using normalised Euclidian distances. Not significantly different pair-wise associations are highlighted. Global *R* = 0.437.

| | | | | | |
|-----------|-----------|-----------|-----------|-----------|-----------|
| NS | 0.450 | 0.476 | 0.508 | 0.582 | 0.552 |
| LS | | 0.033 | 0.136 | 0.262 | 0.259 |
| LP | | | 0.104 | 0.191 | 0.312 |
| PS | | | | - 0.007 | 0.178 |
| PP | | | | | 0.285 |
| | LS | LP | PS | PP | SS |

The global *R*-value suggests that the ANOSIM featured in Table 4.9 is not a very good descriptor of the similarity of the sites, though this may be due in part to the combination of presence/absence and continuous data, in spite of the normalisation. The abiotic data associated with the Newlyn samples were overlapping but clearly separable from the locations of the other samples. Other locations were not separable. In total, four of the interactions on Table 4.9 were not significantly different, though only two of the interactions were well above the 5 % level. These strongly similar groups were between the single and pair trawled hauls from the same port; (Looe *P* = 0.24 and Plymouth *P* = 0.38). It was perhaps surprising that the greatest similarity was geographical rather than between gear types, though this suggests that despite some overlap, the region is demarcated into areas exploited by Looe and Plymouth fishermen. This was supported by anecdotal information. This relationship is examined in more detail in section 4.3.4.

The first axis of the plots on Figure 4.6 can be interpreted as a contrast between sand (0.495), gravely sand (-0.420), depth (-0.353) and average maximum tidal strength (-0.349). The second axis is influenced by slightly gravely sand (-0.501), sandy gravel (0.480), muddy sand (0.421) and average maximum tidal strength (-0.400). How these parameters contribute to the variation of the first and second axes and influence the construction of the PCA plot of Figure 4.6 is shown in Figure 4.7.

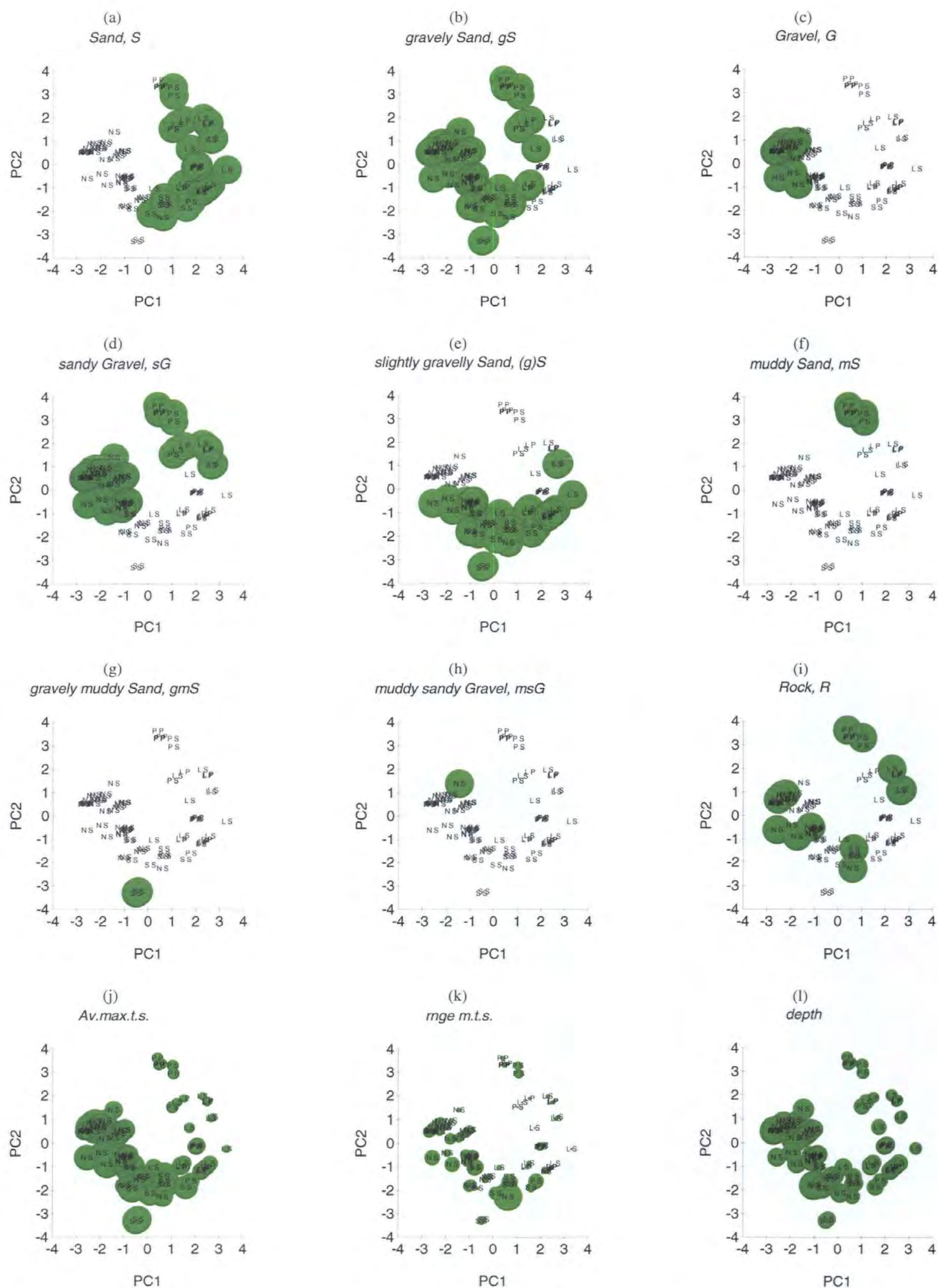


Figure 4.7. Influence of variables on normalised (correlation-based) PCA plot of abiotic data (according to port and type of trawling, N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling) based on the finalised datasets (described on page 89, above). The presence of bubbles relate to the presence/absence of a) sand, b) muddy sand, c) slightly gravelly sand, d) gravelly muddy sand, e) gravelly sand, f) gravel, g) muddy sandy gravel, h) sandy gravel i) rock and magnitude of j) average, and k) range of maximum tidal strength and l) depth.

Figure 4.7 illustrates the influence of the finalised abiotic variables on the overall PCA plot. Interpreting the PCA plot (Figure 4.6) and the bubble plots (Figure 4.7) is aided by examining the overall substrate distribution, shown on Figure 4.4 (above) which shows the area in sufficient detail.

It is clear from Figure 4.7 how the data were arranged according to the presence/absence of sand and gravelly sand. In addition, how the gradient of depth and average maximum tidal strength have been accommodated.

The primary split of the first axis on the top row of Figure 4.7 is clear. Almost all of the Newlyn hauls did not coincide with sand (a), the only one being number 56 that was close inshore to the southern tip of Land's End. The other samples not coincident with sand were some (numbers 33, 34, 47 and 48) which were close to Rame Head, off Plymouth, and several (numbers 51, 52, 77, 78 and 84) off Salcombe. Figure 4.7 (b) shows the general ubiquity of gravelly sand (in 64 samples or 73 %). Gravelly sand was more prevalent in samples coincident with headlands (and stronger tidal maxima) being present in 96 and 90 % of samples from Newlyn and Salcombe respectively and more often absent in the various Looe and Plymouth samples (averaging only 42 % of these hauls). Gravel (G) was also confined to Newlyn.

The horizontal split for the bubble plots on the middle row of Figure 4.7 is also clear, though this is less obvious for the presence of muddy sand. Nevertheless, this substrate type was present in the passage of the six trawl tracks that were all Plymouth based trawls, which passed through an area close to Rame head.

Gravelly muddy Sand (g) was only trawled over from Salcombe although this sediment is found more to the east of the region. Muddy sandy Gravel (h) was only coincidental with one Newlyn sample. Rock (i) was found in 13 samples and these areas of rock were located to the west of Land's End, south of Gribbin Head (just off Fowey), and on the hard ground close to Salcombe, (see Figure 4.4, above). While rock only

contributes minimally to the variation in the first two axes it contributed - 0.718 to the third axis thus its importance was quite separate to the soft substrates.

As mentioned above the average maximum tidal strength (j) was both the fourth largest contributor to the first and second axes. Figure 4.7 (bottom row) shows how the variation was shared across the continuous data factors, range (k) and depth (l), with the larger values in the negative x and y quadrant of the graphs. Comparing the average maximum tidal strength (j), and depth (l), (on Figure 4.7) it appears that the deeper samples also have the greater values of the average maximum tidal strength. Figure 4.8 shows this relationship.

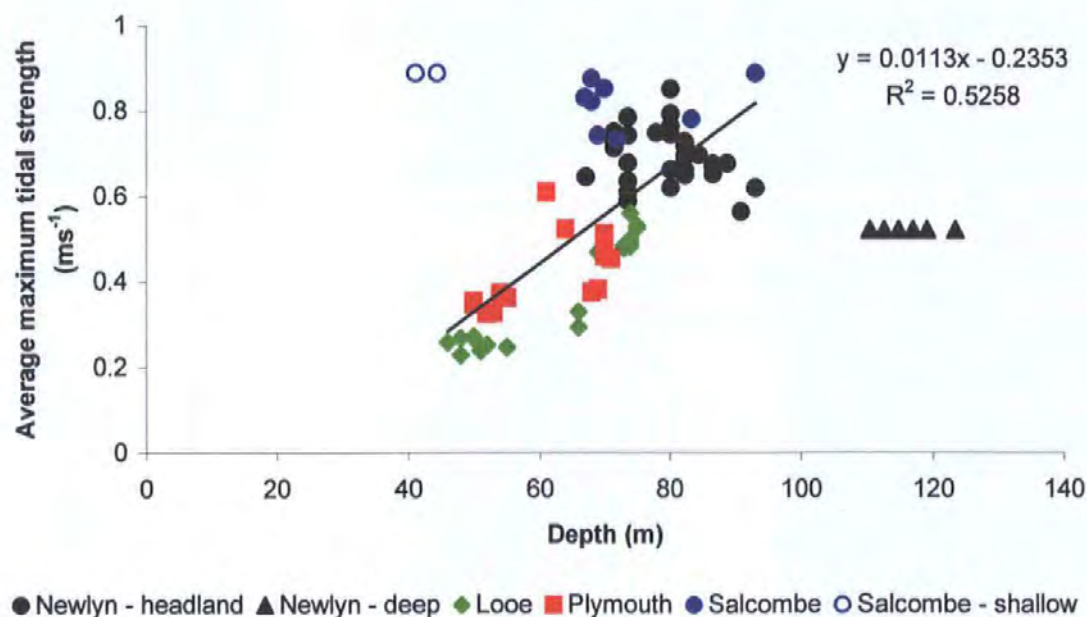


Figure 4.8. Average maximum tidal strength (ms^{-1}) against depth (m). The fitted trend includes neither the deeper and more distant Newlyn samples (black triangles, $n = 10$) nor the very close inshore samples from Salcombe (open blue circles, $n = 2$), which were also close to a headland.

The relationship described by the trend in Figure 4.8 was very highly significant, ($P > 0.001$). Including the outliers from Salcombe the relationship was still very highly significant, ($P > 0.001$) though the fit was less good ($R^2 = 0.3045$). Including all the points on Figure 4.8 the trend was significant ($P = 0.013$), though the fit was poor ($R^2 = 0.0691$). None of the three regressions were strictly valid as their residuals did not approximate a

normal distribution according to the A-D test; ($A^2 = 1.488$, $n = 76$, $P = 0.001$, as shown on Figure 4.8; $A^2 = 1.796$, $n = 78$, $P < 0.001$, including the Salcombe outliers and; $A^2 = 0.959$, $n = 88$, $P = 0.015$ all data).

4.3.4 Looe and Plymouth samples in more detail

Figure 4.6 and Table 4.9, (above) shows the strong similarity between the abiotic datasets for Looe and Plymouth. As shown on Figure 3.1, (page 47), and Figure 4.4, (page 79, above) these trawls generally ran east west and from close inshore to ~ 20 nm from land. The samples from Looe appear to be divisible into those closer inshore and those further offshore represented as those areas sampled from the north or the south of Eddystone Rocks. According to Figure 4.4, the Plymouth hauls do not appear so separable into distinct geographical areas. Table 4.10 shows how these trawls were assigned as inshore or offshore for both ports.

Table 4.10. Haul number and type of trawling operation according to port whether considered inshore or offshore, data are taken from Table 3.2, page 49, above, Figure 4.4, page 79, above.

| Looe | | | | Plymouth | | | |
|---------|------|----------|------|----------|------|----------|------|
| inshore | | offshore | | inshore | | offshore | |
| haul # | type | haul # | type | haul # | type | haul # | type |
| 1 | S | 13 | S | 33 | P | 45 | S |
| 2 | S | 14 | S | 34 | P | 46 | S |
| 31 | S | 15 | S | 47 | P | 67 | P |
| 32 | S | 16 | S | 48 | P | 68 | P |
| 35 | S | 17 | S | 69 | S | 73 | P |
| 36 | S | 49 | P | 70 | S | 74 | P |
| 75 | P | 50 | P | | | 80 | S |
| 76 | P | 53 | P | | | 81 | S |
| 82 | P | 54 | P | | | 87 | S |
| 83 | P | 55 | P | | | 88 | S |

A PCA analysis was run on only the Looe and Plymouth hauls as described in section 4.2.3 though the additional factor of inshore/offshore was included.

Figure 4.9 shows the PCA plot as according port and type of trawling and to whether the trawls were classed as close inshore or further offshore (according to Table 4.10) which should be consulted with reference to the distributional map of the Looe and Plymouth samples, (see Figure 3.1 and Figure 4.4).

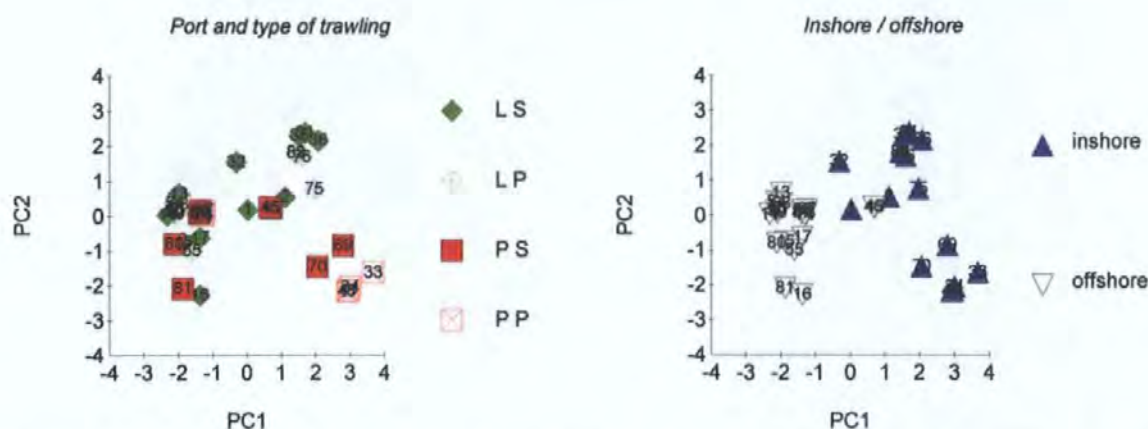


Figure 4.9. Normalised (correlation-based) PCA plot of environmental data showing split into pre-determined inshore and offshore samples (according to port of Looe and Plymouth only) based on (continuous data) average and range of average maximum tidal strength (ms^{-1}), and depth (m), and by (presence/absence of) substrate, S = sand, mS = muddy sand, (g)S = gravelly sand, gS = gravelly sand, sG = sandy gravel, and R = rock. G = gravel, gmS = gravelly, muddy sand, and msG = muddy, sandy gravel were not present in the samples from Looe or Plymouth.

The split of location (inshore/offshore) was well described by the PCA plot in Figure 4.9. Only samples 45 and 46 appearing to have been incorrectly classified, since while these samples were collected south of Eddystone Rocks (actually mostly to the west, see Figure 3.1, page 47, above, and Figure 4.4, page 79, above) they classify as inshore samples according to the PCA plot in Figure 4.9.

The factor of location (inshore/offshore) in the PCA was the single biggest factor (at 0.814) for describing the distribution of the points in the PCA plot of in Figure 4.9.

4.4 Discussion

Sampling at sea on board commercial vessels precluded gathering first-hand, reliable and transferable abiotic data. This Chapter has presented and analysed important parameters that relate to each trawl location. This process enabled an understanding of the environment from which the samples were taken, and this knowledge will feed into further analysis between the biotic and abiotic data, (Chapter 7 and Chapter 8).

Although a generalisation, most of the trawl tracks were parallel to the coastline, which mirrors the 'prevailing' tidal flow; tows from Newlyn were north/south tracks and Looe, Plymouth and Salcombe tracks were east/west. The Looe and Plymouth samples were collected from where the tidal strength was lowest and least variable in its maxima and the substrates were sandy offshore though more complex inshore. The area sampled from Newlyn was more tidally dynamic and the substrates were coarser. The areas sampled from Salcombe were the most tidally dynamic and the substrates were very heterogeneous.

The practise of determining the boats' track from recording its position when shooting and hauling the gear and other (intermediate) positions at changes in the boats' direction has produced meaningful and validated trawl tracks (Appendix F). An improvement to the method would be to download the GPS positional track straight into a GIS although shoot, intermediate and haul positions gave sufficient positional resolution, relative to the scale of abiotic information (sediment information and tidal model grid size). Better methods have nevertheless been employed with considerable success by Rijnsdorp *et al.*, (1998) where the data set was larger. The alternative would have been to use a handheld GPS receiver. Acquiring the positional data at a finer resolution will become more important as similarly scaled information about the sediment is also more widely available.

The explanation for the largest correlation values being negative when examining only the presence/absence of substrate values across all hauls was due to the general split

between the western (Newlyn) based hauls that were predominantly over gravely sand and sandy gravel, and the other more eastern hauls from the other three ports where (on presence/absence terms) sand dominates the substrates as was shown on Figure 4.4, (above).

The most commonly occurring substrates were the coarsest substrates. There may be a degree of pattern modification by fishing gear here; in that the finer sediments once lifted up into the water column will move further than the coarsest, although overall the disturbance by the natural process of storms was calculated (Hamilton *et al.*, 1980) to have the ability to entrain medium-sized particles, greater than the average in the western English Channel, (Evans, 1990) at depths greater than in this study. Therefore, it is likely that overall, naturally caused physical disturbance has a greater impact than anthropogenic (fishing) disturbance on the distribution of the sediments, though there are likely to be areas where the reverse is true. Importantly the sources used to generate the substrate data suffer from being collected over a long period of time (1971 to 1985 for the British Geological Survey data) and it is likely that this timescale could mask subtle changes due to chronic disturbance events. Targeted studies would be required to gather the detailed derived datasets required to examine this further, and this was outside the scope and resources available here.

The outcome of narrowing down the non-presence/absence suite of abiotic parameters showed that the minima and maxima of maximum tidal strength were redundant and could be represented by just the average maximum tidal strength without loss of information. This was largely due to the similar lengths of trawl tracks and relatively large range overall of average maximum tidal strength values. Had a larger range of different fishing methods been studied then this may not have been the case.

Although not directly comparable none of the substrate presence/absence data could be considered as redundant and all were necessary to fully describe the trawled areas. Exactly which relate most strongly to the biotic data is explored in Chapter 7.

The reason for the positive trend between depth and maximum tidal strength (as shown on Figure 4.8, above) was likely to be due to the prevalence of the generally deeper samples being from Newlyn (average depth = 79.63 m, 95 % C.I. = 2.21, $n = 32$) which were close to the Land's End Peninsula and therefore generally have stronger tides (average maximum tidal strength = 0.69 ms^{-1} , 95 % C.I. = 0.02, $n = 32$). Conversely the samples from Looe, Plymouth and Salcombe were mostly taken from within the bay between Dodman and Start Point where the water is more shallow (average depth = 64.88 m, 95 % C.I. = 3.20, $n = 44$) and the tides were weaker (average maximum tidal strength = 0.48 ms^{-1} , 95 % C.I. = 0.05, $n = 44$). That these values for Looe, Plymouth and Salcombe had a greater range in their values was probably due to their larger geographical extent.

Given that tidal strength diminishes with depth, and friction with the seabed plays an important part in this (Huntley *pers com.*), the expected tidal strength near the sea floor would be much lower than that recorded (or modelled) at the surface. This has important consequences for the general stability of the seabed when compared to the average surface tidal movement as measured here, though this could not be examined here.

The particular similarity of the substrates trawled over separately by the Looe and Plymouth boats showed the strong geographical constraint for all these boats and their activity.

Although not explored here it was recognised that the dominance of the presence/absence substrate data has produced an artefact in the PCA plot. Ways to mitigate this involve down weighting the importance of each individual presence/absence factor, such that the influence of the tide and the substrate each have half the total power of influence. This was not done here, as it was not known *a priori* if this would generate an outcome that was more 'correct'.

Chapter 5

5 Spatial, temporal, disturbance and species analysis of the sample

5.1 Introduction

Chapter 3 described the quantity and location of the sampled hauls and introduced the species encountered in the samples. It was evident from Chapter 3 that the samples were gathered over a relatively large spatial extent and that there were both similarities and differences in the species sampled according to port and type of trawling. The sample data (Aim 1, Sample Theme, Figure 1.4, page 17, above) is the mainstay for analysis in this study as shown in the conceptual diagram in Figure 1.3, page 16, above. This Chapter is the first of two (together with Chapter 6) which examine the sample data. There are three parts to the analysis in this Chapter:

- 1 Patterns of similarity in trawled assemblages between ports and type of trawling.
- 2 Measures of degree of disturbance to the trawled areas.
- 3 Interpretation of the fish community data to understand the relationship between species.

The first of these represents the full sample dataset then according to port and type of trawling and in increasing levels of resolution (from the full sample then into its fish and non-fish components). The second determines the level of disturbance that is apparent

from the sample data set. The third part delves a little deeper into the sample data to assess some of the within and between species patterns.

5.1.1 Patterns in trawled assemblages between ports and type of trawling

Chapter 4 principally presented the derived sediment and tidal data and showed how the complexity of the sample locations could be resolved according to port and type of trawling though also how other factors were important. The related aim of this section is to similarly (though separately) resolve the biotic assemblages into a depiction of how the samples (by port and type of trawling) interrelate and are different, through graphical and formal testing of the patterns. This is examined according to the full sample and the contribution of the fishes (whether landed or discarded) and the non-fishes (invertebrate) species. While the shellfish were landed here, they were treated as part of the non-fish species.

Aspects of this analysis feed into Chapter 6 and the relationship between this analysis and the derived environmental data are brought together in Chapter 7.

5.1.2 Degree of disturbance to the trawled areas

The second theme in this Chapter uses the species level resolution of the sample data to examine the Degree of disturbance to the trawled areas. The purpose of this analysis was to ascertain whether this trawling data provides a useful method of determining environmental disturbance, and whether the analysis can be expanded from the typical macrobenthic samples (Agard *et al.*, 1993; Warwick & Clarke, 1994) to include the fishes

and what implications this generates. This analysis was achieved through an Abundance-Biomass Comparison (ABC).

ABC has a theoretical background in classical evolutionary theory of *r*- and *K*-selection. Undisturbed communities, under stable conditions are characterised by large and long-lived (*K*-selected) species. These are rarely numerically abundant though dominate the biomass. Under disturbance (or pollution) stress, these *K*-selected species become replaced by *r*-selected species that are opportunistic in nature. *r*-selected species characteristically are short-lived and numerically dominant though they do not represent a large proportion of the biomass.

ABC curves are simultaneous plots of *k*-dominance curves (Lambshead *et al.*, 1983) of species in rank-order of abundance or biomass (*x* axis) and cumulative percentage dominance (*y* axis). In undisturbed communities, the biomass of the few *K*-selected species lies above the low abundance line. In sites of moderate disturbance, the biomass and abundance lines lie close together (or crossing) and in communities defined as more disturbed (or polluted) the abundance line lies above the biomass one.

Simultaneous plots were first devised by Warwick, (1986). Clarke, (1990) suggested improvements which mitigate the disadvantage of the original method (over dependence on the single most dominant species) though the many ($n = 88$) samples here and expected variability preclude assessment at the single sample level. The method advocated by Warwick & Clarke, (1994) has the advantage that it includes the Clarke, (1990) '*W*' (for Warwick) test statistic, ($|W| \leq 1$) which is a useful single summary statistic and enables comparisons between a large number of simultaneous ABC curves, although representing the assemblage by a single statistic inevitably means that information is lost. In general, $W > 0$ for undisturbed; $W \approx 0$ for moderately disturbed and $W < 0$ for grossly disturbed (or polluted) assemblages. Further information is contained in Clarke & Warwick, (2001a p8-6, 8-7 & 8-12).

The use of the *W*-test statistic has been widespread in pollution and disturbance studies of the benthos however, it is more common and arguably much more appropriate to employ a sampling method that does not suffer from peculiarities associated with size selection, which is an inevitable artefact of trawling. This is recognised in this study by first examining the non-fish (invertebrate) part of the sample, then carrying out a size spectra analysis before expanding the ABC analysis into the full sample. ABC also required a reasonably large data set and this analysis was undertaken with sensitivity to the species accumulation curve (Figure 3.2, page 59, above).

The most commonly quoted size-spectrum (Schwinghamer, 1981) has a characteristic bimodal distribution with the peaks being associated with the categories of meiofauna and macrofauna. The bimodal distribution has also been criticised by Ramsay (*pers com*), who suggests that it is an artefact from sampling methods, and Manly, (1996), who questions (posing as many further questions as he answers) the fundamental distribution of body size. Nevertheless the earlier work by Warwick, (1984) makes a compelling case for the bimodal distribution.

Analysis of fish together with macrobenthos was first carried out by Penczak & Kruk, (1999). Warwick (*pers com*) has supported the calculation of *W*-test statistics for complete samples and suggested that there is nothing intrinsic in the samples collected in this study to invalidate the calculation of the *W*-test statistic. More recently Blanchard *et al.*, (2004); Shin *et al.*, (2005); Yemane *et al.*, (2005) have examined fishing effects on diversity, and ecosystem effects of fishing employing ABC.

5.1.3 Interpretation of the fish community data to understand the relationship between species

Detecting the effects of fishing has employed methods across a wide range of spatial scales. At the smallest scale are techniques (grab samples and box corers, Mudroch & Azcue, 1995; Eleftheriou & McIntyre, 2005) that gather very detailed samples over small areas. Methods which cover the largest area include acoustic seabed classification system (e.g. RoxAnn), sidescan sonar and video-sledges (Humborstad *et al.*, 2004). These latter methods suffer in that they do not collect biological samples. Between these are trawl and dredge sampling techniques (Kaiser, 2003), which cover large spatial scales and collect biological samples, though suffer in that they tend not to retain examples of the smallest species (Blyth *et al.*, 2004). Nevertheless, trawl sampling, whether scientific or commercially based is a valuable research tool.

Other areas of Chapter 5 and Chapter 6 assess the degree of disturbance apparent from the sample data. Neither Chapter however takes into account relationships between individual species in assessing further patterns in the fish community data, which is the subject of this section. The three parts to this section examine different types of relationships between species.

5.1.3.1 Ray species

Due to their life history (Stevens *et al.*, 2000) and extensive exploitation, ray species (*Raja* spp.) are particularly vulnerable (Dulvy & Reynolds, 2003), and as a group are proposed as reference points of understanding ecosystem effects of fishing (ICES, 2005). Walker & Hislop, (1998), hypothesized that ray species occur in abundance according to their replacement mortality, (Walker & Hislop, 1998, Table 3). They suggested that an increase in total mortality would lead to a decline in species abundance in the order of *R. batis*, *R. clavata*, *R. montagui*, *R. naevus* then *R. radiata*. Thus, in essence, the common skate (*R.*

batis) is most susceptible to fishing and the starry skate (*R. radiata*) is the least. Whilst Walker & Hislop, (1998) concentrated their assessment on the central and north-western North Sea it is suggested that it is nevertheless possible to test whether the rankings observed in this study mirror those hypothesized by Walker & Hislop, (1998).

Two further species, the shagreen ray (*R. fullonica*) and the blonde ray (*R. brachyura*) could not be included in the list compiled by Walker & Hislop, (1998) as they had insufficient data. Therefore, in addition to examining whether the order of those species in this study agreed with those in Walker & Hislop, (1998) it was attempted to extend the analysis to include these and any other ray species present.

5.1.3.2 Predator-prey interactions

According to Veale *et al.*, (2000) the three most common predators of *Pecten maximus* were *A. rubens*, *Pagurus* spp. and *Liocarcinus* spp. They found that when damaged and undamaged by-catch specimens of *P. maximus* were placed in front of a time-lapse video system in an area closed to fishing off the Isle of Man these species constituted 78 % of the recorded predation events.

Across all samples in this study (Table 3.4) by biomass *P. maximus* ranked 37 and *A. rubens* ranked 32. All *Liocarcinus* sp combined together would rank 36 (between *D. labrax* and *M. surmuletus*) and together all *Pagurus* spp. would rank 81 (where *P. bernhardus* was situated). According to port and type of trawling, (Table 3.5) *A. rubens* occurred in the top 30 species and *P. maximus* had an average rank of 37. The *Liocarcinus* spp. also featured prominently in Table 3.5 especially in the Looe and Plymouth samples; therefore, all these species were among those well represented across all the samples though they were not ubiquitous in all samples. Whilst no visual evidence of predation by *A. rubens*, *Pagurus* spp. and *Liocarcinus* spp. on *P. maximus* was recorded in the samples, on the basis of the evidence from Veale *et al.*, (2000) the analysis is concerned with the co-occurrence of these species in relation to their individual occurrence in samples.

5.1.3.3 Impacts on echinoderms

As shown on Table 3.4 a greater weight of *M. glacialis* were collected in the sample than *A. rubens*. *E. esculentus* ranked 33 overall, (one place below *A. rubens*). Generally this was consistent across ports and type of trawling (Table 3.5) except for Salcombe where *M. glacialis* ranked between *A. rubens* and *E. esculentus*, which is in agreement with the previously documented range of this species (rarely occurring to the east of Start Point, Ager, 2003). Locally these three species are dominant and together they would have ranked 9 across the full sample.

These 3 common species occur on a wide variety of substrates. MarLIN (MarLIN, 2004) lists these species' preferred substrates as: *M. glacialis*: "...found in a variety of habitats from sheltered muddy sites to wave exposed rock faces," (Ager, 2003). "*A. rubens* occurs in varying abundance upon a variety of substrata that include coarse and shelly gravel and rock," (Budd, 2001), and *E. esculentus* is "...found on rocky substrata from the sublittoral fringe to circa 40 m, although it may be found at depths of 100 m or more," (Tyler-Walters, 2003).

Damage to *A. rubens* has long been used as an indicator of fishing (Kaiser, 1996; Ramsay *et al.*, 2001). Given these three species' near ubiquity here, it was decided to determine whether *M. glacialis* or *E. esculentus* might offer any benefits as indicators. This was undertaken as an assessment of the frequency of arm loss in *M. glacialis* and *A. rubens*, or general damage in *E. esculentus*.

Arm loss in *M. glacialis* and *A. rubens* (as well as other asteroids) is not confined to damage or disturbance caused by fishing. Ramsay *et al.*, (2000b) demonstrated a significant positive correlation between predator density and arm loss in both of these species in an environment from which anthropogenic disturbance events could be "virtually eliminated." In this study disturbance was the method of gathering data, though

it was possible to ascertain whether the presence of the predators of *M. glacialis* and *A. rubens* might be responsible for some of the arm loss of these species here.

5.2 Methods

5.2.1 Patterns in trawled assemblages between ports and type of trawling

Initial examination of the sampled assemblages was carried out via *non-Metric Multidimensional Scaling* (nMDS, or MDS) in PRIMER-E (Clarke & Warwick, 2001a) of the full sample data according to port. For this and all subsequent analyses each MDS plot was based on a similarity matrix generated from the site/species matrix of weight by sample and species. The similarity matrix were calculated using the Bray-Curtis measure (Digby & Kempton, 1987; Southwood & Henderson, 2000; Waite, 2000) on double square root transformed data. This transformation was chosen as it best balanced the contributions between the common and rare species. Appendix G presents the rationale for and results of the transformation analyses.

The next MDS analysis examined relationships of similarity by port and type of trawling. Following this, the combined landed and discarded fish component of the sample was examined according only to port; then the type of trawling was added. The data used in this Chapter were the sum of weights by sample for each species and it was not relevant to know whether the individual fish were intended to be landed or discarded.

When a sub-set of the full data set was analysed sites or species were removed from the full matrix and a new similarity matrix was generated from the sub-set. The same transformation and measure was applied to generate this subset as described in Appendix G.

Next, the contribution to the pattern of the non-fish species was examined by port then according to port and type of trawling.

The relationships illustrated in the MDS plots were tested for significance of the groups according to the chosen factor (port, or port and type of trawling) by analysing the similarity matrices using the ANOSIM routine (again in PRIMER-E, Clarke & Warwick, 2001a). Each ANOSIM tested the null hypothesis that there were no assemblage differences between groups of samples and generated global R and pair-wise R statistics. The global R ($|R| \leq 1$) though generally ($R \in [0,1]$) is a measure of the validity of the chosen factor in explaining patterns for the analysis as a whole. $R = 1$ if *all* replicates within sites are more similar to each other than any replicate from different sites and $R \approx 0$ where the similarities between and within sites are the same on average (Clarke & Warwick, 2001a). The pair-wise R ($|R| \leq 1$) though generally R ($R \in [0,1]$) statistic gives an absolute measure of how well separated the particular groups are on a scale of 0 (indistinguishable) to 1 (all similarities within groups were less than any similarities between groups). Clarke & Gorley, (2001, p60) interpret these pair-wise R -values as; $R > 0.75$ = well separated, $R > 0.5$ = overlapping but clearly different and $R < 0.25$ barely separable at all. Where pair-wise comparisons showed the data were not significantly different by groups, using the $< 5\%$ level (Clarke & Gorley, 2001) the pairs are highlighted.

The MDS plot for the samples according to port (see Figure 5.3), and port and type of trawling (see Figure 5.4) are structurally the same, and only differ in their labels. While all the ANOSIMs are presented not all MDS plots according only to port are shown.

Having analysed the full sample and its components, the relationship between the sites to determine the relative influence of each component on the overall pattern was undertaken by *RELATE* in PRIMER-E (Clarke & Warwick, 2001a). This uses the non-parametric Spearman's rank-order correlation (r_s) coefficient to assess the similarity between similarity matrices.

5.2.1.1 Spatial and temporal analysis of the Newlyn samples

The Newlyn samples were collected at similar times of successive years and over a relatively small geographical area (Figure 5.1).

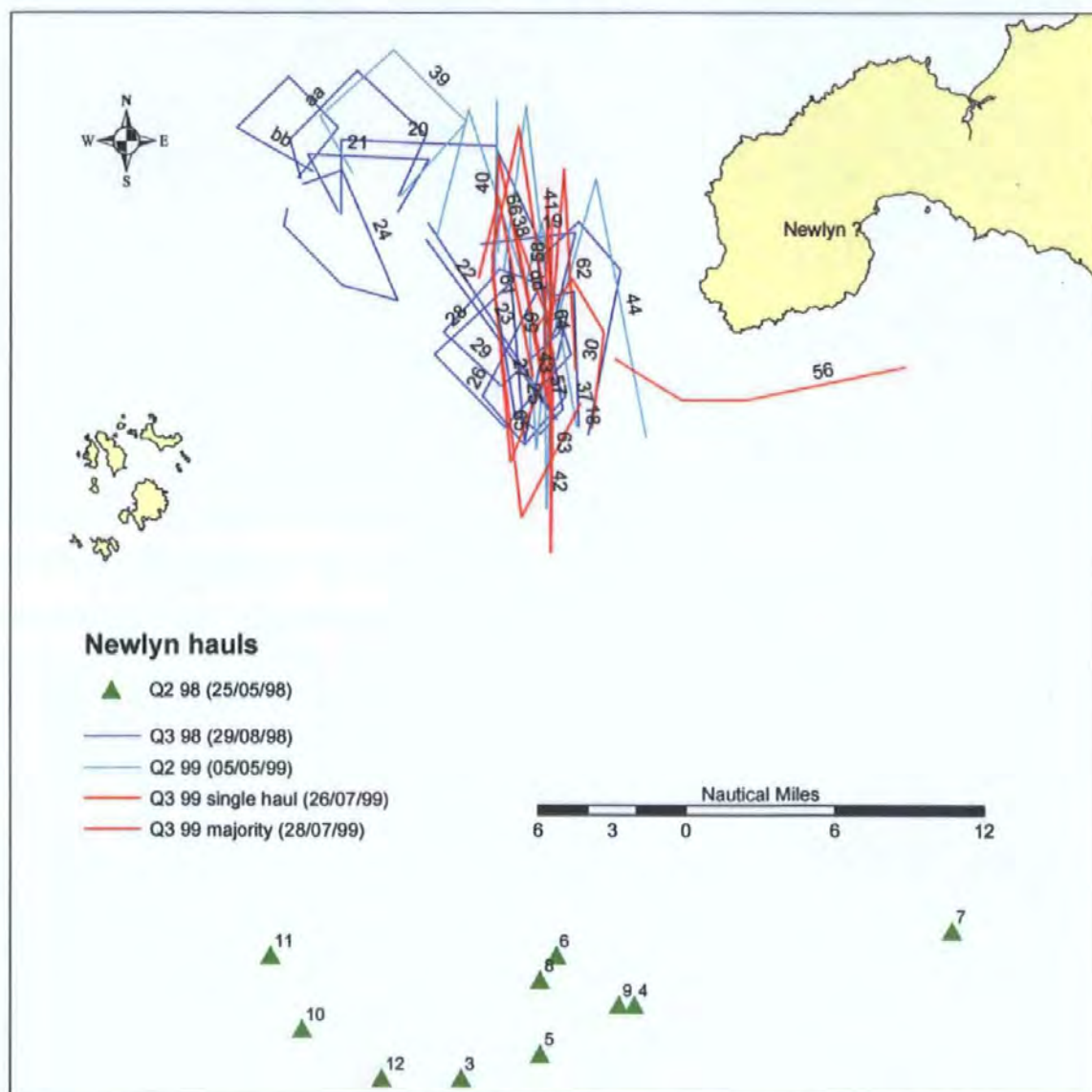


Figure 5.1. Location of Newlyn hauls (colour coded) according to year and quarter, and numbered according to their sequential haul number (Table 3.2, page 49, above). Only haul position was recorded for Q2-'98.

Temporal pattern analysis could therefore be carried out to examine whether, within the scope of the data, there was a consistent pattern between quarters 2 and 3 of the 2 subsequent years' sampling, (see Table 3.2, page 49, above). The temporal analysis

followed the same route of ANOSIM by year and quarter, which was illustrated by MDS as undertaken for all the samples. As for the spatial analysis, the temporal examination of the Newlyn samples began with the full sample and examined the fish and the non-fish (invertebrate) components using the same techniques as described above. Additionally, the contribution of the invertebrate and non-shellfish species was also investigated.

5.2.2 Degree of disturbance to the trawled areas

Given that the accumulation of species sampled in this study (Figure 3.2, page 59, above) appeared to approach an asymptote (especially for the fishes) the data were considered suitable to examine the degree of disturbance to the trawled areas through plotting Abundance-Biomass Comparison (ABC) curves.

The derived pattern in the environmental factors (Figure 4.6, page 90, above) and species abundances (Table 3.5, page 56 above) and relatedness (Figure 5.4, page 118, below) patterns in disturbance were examined first on the full sample then according to port and type of trawling, (as combinations of individual samples).

5.2.2.1 ABC curves

The two matrices used for the ABC analysis were the site (sample) species matrices for both biomass (weight) and numbers of individuals (counts). In the counts matrix colonial organisms were treated as a single individual of that species. In addition, the weight of each organism was not corrected for its degree of completeness (section 2.3.3), though none of the following were included in the analysis: individual arms of starfishes or brittle stars; smashed examples of echinoids or crabs; lone appendages of crabs or squid; empty gastropod or bivalve shells.

The ABC curves were generated according to Clarke & Warwick, (2001a).

Dominance Plot in PRIMER-E allows ABC curves (and *W*-test statistics) to be calculated

on any sub group of the samples (e.g. individual samples, all samples collected each trip/day, all those from each port) that is defined at 'factor level' or by user generated 'subset' and the same applies to the variables (species). In section 5.3.2.1 and 5.3.2.3, the *W*-test statistics for a variety of ABCs are presented. Rather than create sub groups in PRIMER for the component under scrutiny the sub group was reported as the average of the *W*-test statistics of samples that comprised this level rather than create a sub group and test this. The reason for this was that this study is a collection of related though independent samples taken from hauls therefore the analysis must be carried out at the level of the sample. Only for the summary descriptions (non-fish part of the sample for all samples and full sample for all samples) were ABC curves and *W*-test statistics generated for larger groups.

As mentioned above, in keeping with the traditional use of ABC the first analysis examined only the non-fish species (the invertebrates). In extending the analysis into the fishes the weight (g) of individual fishes was used based on their measured length (to the nearest cm below, see section 2.2.2), though since only the sample not the haul specimens were included no gutted to un-gutted conversion was required.

5.2.2.2 Size spectra

Commonly plots of size spectra take the form of \log_2 transformed plots of biomass against Equivalent Spherical Diameter (ESD) (Sheldon *et al.*, 1972;Schwinghamer, 1981;Ramsay *et al.*, 1997). Ramsay *et al.*, (1997b) suggest that for categories where clearly defined measurements have been made over a long period of time (e.g. length in fishes) these data can be carried forward for analysis rather than converting values to ESD. In this study, since both fishes and a wide variety of invertebrate growth forms were included in the samples, data for all species were converted from wet weight to ESD. Duplisea, (1988, Figure 3) provides direct estimates of this conversion, which were extrapolated to encompass the range of weights encountered in this study (Figure 5.2). The conversion

also included a density factor (Ramsay *et al.*, 1997b, p1,719); based on Schwinghamer, (1981), to compensate for differences in density across the range of sampled organisms, ideally however, a different density factor should be applied for different types of organisms.

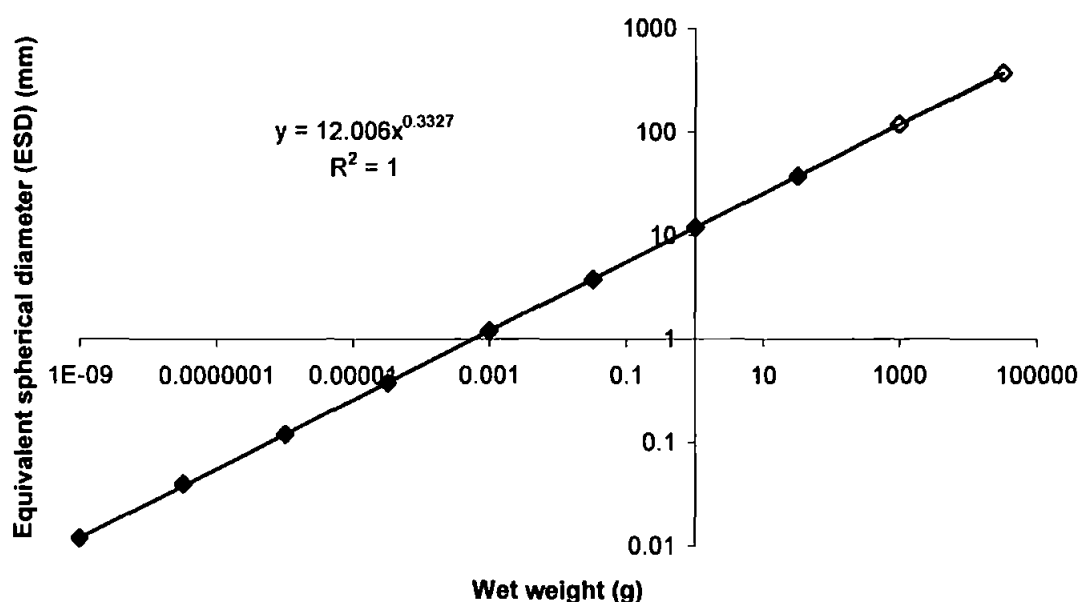


Figure 5.2. Conversion factor between wet weight (g) and Equivalent Spherical Diameter (EDS) (mm) according to data from Duplisea, (1988), (closed data points direct estimates of conversion between wet weight and ESD). Open data points are extrapolations necessary to encompass wet weights for the data range in this study.

The straight line on Figure 5.2 permitted a degree of confidence in extrapolating the line to include data of the range of wet weights found in this study and enabled comparison with other data sets where other methodologies (e.g. sieving) were employed in sampling a habitat. These include the deep-sea, (Sheldon *et al.*, 1972); intertidal infauna, (Schwinghamer, 1981); and stream benthos (Ramsay *et al.*, 1997).

Commonly biomass, as transformed values of mass per unit area or volume is plotted against ESD values. Biomass values (as weight per unit area) are difficult to quantify and cross compare in trawl sampling as the weight of material is selected by the gear from that on or just above the seabed and the area (or more correctly the volume) is

(despite being able to calculate the area swept by the gear) always an approximation. Therefore, frequency of numbers in size classes was used instead of biomass.

CurveExpert 1.3 (Hyams, 2000) was used to generate the equation of the line for frequency against size (as \log_2 ESD) and the best equation was the minimum order polynomial that generated a fit that was better than any other method (e.g. sinusoidal, or reciprocal quadratic).

5.2.3 Interpretation of the fish community data to understand the relationship between species

5.2.3.1 Ray species

In the haul data, the ray species were aggregated to a single group (Table 3.3). Though unfortunate for analysis, it is commonly how this group is often recorded in discard studies (Course *et al.*, 1996) and market data (MAFF/DEFRA, 1990-2001). In the sample data, length for each specimen by species was recorded and weights estimated as described in section 2.2.2.1. The rank-order of species and average length data in this study was compared to the replacement mortality rank in Walker & Hislop, (1998).

A further notable point is the division of caught rays according to whether they were likely to be mature. Maturity was not assessed at sea, therefore this analysis was concerned with those larger or smaller than literature values (McEachran & Dunn, 1998); Walker & Hislop, 1998; Froese & Pauly, 2003) for their length at maturity.

5.2.3.2 Predator-prey interactions

This analysis compared the number of samples that contained the predator, its prey, both, or neither of these species. Veale *et al.*, (2000) did not discriminate between any *Pagurus*

spp. and *Liocarcinus* spp. due to that study being video-based. Similarly, here sample containing a whole representative of these species was acceptable.

5.2.3.3 Impacts on echinoderms

Section 2.3.3.1.6 outlined the method of describing the degree to which specimens of the echinoderms were damaged. This analysis centres on describing the difference in weight between all (any amount of damage) and complete only specimens of the three species in order to determine the degree to which the differences in weight was apparent between the groups.

Ramsay *et al.*, (2000b) found that possible predators of *M. glacialis* and *A. rubens* include other starfish; *Luidia ciliaris* (Phililli), *Solaster endeca* L., *Crossaster papposus* L., the crabs *Cancer pagurus* L. and *Hyas araneus* L. and these authors were able to quantify the relative density of both predatory and prey species. This was not possible for this study. Instead, the hypothesis tested was that the proportion of undamaged *M. glacialis* and *A. rubens* was negatively correlated with the number of their predators in the sample. Neither the numbers of predators nor the proportion of undamaged specimens was normally distributed as shown by Table 5.1.

Table 5.1. Results of Anderson-Darling (A-D) tests of normality on number of predators and % of undamaged specimens for both *Asterias rubens* and *Marthasterias glacialis*.

| measure | <i>A. rubens</i> | | <i>M. glacialis</i> | |
|----------------|---------------------|-----------------------|---------------------|-----------------------|
| | number of predators | % undamaged specimens | number of predators | % undamaged specimens |
| A ² | 6.193 | 4.818 | 2.406 | 2.195 |
| n | 51 | 51 | 55 | 55 |
| P | < 0.001 | < 0.001 | < 0.001 | < 0.001 |

Due to the outcome of the A-D test shown in Table 5.1 and in agreement with Ramsay *et al.*, (2000b) the correlations between the number of predators and % of undamaged

specimens were examined using the non-parametric Kendall's τ (tau) rank-order correlation.

5.3 Results

5.3.1 Patterns in trawled assemblages between ports and type of trawling

5.3.1.1 All ports

5.3.1.1.1 The full sample

Figure 5.3 shows the MDS plot of trawled assemblages of the full sample data according to port of trawling.

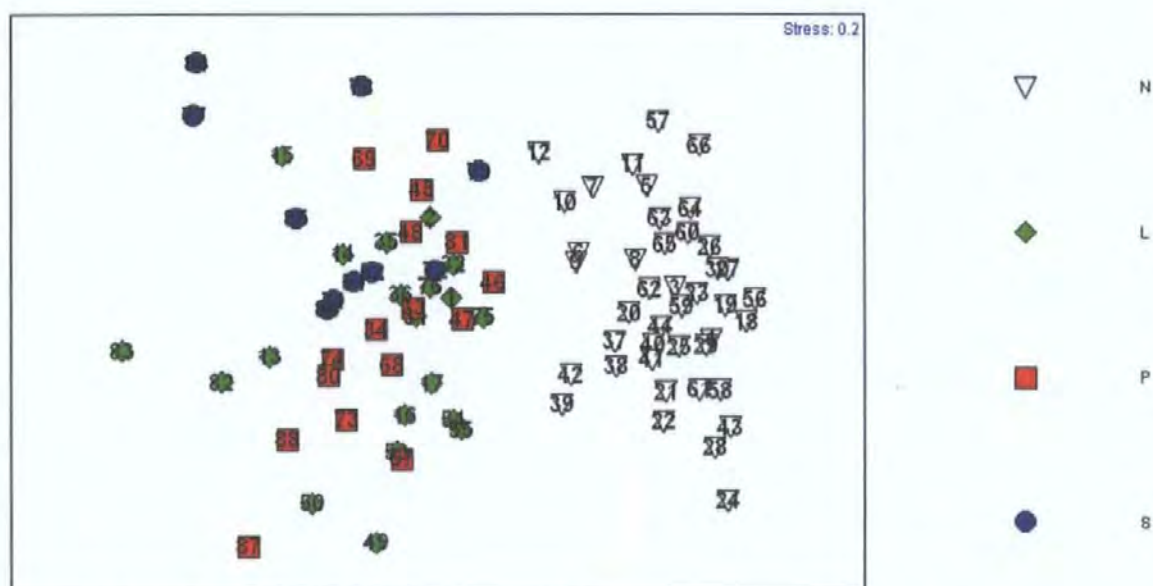


Figure 5.3. MDS plot of $\sqrt{\sqrt{}}$ transformed data by site, according to port of trawling, (N = Newlyn, L = Looe, P = Plymouth and S = Salcombe). Data points are labelled according to haul number, (Table 3.2, page 49, above) and the stress value is shown on the figure. ANOSIM global $R = 0.672$, $P < 0.001$.

The two dimensional MDS plot shown in Figure 5.3 was an acceptably good representation of the data as the stress value was 0.2, and the choice of port was a good factor at describing the data according to the global *R* value. It is apparent from Figure 5.3 that for the full sample the hauls from Newlyn were quite different to those from the other ports. Also, there was a degree of consistency in the hauls from Salcombe in that they cluster in one part of the plot, though these seem to be divisible further into two groups. Those hauls away from the main group (hauls 77, and 84; top left on Figure 5.3) were located the closest inshore (see Figure 3.1, page 47, above) so regardless of other factors there appears to be a degree of geographical distribution in these data. It is also apparent that pairs of hauls sampled on the same day tend to cluster together. Examples of this are hauls 16 and 17, and 35 and 36, single boat trawls from Looe; 51 and 52 from Salcombe, 69 and 70 single boat trawls from Plymouth; 75 and 76 pair boat trawls from Looe, see Figure 5.4, page 118, below. This was regardless of their spatial or temporal distribution, suggesting that the similarity between these trawls was higher than the similarity with reference to other factors. It is also apparent that there was considerable overlap in the hauls from Looe and Plymouth and this is supported by the pair-wise ANOSIM values in Table 5.2.

Table 5.2. ANOSIM as pair-wise *R*-values between full samples according to port, N = Newlyn, L = Looe, P = Plymouth and S = Salcombe. Not significantly different pair-wise associations are highlighted.

| | | | |
|---|-------|-------|-------|
| N | 0.806 | 0.818 | 0.911 |
| L | | 0.046 | 0.183 |
| P | | | 0.326 |
| | L | P | S |

Table 5.2 shows that the full samples from Newlyn were well separated ($R > 0.75$) from all other ports supporting the interpretation of the MDS. Full samples from Looe and Plymouth were not significantly different. The Salcombe samples overlapped but were clearly different to those from Plymouth, though the Salcombe and Looe samples were barely separable at all.

Figure 5.4 shows the MDS plot of the full sample according to port and type of trawling.

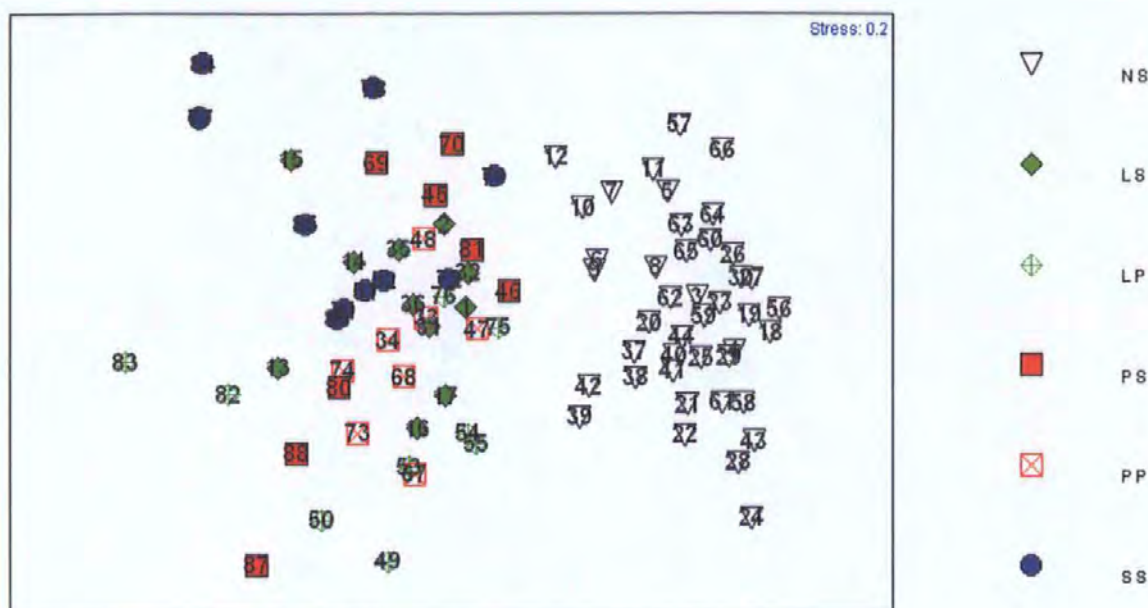


Figure 5.4. MDS plot of $\sqrt{\sqrt{}}$ transformed data by site, according to port (N- = Newlyn, L- = Looe, P- = Plymouth and S- = Salcombe) and type (-S = single boat and -P = pair boat) of trawling. Data points are labelled according to haul number, (Table 3.2, page 49, above) and the stress value is shown on the figure. ANOSIM global $R = 0.671$, $P = 0.001$.

There is virtually no effect on the global R -value by considering type of trawling as a factor. The Plymouth pair trawl samples on Figure 5.4 cluster together and in between two areas of Plymouth single boat samples indicating considerable overlap. This split of the Plymouth single boat samples was reflected in their geographical placement; those lower on Figure 5.4 were to the east and south of Eddystone Rocks. In contrast, the Looe single and pair boat samples did not similarly clump together. The pair-wise ANOSIM for the port and type of trawling data for the full sample is shown in Table 5.3.

Table 5.3. ANOSIM as pair-wise R -values between full samples according to port (N- = Newlyn, L- = Looe, P- = Plymouth and S- = Salcombe) and type (-S = single boat and -P = pair boat) of trawling. Not significantly different pair-wise associations are highlighted.

| | | | | | |
|-----------|-----------|-----------|-----------|-----------|-----------|
| NS | 0.834 | 0.837 | 0.811 | 0.833 | 0.911 |
| LS | | 0.277 | 0.205 | -0.036 | 0.163 |
| LP | | | 0.313 | 0.170 | 0.385 |
| PS | | | | 0.150 | 0.412 |
| PP | | | | | 0.202 |
| | LS | LP | PS | PP | SS |

It is apparent from comparing Table 5.3 with Table 5.2 that most of the similarity between the full samples from Looe and Plymouth was actually between the single boat samples from Looe and the pair boat samples from Plymouth. The Plymouth single and pair trawl full samples were the only other sets that were not significantly different. The Looe single and pair boat samples were overlapping but just separable and the single boat samples from Plymouth and Looe were barely separable ($R = 0.205$) as were the pair samples from the same ports ($R = 0.170$).

The clearest message from Table 5.3 and Table 5.2 was that Newlyn was different from all other ports. ANOSIM comparing samples confirmed this; global $R = 0.729$, $P < 0.001$).

5.3.1.1.2 Fish species part of the sample

Figure 5.5 shows the MDS plot of trawled assemblages of landed and discarded fishes, (though not the shellfish) abundance of species by sample according to port and type of trawling. The MDS plot according only to port was not shown, as it was structurally the same as Figure 5.5 (only differing in labels).

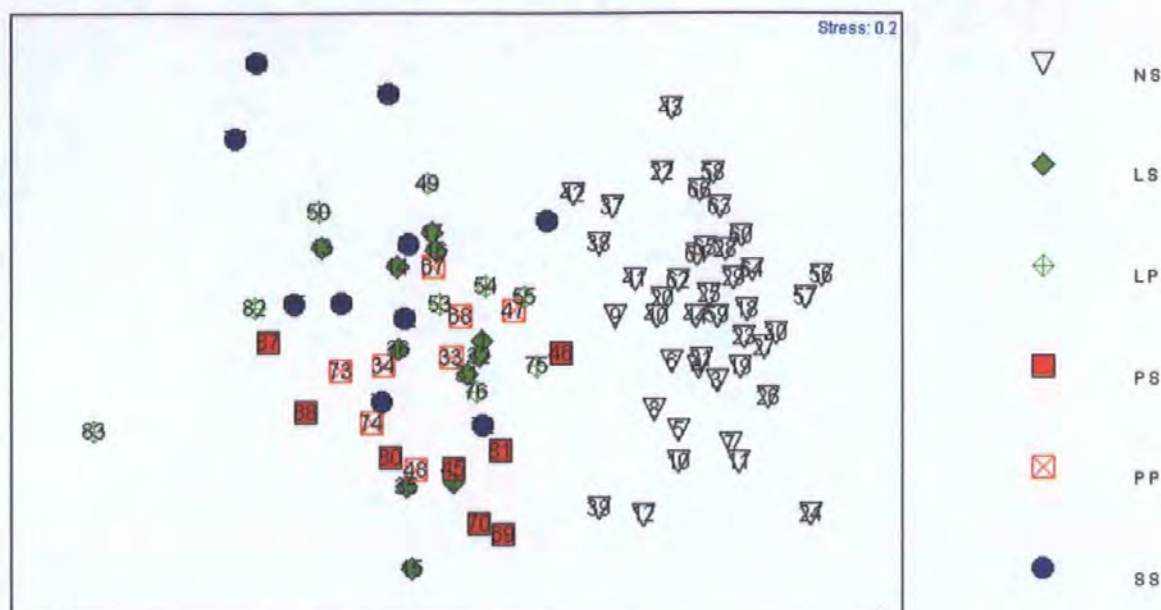


Figure 5.5. MDS plot of $\sqrt{\sqrt{}}$ transformed data by site for the fish only part of the sample according to port (N- = Newlyn, L- = Looe, P- = Plymouth and S- = Salcombe) and type (-S = single boat and -P = pair boat) of trawling. Data points are labelled according to haul number, (Table 3.2, page 49, above) and the stress value is shown on the figure. Global $R = 0.596$, $P = 0.001$.

Figure 5.5 and Figure 5.4 (above) appear quite similar, suggesting that the fish species formed a dominant part of the overall description of the sample. This was borne out by the degree to which the two underlying similarity matrices were similar (*RELATE*, $r_s = 0.918$). Removing the non-fish part of the sample has reduced the global R -value so some explanatory power has also been lost. This similarity was perhaps not surprising since the biomass of the fishes generally dominated the sample (see section 3.3 and 3.6). This similarity was borne out by the ANOSIM of the fish only part of the sample, which is shown by port only in Table 5.4, and by port and type of trawling in Table 5.5 (below).

Table 5.4. ANOSIM as pair-wise R -values between the fish only part of the sample according to port, N = Newlyn, L = Looe, P = Plymouth and S = Salcombe. Not significantly different pair-wise associations are highlighted. Global $R = 0.612$, $P = 0.001$.

| | | | |
|---|-------|-------|-------|
| N | 0.740 | 0.754 | 0.846 |
| L | | 0.033 | 0.169 |
| P | | | 0.316 |
| | L | P | S |

None of the differences in pair-wise R -values > 0.1 reinforcing the fact that the fish form a strong component of the sample and that again there was no significant difference between Looe and Plymouth. The clear separation of the Newlyn samples was maintained.

Table 5.5 shows the ANOSIM pair-wise R - values for the fish only part of the sample according to port and type of trawling.

Table 5.5. ANOSIM as pair-wise R -values between the fish only part of the sample according to port (N- = Newlyn, L- = Looe, P- = Plymouth and S- = Salcombe) and type (- S = single boat and -P = pair boat) of trawling. Not significantly different pair-wise associations are highlighted. Global $R = 0.596$, $P = 0.001$.

| | | | | | |
|------------|------------|------------|------------|------------|------------|
| N S | 0.765 | 0.748 | 0.761 | 0.747 | 0.846 |
| L S | | 0.157 | 0.147 | -0.063 | 0.129 |
| L P | | | 0.247 | 0.131 | 0.294 |
| P S | | | | 0.128 | 0.375 |
| P P | | | | | 0.22 |
| | L S | L P | P S | P P | S S |

The ANOSIM pair-wise R -values in Table 5.5 were generally lower (in 14 out of 15 cases) than in Table 5.3, above (showing the ANOSIM for the full sample) though only between the Looe single and Looe pair trawling was the difference > 0.1 . This suggests that concentrating only on the non-fish species did not greatly reduce the degree of separation, or overlap, of the samples according to port and type of trawling, though this was at the expense of removing 132 species of invertebrates and the four types of other material and concentrating only on the 54 fish species (see Table 3.3, page 51, above). While the pair-wise R -values were not very different between Table 5.3 and Table 5.5, the decrease in global R -values between the full and the fish only part of the sample suggests that the degree of discrimination of groups is less clear for the sub-group of fish when compared to the full sample.

5.3.1.1.3 Non-fish (invertebrate) part of the sample

Figure 5.6 shows the MDS of the non-fish (shellfish and other invertebrate species) data according to port and type of trawling.

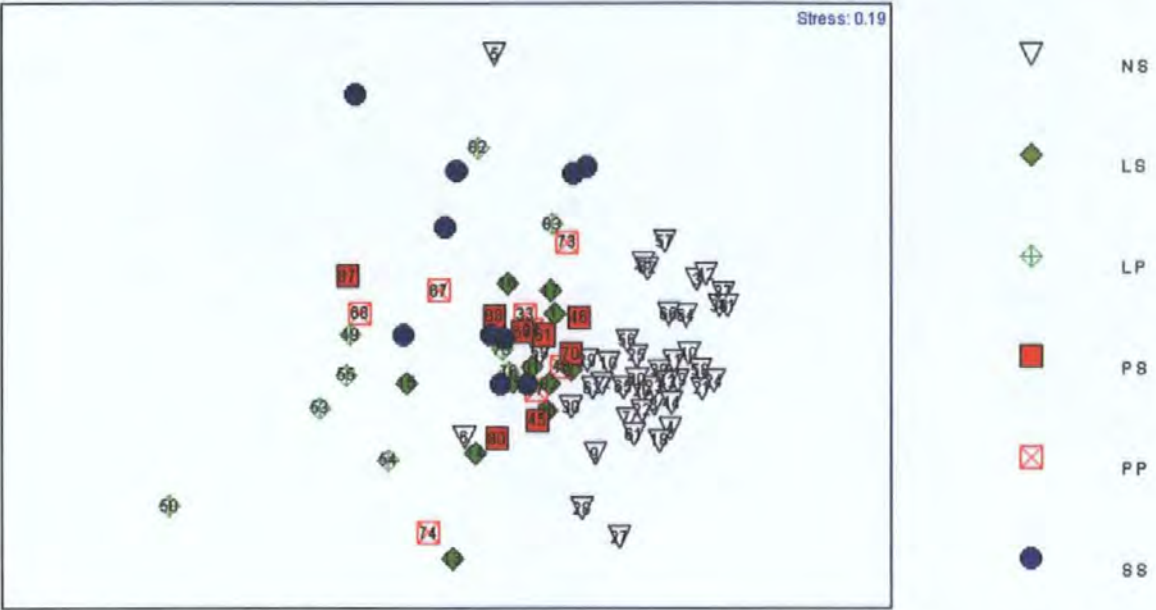


Figure 5.6. MDS plot of $\sqrt{\sqrt{}}$ transformed data by site for the non-fish part of the sample according to port (N- = Newlyn, L- = Looe, P- = Plymouth and S- = Salcombe) and type (-S = single boat and -P = pair boat) of trawling. Data points are labelled according to haul number, (Table 3.2, page 49, above) and the stress value is shown on the figure. Global $R = 0.429$, $P = 0.001$.

The sample data for Newlyn Figure 5.6 still appeared quite distinct to the rest although this was less obvious than in the previous analysis. Also, that the hauls from Salcombe were still broadly in two groups which corresponded to those closer inshore and those further offshore, and the hauls from Looe and Plymouth were quite variedly distributed. Table 5.6 shows the ANOSIM values for the non-fish part of the sample according to port of trawling. The results of this ANOMSIM were included so that the comparison with the analysis in Table 5.2 and Table 5.4 (above) can be made.

Table 5.6. ANOSIM as pair-wise R -values between the non-fish only (invertebrate) part of the sample according to port N = Newlyn, L = Looe, P = Plymouth and S = Salcombe. Not significantly different pair-wise associations are highlighted. Global $R = 0.404$, $P = 0.001$.

| | | | |
|---|-------|-------|-------|
| N | 0.462 | 0.513 | 0.569 |
| L | | 0.037 | 0.022 |
| P | | | 0.162 |
| | L | P | S |

According to Table 5.6 Looe and Plymouth, and Looe and Salcombe were not significantly different according to the non-fish only part of the sample by port. Also after removing the fish species, the Newlyn samples were much less distinct as borne out in the MDS plot in Figure 5.6. Overall, the pair-wise R -values between Newlyn and the other ports were reduced by 0.330.

Table 5.7 expands the analysis shown in Table 5.6 to include type of trawling in addition to port. It is the ANOSIM to represent Figure 5.6.

Table 5.7. ANOSIM as pair-wise R -values between non-fish (invertebrate) part of the sample according to port (N- = Newlyn, L- = Looe, P- = Plymouth and S- = Salcombe) and type (-S = single boat and -P = pair boat) of trawling. Not significantly different pair-wise associations are highlighted. Global $R = 0.429$.

| | | | | | |
|----|-------|-------|-------|-------|-------|
| NS | 0.468 | 0.549 | 0.517 | 0.512 | 0.569 |
| LS | | 0.312 | 0.172 | 0.069 | 0.139 |
| LP | | | 0.250 | 0.162 | 0.298 |
| PS | | | | 0.082 | 0.364 |
| PP | | | | | 0.097 |
| | LS | LP | PS | PP | SS |

Including type of trawling in addition to port for the non-fish part of the sample shows similarities with the previous example (Table 5.6) but there are quite distinct differences to the fish only (and the full sample). The global R was a little higher for the ANOSIM presented in Table 5.7 than Table 5.6 suggesting that it is relevant to include the type of trawling to better explain the distribution of the non-fish species. This is the first time that the port and type of trawling has been better resolved than the data only according to port. Table 5.7 shows it is still the case that the hauls from Newlyn were quite different to the other ports, which was in keeping with the fish only and full sample analysis and given

their geographical distribution, this was not unexpected. Overall, the Looe and Plymouth and Salcombe samples were barely separable for the non-fish (invertebrate) species. Table 5.7 also shows that in addition to the strong similarity within port, there was a high degree of similarity between types of trawling across port.

The relationships between the similarity matrices for the full sample, fish and non-fish (invertebrate) species is shown in Table 5.8.

Table 5.8. Level of similarity (according to *RELATE*) between the similarity matrices for the full sample, fish and non-fish (invertebrate) parts of the samples according to Spearman's rank-order (r_s) correlation.

| | | |
|--------------------|-------------|------------------------------------|
| full sample | 0.918 | 0.648 |
| fish | | 0.347 |
| | fish | non-fish (Invertebrates) |

Table 5.8 reinforces the strength of the fish part of the sample in describing the full sample, and dissimilarity between the fish and non-fish.

5.3.1.2 Spatial and temporal analysis of the Newlyn samples

Section 5.3.1.1 concentrated on examining differences between the ports and types of trawling. In these analyses, the samples from Newlyn were both numerous ($n = 42$, 47 % of the samples) and were well separated from the others shown on Figure 5.1 (page 110, above). They were also collected at similar times of subsequent years and over a relatively small geographical area. This analysis explores the degree to which there was measurable seasonality in the samples for the same time of each year. Figure 5.7 shows the MDS plot based on the full samples from the Newlyn hauls according to the year and quarter of the year they were taken.



Figure 5.7. MDS plot of $\sqrt{\sqrt{}}$ transformed data for the Newlyn hauls (based on the full sample). Data points are labelled according to quarter and year (Figure 5.1, page 110, above) and haul number, (Table 3.2, page 49, above). The stress value is shown on the figure. Global $R = 0.498$, $P < 0.001$.

The stress value of Figure 5.7 (at 0.28) is sufficiently high to warrant a deal of scepticism in the precise arrangement of the data, though since the value is < 0.3 the arrangement cannot be considered as arbitrary (Clarke & Warwick, 2001a). Nevertheless, there was a high degree of difference (or separation) between the four trips shown in Figure 5.7 (despite the geographical overlap). Table 5.9 shows the formal separation of the groups according to an ANOSIM.

Table 5.9. ANOSIM as pair-wise R -values for full samples between trips from Newlyn according to quarter of the year.

| | | | |
|------|-------|-------|-------|
| 98-2 | 0.461 | 0.505 | 0.641 |
| 98-3 | | 0.438 | 0.404 |
| 99-2 | | | 0.604 |
| | 98-3 | 99-2 | 99-3 |

Table 5.9 shows that the groups (trips by quarter of the year) were overlapping but clearly different so overall there was no consistency across years, although the greatest separations were between '98-2 and '99-3, which were spatially and temporally different, and between '99-2 and '99-3 which were only temporally different. The average between year, (same

quarter) average pair-wise R -value ($R = 0.455$) was lower than the average within year (different quarter) R -value ($R = 0.536$).

Figure 5.8 shows the MDS plot for the fish only part of the sample for the hauls from Newlyn.

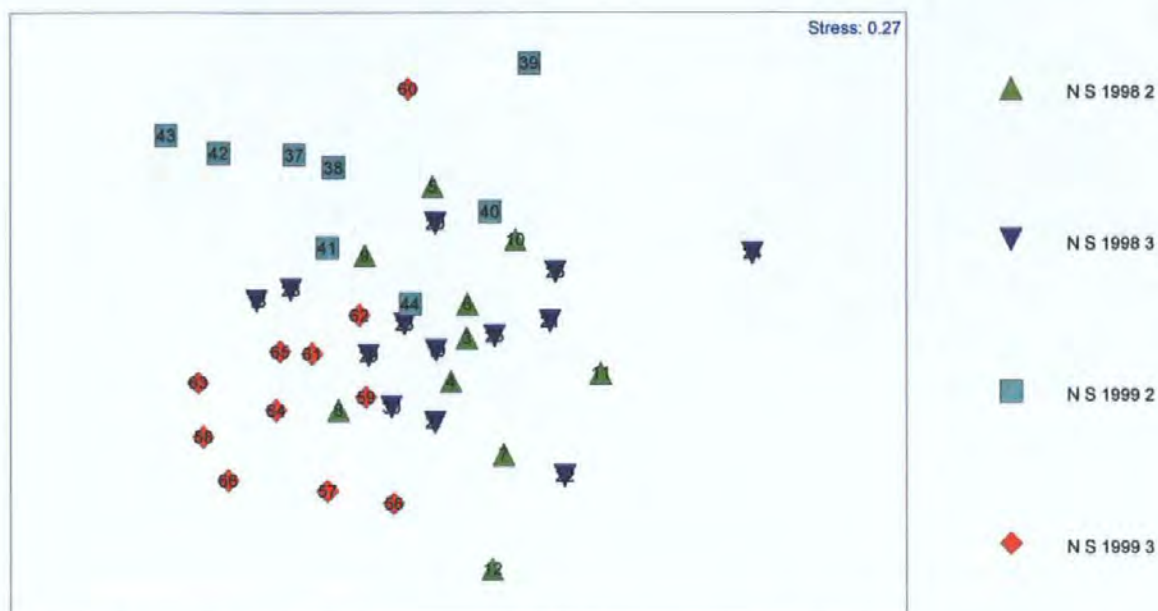


Figure 5.8. MDS plot of $\sqrt{\sqrt{}}$ transformed data for the Newlyn hauls (based on the fish only part of the sample). Data points are labelled according to quarter and year (Figure 5.1, page 110, above) and haul number, (Table 3.2, page 49, above). The stress value is shown on the figure. Global $R = 0.317$, $P = 0.001$.

It is apparent that the separation into groups according to the trip (for the fish only part of these samples, Figure 5.8) was less distinct when compared to the full sample (Figure 5.7).

The ANOSIM (Table 5.10) shows this numerically.

Table 5.10. ANOSIM as pair-wise R -values for the fish only part of the sample between trips from Newlyn according to quarter of the year.

| | | | |
|------|-------|-------|-------|
| 98-2 | 0.119 | 0.260 | 0.327 |
| 98-3 | | 0.416 | 0.322 |
| 99-2 | | | 0.519 |
| | 98-3 | 99-2 | 99-3 |

Earlier, (section 5.3.1.1) it was noted that the pair-wise R -values between the full samples (Table 5.3) were generally higher than between the fish only parts of the sample for the

other ports and types of trawling (Table 5.5). That situation is maintained here suggesting that there were components of the non-fish part of the sample (excluded here) which contribute to the distinctness between the samples, as the full samples (Table 5.9) are more distinctly separated than the fish only part of the sample (Table 5.10). Again, the average between year, (same quarter) average pair-wise R -value ($R = 0.291$) was lower than the average within year (different quarter) R -value ($R = 0.345$).

Sample 5 (sample 3 from 24/05/98) contained very little non-fish material except litter. This sample was removed from the non-fish analysis, as it was an outlier. Removing this sample resolved the MDS as shown in Figure 5.9.



Figure 5.9. MDS plot of $\sqrt{\sqrt{}}$ transformed data by site for the Newlyn only hauls (based on the non-fish part of the sample) according to the quarter of the year they were sampled. Haul 5 (sample 3 from 24/05/98) has been removed. Data points are labelled according to haul number, (Table 3.2, page 49, above) and the stress value is shown on the figure. Global $R = 0.466$, $P = 0.001$.

Again the stress value on Figure 5.9 suggests care must be exercised in interpreting the data though the arrangement cannot be considered as arbitrary (Clarke & Warwick, 2001a). Only the hauls during the Q2 '99 occupied a small region of the MDS plot suggesting they were more similar to each other though there were other hauls from different trips in this

region that were similar in terms of their non-fish composition. Table 5.11 shows the ANOSIM based on the data set of the MDS plot shown in Figure 5.9.

Table 5.11. ANOSIM as pair-wise R -values for non-fish (invertebrate) parts of the sample between trips from Newlyn according to quarter of the year (with haul 5, sample 3 from 24/05/98, removed).

| | | | |
|------|-------|-------|-------|
| 98-2 | 0.730 | 0.615 | 0.253 |
| 98-3 | | 0.620 | 0.217 |
| 99-2 | | | 0.435 |
| | 98-3 | 99-2 | 99-3 |

According to Table 5.11, the samples from Q3-99 were barely separable from the others in the similar location except those from Q2-99. Otherwise, the samples by quarter and year were all well separated.

Figure 5.10 shows the MDS plot for the non-fish and non-shellfish part of the Newlyn samples from which sample 5 has been removed.



Figure 5.10. MDS plot of $\sqrt{\sqrt{}}$ transformed data by site for the Newlyn only hauls (based on the non-fish part of the sample, without the shellfish) according to the quarter of the year they were sampled. Haul 5 (sample 3 from 24/05/98) has been removed. Data points are labelled according to haul number, (Table 3.2, page 49, above) and the stress value is shown on the figure. Global $R = 0.178$, $P = 0.001$.

The separation of the groups on Figure 5.10 is much less distinct. Table 5.12 shows the ANOSIM results for the non-fish and non-shellfish species.

Table 5.12. ANOSIM as pair-wise R -values for non-fish (invertebrate) and without the shellfish parts of the sample between trips from Newlyn according to quarter of the year (with haul 5, sample 3 from 24/05/98, removed). Not significantly different association are highlighted. Global $R = 0.178$.

| | | | |
|-------------|-------------|-------------|-------------|
| 98-2 | 0.151 | 0.418 | 0.188 |
| 98-3 | | 0.206 | 0.092 |
| 99-2 | | | 0.125 |
| | 98-3 | 99-2 | 99-3 |

While the global R -value for the non-fish and non-shellfish part of the sample was quite low it is nevertheless the case that much of the degree of separation for the non-fish species was due to the shellfish. The lowest pair-wise R -values on Table 5.12 representing the most similar samples by year and quarter were for the same geographical area regardless of the time of year.

5.3.2 Degree of disturbance to the trawled areas

To follow the traditional use of the techniques the results first present the ABC for the non-fish material. Next is the size spectra analysis to establish the validity of extending the ABC into the full sample.

5.3.2.1 ABC curves – non-fish species

Figure 5.11 shows the ABC curves for all invertebrates, $n = 88$.

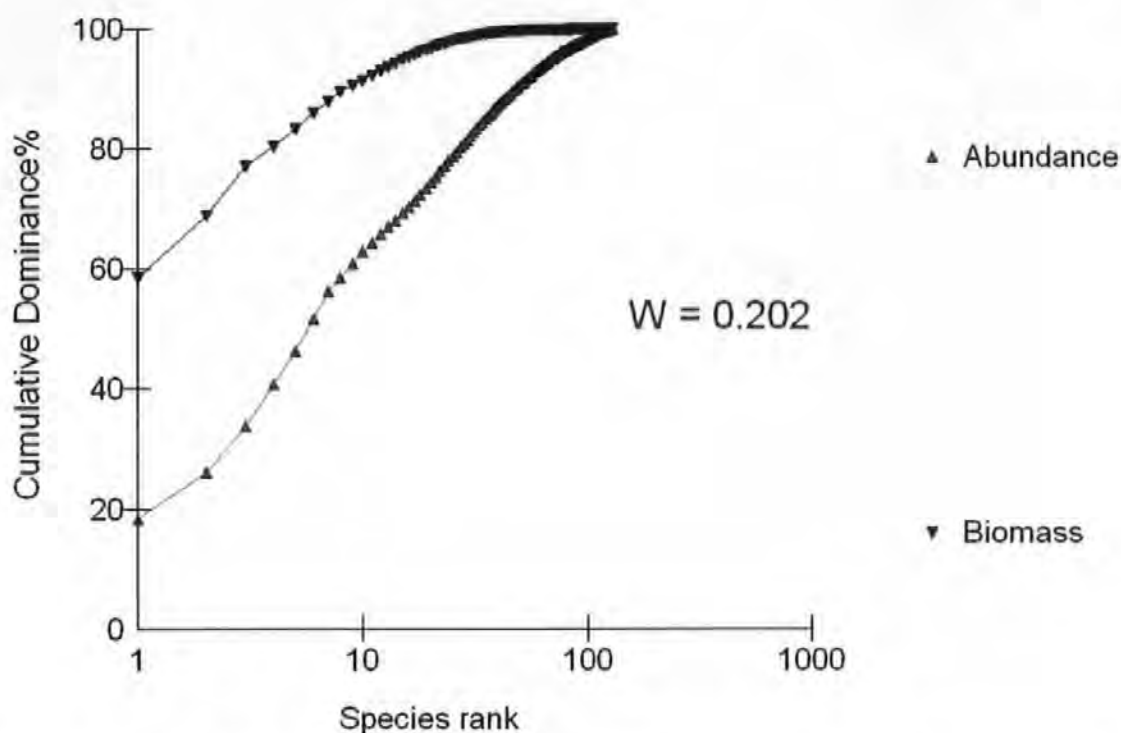


Figure 5.11. Abundance-Biomass Comparison (ABC) curve for all invertebrates (non-fish part of the sample and all hauls, ($n = 88$)).

The shape and position of the curves and W test statistic shown in Figure 5.11 suggest that generally the whole region can be categorised as towards undisturbed. The convergent nature of the abundance and biomass curves with increasing species rank, and dominance of the first few species' biomass was due to their large size. The first four of these were squids and *M. glacialis* (see Table 3.4, page 54, above).

Rather than present all 88 individual plots for each sample Figure 5.12 shows the frequency histogram of the W -test statistic from all samples.

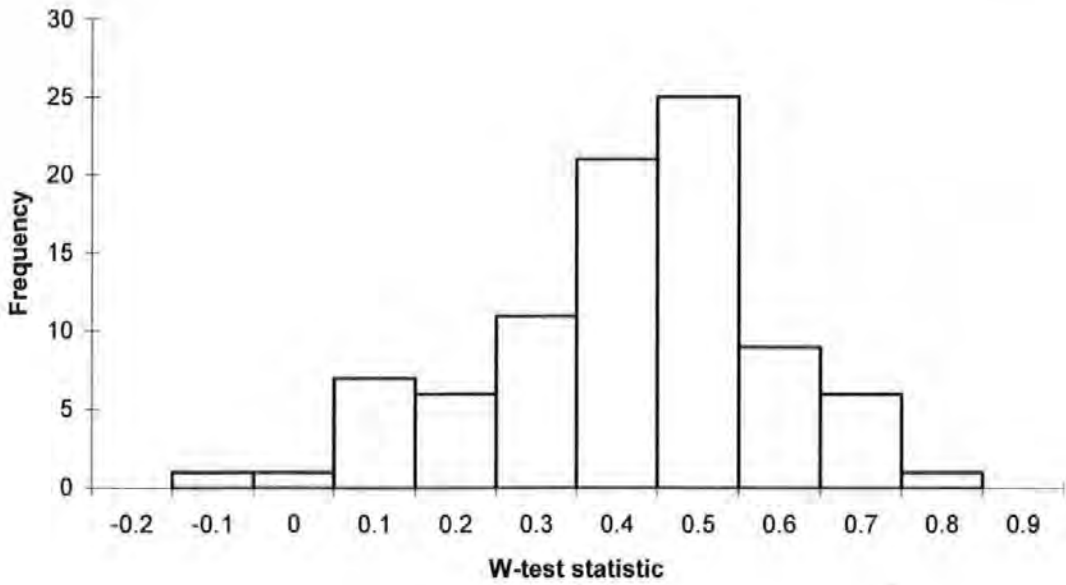


Figure 5.12. Frequency histogram of W -test statistic for all invertebrate samples, $n = 88$.

Figure 5.12 describes the distribution of the W -test statistic according to average of the sample by sample analysis and shows that the average value for W was highly positive with only two values representing samples from particularly disturbed areas (samples 20 and 21 Q3, 99 from Newlyn). However, the value for all the averaged data (see Figure 5.11 above) was ≈ 0.2 rather than the mode value of 0.5 on Figure 5.12, and the distribution on Figure 5.12 was left skewed ($g_1 = -0.451$). Importantly too, the frequency distribution described in Figure 5.12 was based on all hauls while the trends and values in Figure 5.11 were averaged for each trip thus the negative values were smoothed.

Figure 5.13 shows the means and 95% confidence intervals of W by port and type of trawling.

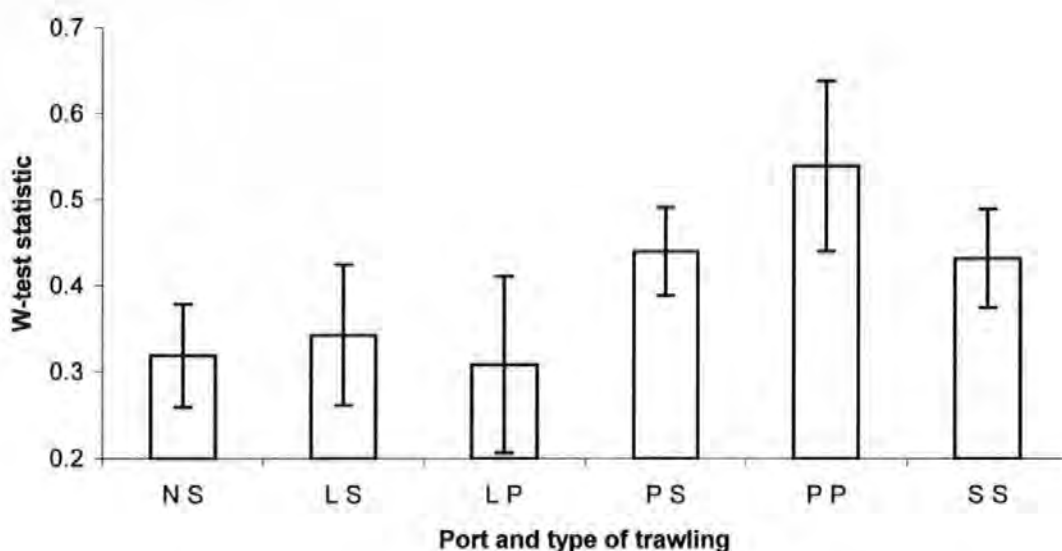


Figure 5.13. Mean and 95 % confidence intervals for the W -test statistic for the non-fish part of the sample according to port and type of trawling N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe. -S = single boat trawling, -P = pair boat trawling.

Figure 5.13 suggests that the areas trawled by boats from Newlyn and Looe were more disturbed than areas similarly trawled by boats from Plymouth and Salcombe based on the W -test statistic for invertebrates. None of the values of the W -test statistic from all samples for the non-fishes approximated normal distribution according to the A-D test ($A^2 = 0.913$, $n = 88$, $P = 0.019$) and while by port and type of trawling they almost all did (except P S, $A^2 = 0.671$, $n = 8$, $P = 0.049$), the W -test statistics (according to Figure 5.13) did not satisfy the equality of variance required by ANOVA (Dytham, 1999, p192) according to the Levene's test ($L = 3.394$, $d.f._1 = 5$, $d.f._2 = 82$, $P = 0.008$). Therefore, the W -test statistics according to port and type of trawling was examined by the K-W test. Table 5.13 shows the results.

Table 5.13. Kruskal-Wallis test of median of W -test statistic for the non-fish part of the sample according to port and type of trawling, N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling. $H = 14.48$, d.f. = 5, $P = 0.013$ (adjusted for ties).

| port and type of trawling | n | median | average rank | Z |
|---------------------------|-----|--------|--------------|--------|
| N S | 42 | 0.355 | 39.0 | - 1.94 |
| L S | 11 | 0.334 | 39.9 | - 0.64 |
| L P | 9 | 0.332 | 33.3 | - 1.39 |
| P S | 8 | 0.430 | 54.0 | 1.10 |
| P P | 8 | 0.487 | 69.0 | 2.84 |
| S S | 10 | 0.447 | 55.8 | 1.48 |
| overall | 88 | | 44.5 | |

Table 5.14 shows the further analysis, by *post hoc* Dunn's Test for Multiple Comparisons of the significant outcome of the K-W test in Table 5.13.

Table 5.14. Results of Kruskal-Wallis *post hoc* Dunn's Test for Multiple Comparisons (Q) of median W -test statistic for the non-fish part of the sample according to port and type of trawling, N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling according to 2 d.p. $K = 2.94$ and significantly different pairs are highlighted.

| | | | | | |
|-----|------|------|------|------|------|
| N S | 0.10 | 0.61 | 1.52 | 3.04 | 1.87 |
| L S | | 0.57 | 1.19 | 2.45 | 1.42 |
| L P | | | 1.67 | 2.88 | 1.92 |
| P S | | | | 1.17 | 0.15 |
| P P | | | | | 1.09 |
| | L S | L P | P S | P P | S S |

Table 5.14 shows that the only significant interaction was between the Newlyn and Plymouth pair trawl samples. Nevertheless, the hypothesis that the pool of the Newlyn and Looe (single and pair) W -test statistics (pool 1) were significantly smaller than the pool of Plymouth (single and pair) and Salcombe (pool 2) could not be rejected at the 5 % level (according to a lower-tailed Mann-Whitney test, $W = 2374.5$, $P < 0.001$). This test was chosen as while the W -test statistic for pool 1 approximated a normal distribution according to the A-D test ($A^2 = 0.344$, $n = 62$, $P = 0.478$) pool 2 did not ($A^2 = 0.745$, $n = 26$, $P = 0.046$).

The difference between the average W -test statistic according to port and type of trawling ($W = 0.365$) and the outcome for all invertebrates (as shown in Figure 5.11) was

because as always with an ABC curves the abundance and biomass do not necessarily refer to values for the same species; instead the rank-ordering was performed separately for abundance and biomass on each occasion.

5.3.2.2 Size spectra

Figure 5.14 shows the frequency of \log_2 ESD (mm) for the non-fish, fish only and the full sample.

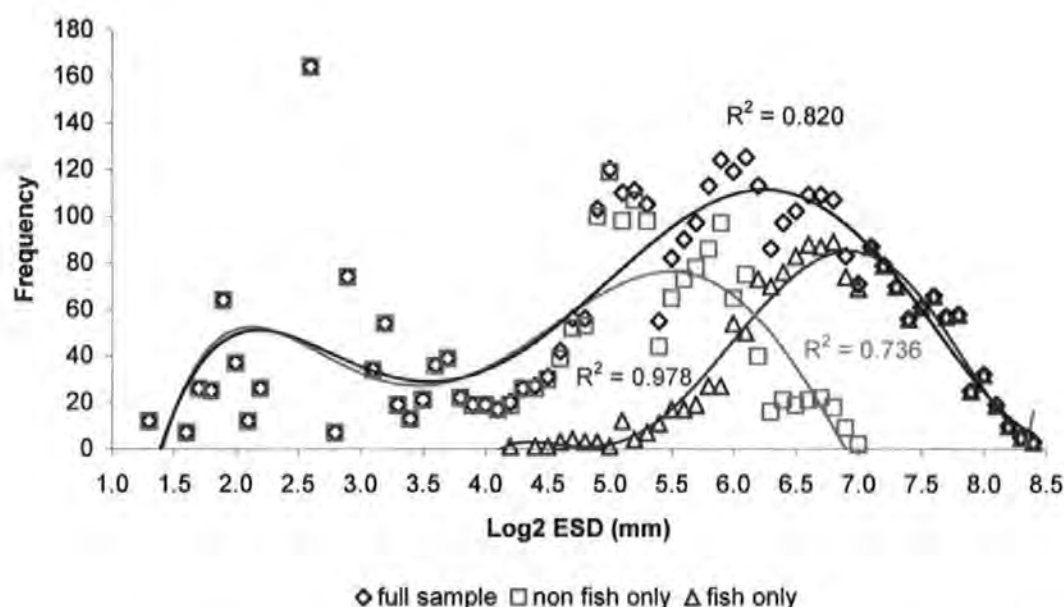


Figure 5.14. Frequency distribution of \log_2 ESD (mm). The class interval of \log_2 ESD (mm) was 0.1. See Figure 5.2, page 113 above, for a conversion between wet weight (g) and \log_2 ESD (mm). The R^2 values are shown on the figure. The polynomial equations for the fitted curves are: full sample $y = 0.528x^5 - 13.542x^4 + 128.451x^3 - 555.783x^2 + 1093.899x - 742.551$; fish only $y = -0.9626x^6 + 39.452x^5 - 661.661x^4 + 5797.662x^3 - 27969.923x^2 + 70450.042x - 72433.903$; non-fish $y = 1.1331x^6 - 27.310x^5 + 258.154x^4 - 1212.471x^3 + 2948.215x^2 - 3468.231x + 1557.400$.

The polynomial equations for the fitted curves on Figure 5.14 are only valid within the range of \log_2 ESD (mm) data shown in the figure: full sample 1.3 to 8.5; non-fish 1.3 to 7.1; fish only 4.4 to 8.5. Also the curves for the non-fish part of the sample and the full sample appear to underestimate frequency at low values, (2.5 to 3.5 \log_2 ESD (mm) which corresponds to 0.1 to 1.0 g) and over estimate at higher values, (around 4 \log_2 ESD (mm)

which corresponds to ~ 2.3 g). Despite this, the distributions for the full sample and the non-fish part of the sample in Figure 5.14 do show characteristic bimodal distributions though the trend line for non-fish part of the sample was the poorest fit, and the trend for the full sample was good. The curve for the fish part of the sample was well fitted since this was a more “normal” curve though it also encompassed a low number of small fishes. The most abundant size across the full sample was a \log_2 ESD value of ~ 6.2 . This corresponded to a wet weight of ~ 220 g that represented a relatively large weight for the non-fish and a relatively low weight from amongst the fish species. The most abundant size across the non-fish only part of the sample was a \log_2 ESD value of ~ 5.5 . This corresponded to a wet weight of ~ 50 g, which approximately equates to the weight of a swimming crab. The low peak and trough of both the full sample and non-fish only parts of the sample were \log_2 ESD value of ~ 3.5 and ~ 2.2 which corresponded to wet weights of ~ 0.8 and ~ 0.05 g respectively. The most abundant size across the fish only part of the sample was a \log_2 ESD value of ~ 6.8 , which corresponds to a wet weight of ~ 935 g.

The results presented in this section have showed that the abundances (numbers according to species by sample) and biomass values (as summed weight according to individual species by sample) generated reliable trends in size-spectra therefore it was considered valid to extend the ABC analysis, initially undertaken on just the non-fish part of the sample to encompass the full sample.

5.3.2.3 ABC curves – full sample

Figure 5.15 shows the ABC curves for the full sample.

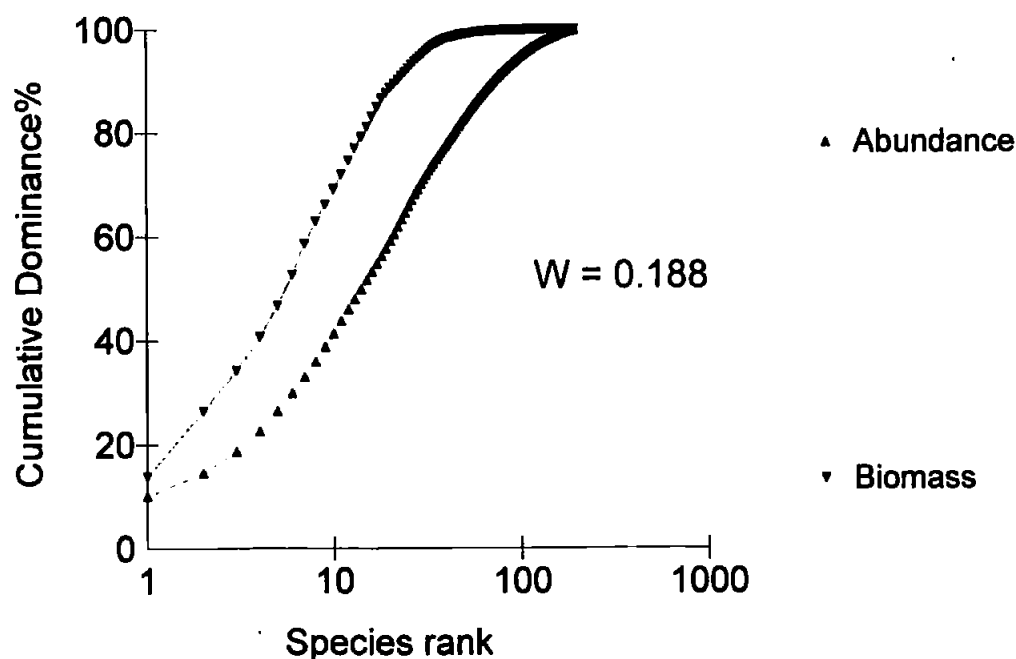


Figure 5.15. Abundance-Biomass Comparison (ABC) curve for the full sample and all hauls, ($n = 88$).

Across all samples and for the full sample on the ABC curves (Figure 5.15) the biomass line was above the abundance one which suggests graphically, that the region again can be categorised as towards undisturbed, and the overall value of the W -test statistic was very similar to when only the non-fish part of the sample were examined. The curves on Figure 5.15 differed from Figure 5.11 (above) in that there was less dependence on the most dominant species when considering the whole sample.

Figure 5.16 shows the frequency distributions of the W -test statistics for the full sample and the non-fish only part of the sample.

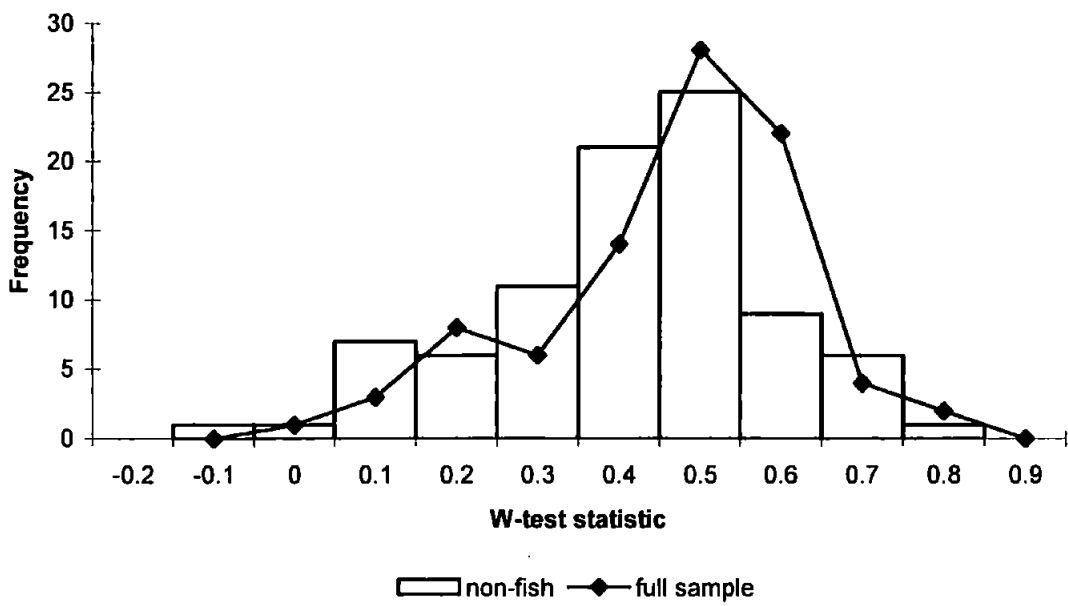


Figure 5.16. Frequency histogram of *W*-test statistic for invertebrates and fish and invertebrates only, $n = 88$.

While the frequency distribution shown in Figure 5.16 look quite similar the *W*-test statistics between the full sample data and non-fish only were significantly different between pairs of *W*-test statistic values from the same sample according to the Wilcoxon Signed Ranks Test; ($Z = -3.558, n = 88, P < 0.001$), with the average *W*-test statistic for the full sample being higher. This test was chosen in preference to the paired *t*-test because neither the *W*-test statistics for the full sample ($A^2 = 1.320, n = 88, P = 0.002$) nor the non-fish only part of the sample (see page 132, above) approximated a normal distribution.

Figure 5.17 shows the mean and 95 % confidence intervals for the *W*-test statistic for the full sample according to port and type of trawling.

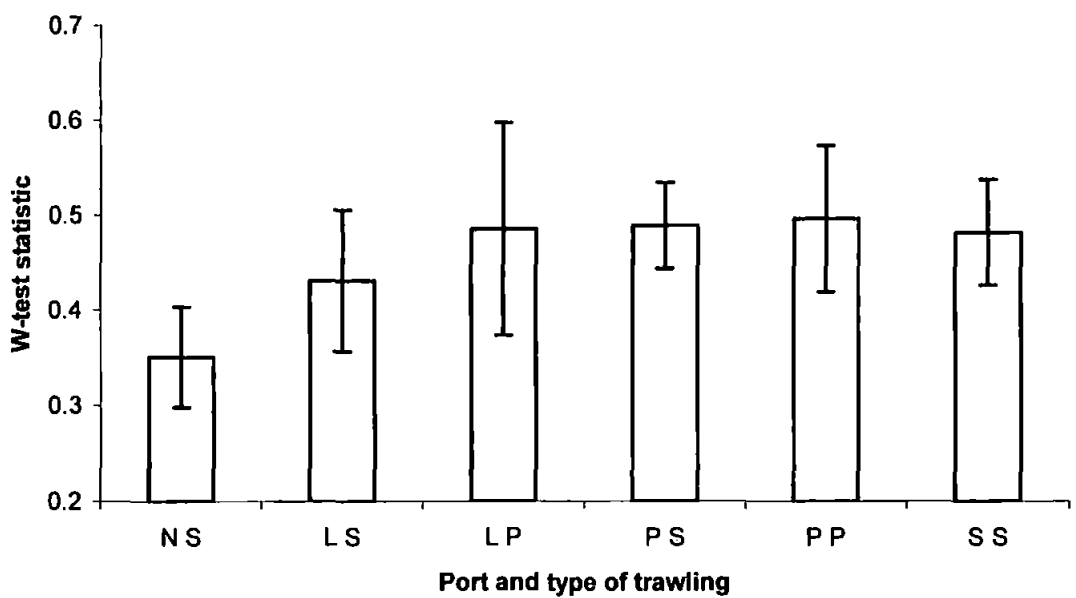


Figure 5.17. Mean and 95 % confidence intervals for the *W*-test statistic for the full sample according to port and type of trawling N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe. -S = single boat trawling, -P = pair boat trawling.

On Figure 5.17 the average *W*-test statistic is lowest for the Newlyn samples, higher for the Looe single boat samples and relatively constant for the others, thus while apparently relatively undisturbed overall the Newlyn samples appeared to be the most impacted, next were the Looe single boat samples and the others possess somewhat similar levels of relatively low disturbance.

Much of the spread in the average *W*-test statistic by port and type of trawling across the full time period of the study was due to the variability caused by the pair trawling and the Q2 '99 trip from Newlyn appeared to have generated a particularly low average ($W = 0.164$).

The largest difference among the *W*-test statistics by port and type of trawling between the full (Figure 5.17) and non-fish (Figure 5.13, above) part of the sample was the relative increase for Looe pair trawls and relative decrease for the Plymouth pair trawls when the analysis was expanded. Not all of the *W*-test statistics by port and type of trawling for the full sample approximated normal distributions (N S, $A^2 = 0.899$, $n = 42$, P

= 0.020) therefore (as for the non-fish part of the sample) analysis by port and type of trawling was by the K-W test. Table 5.15 shows these results.

Table 5.15. Kruskal-Wallis test of median of *W*-test statistic for the full sample according to port and type of trawling, N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling. $H = 11.25$, d.f. = 5, $P < 0.047$ (adjusted for ties).

| port and type of trawling | <i>n</i> | median | average rank | Z |
|---------------------------|----------|--------|--------------|--------|
| N S | 42 | 0.399 | 35.7 | - 3.10 |
| L S | 11 | 0.406 | 44.7 | 0.03 |
| L P | 9 | 0.468 | 51.3 | 0.85 |
| P S | 8 | 0.501 | 57.4 | 1.50 |
| P P | 8 | 0.440 | 55.2 | 1.24 |
| S S | 10 | 0.504 | 56.3 | 1.55 |
| overall | 88 | | 44.5 | |

While Table 5.15 suggests there was a significant differences between the medians of the *W*-test statistic according to port and type of trawling this was not detected by the *post hoc* Dunn's Test for Multiple Comparisons. The largest difference was between Newlyn and Salcombe, $Q = 2.29$ against $K = 2.94$.

5.3.3 Interpretation of the fish community data to understand the relationship between species

5.3.3.1 Ray species

In this study, 124 examples of seven species of ray were collected in the samples. Their overall rank-order was shown in Table 3.4, (page 54, above) and this was not in agreement with Walker & Hislop, (1998). Figure 5.18 shows the average length with appropriate confidence intervals for the ray species.

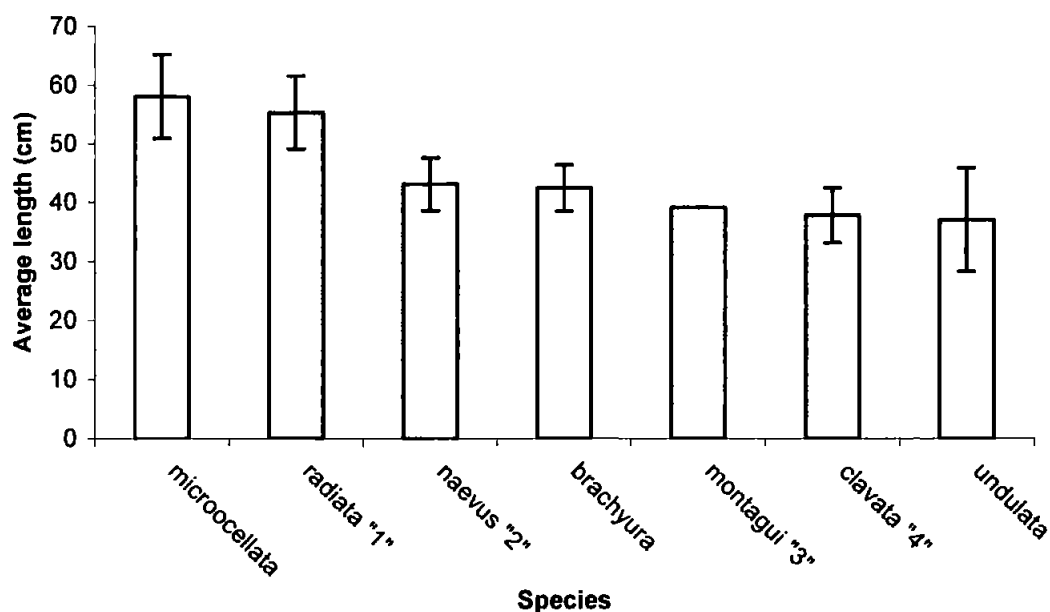


Figure 5.18. Average and (usually) 95 % confidence intervals of total length in 7 species of skate. *R. microocellata* (SER = small eyed ray, $n = 3$, 66 % C.I.). *R. radiata* (STR = starry skate, $n = 5$). *R. naevus* (CUR = cuckoo ray, $n = 42$). *R. brachyura* (BLR = blonde ray, $n = 35$). *R. montagui* (SPO = spotted ray, $n = 1$). *R. clavata* (THR = thornback ray, $n = 36$). *R. undulata* (UDR = undulate ray, $n = 2$, 50 % C.I.). On the figure numbers after the species name (and highlighted data) refers to the order of sensitivity with 1 being the least sensitive to fishing and 4 being the most (of the species here) according to Walker & Hislop, (1998).

Figure 5.18 shows that for the species encountered in this study and for which Walker & Hislop, (1998) were able to calculate their sensitivity to fishing the least sensitive rays were found to be the longest in length. Expanding this to the species which Walker & Hislop, (1998) were not able to include in their sensitivity ranking it is suggested that small eyed ray (*R. microocellata*) is least sensitive to fishing the blonde ray (*R. brachyura*) is more so and the undulate ray (*R. undulata*) is most sensitive to fishing. *R. fullonica* was not encountered in this study.

Table 5.16 shows the number and percentage of mature or immature rays according to species.

Table 5.16. Number and percentage of immature and mature rays according to species. Length at maturity from Walker & Hislop, (1998) except * = data from Froese & Pauly, (2003); (McEachran & Dunn, 1998). In the table numbers after the species name (and highlighted data) refers to the order of sensitivity with 1 being the least sensitive to fishing and 4 being the most (of the species here) according to Walker & Hislop, (1998).

| name | | | length at maturity | number | | | % | |
|-------------------------|------------|---------|--------------------|--------|----------|--------|----------|--------|
| species | common | code | | total | immature | mature | immature | mature |
| <i>R. microocellata</i> | small eyed | SER | *44 | 3 | 0 | 3 | 0 | 100 |
| <i>R. radiata</i> | starry | STR "1" | 40 | 5 | 0 | 5 | 0 | 100 |
| <i>R. naevus</i> | cuckoo | CUR "2" | 59 | 42 | 33 | 9 | 79 | 21 |
| <i>R. brachyura</i> | blonde | BLR | 92 | 35 | 35 | 0 | 100 | 0 |
| <i>R. montagui</i> | spotted | SPO "3" | 58 | 1 | 1 | 0 | 100 | 0 |
| <i>R. clavata</i> | thornback | THR "4" | 72 | 36 | 36 | 0 | 100 | 0 |
| <i>R. undulata</i> | undulate | UDR | *56 | 2 | 2 | 0 | 100 | 0 |

Amongst those species which were ranked by Walker & Hislop, (1998) all the *R. radiata* were likely to be mature. Approximately one fifth of the *R. naevus* were likely to be mature, though none of the *R. montagui* or *R. clavata* were likely to be mature. Amongst those encountered species not analysed by Walker & Hislop, (1998) that *R. microocellata* might be least sensitive to fishing was borne out by the fact that all these rays were likely to have been mature. The position of *R. undulata* towards the sensitive end of the continuum is supported by the fact that all examples of this species in the sample were likely to be immature. The analysis for *R. brachyura* suggests it was also a less sensitive species however, according to Stehmann & Bürkel, (1984) the length at maturity for *R. brachyura* was 61 cm which would have meant 33 or 94 % of this species was likely to be mature. While it is possible that this older data illustrates a degree of recruitment over fishing, nevertheless, this earlier data supports the positioning of this species towards the middle of the continuum. Thus the ordering of the ray species according to their length closely matches the hypothesis of Walker & Hislop, (1998) as does their ordering as described by maturity. Nevertheless, a larger sample size would improve the confidence that can be applied to these data.

5.3.3.2 Predator-prey interactions

Figure 5.19 shows as a Venn diagram (with predator species on the left) how many of the 88 hauls sampled here contained both, either or neither *P. maximus* and *A. rubens*, *Pagurus* spp. and *Liocarcinus* spp.

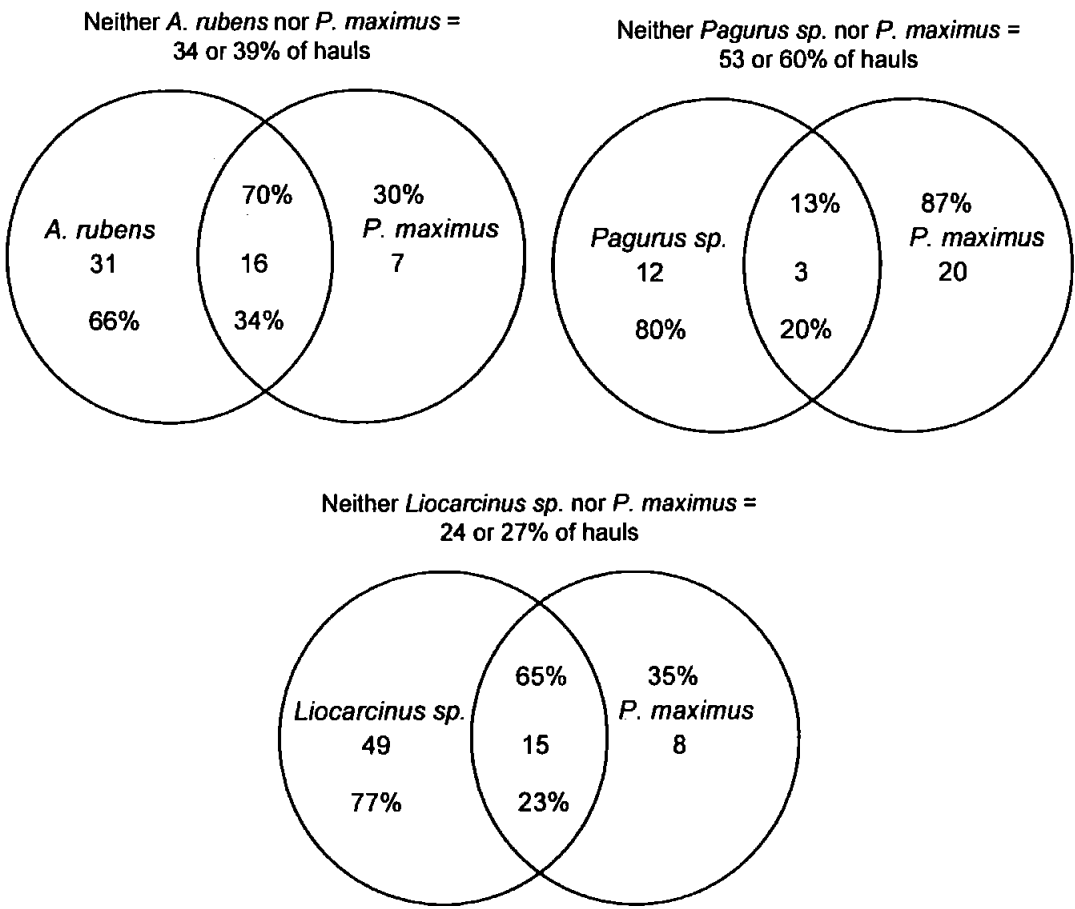


Figure 5.19. Venn style diagram showing the number and percentage of hauls containing or not containing the predator *Asterias rubens*, *Pagurus* spp., *Liocarcinus* spp. (on the left) and/or the prey species *Pecten maximus*.

Figure 5.19 shows that *P. maximus* was found in 23 samples. When present *A. rubens* was also present in 70 % of these although *A. rubens* was not ubiquitous in the samples. It was not present in 39 % of the samples and when it did occur, it was only also found with *P. maximus* in 34 % of samples. *Pagurus* spp. were not commonly found in this study (being present overall in only 17 % of samples). *P. maximus* did not commonly co-occur with *Pagurus* spp. Amongst the three groups in this investigation, *Liocarcinus* spp. was present

in the most number of samples. Its pattern of co-occurrence with *P. maximus* was similar to that described for *A. rubens* suggesting it too is an active predator.

5.3.3.3 Impacts on echinoderms

Figure 5.20 shows the average weight and 95 % CI for all (complete plus any amount of damage) and complete only specimens of *M. glacialis*, *A. rubens* and *E. esculentus* according to all the samples and by port and type of trawling.

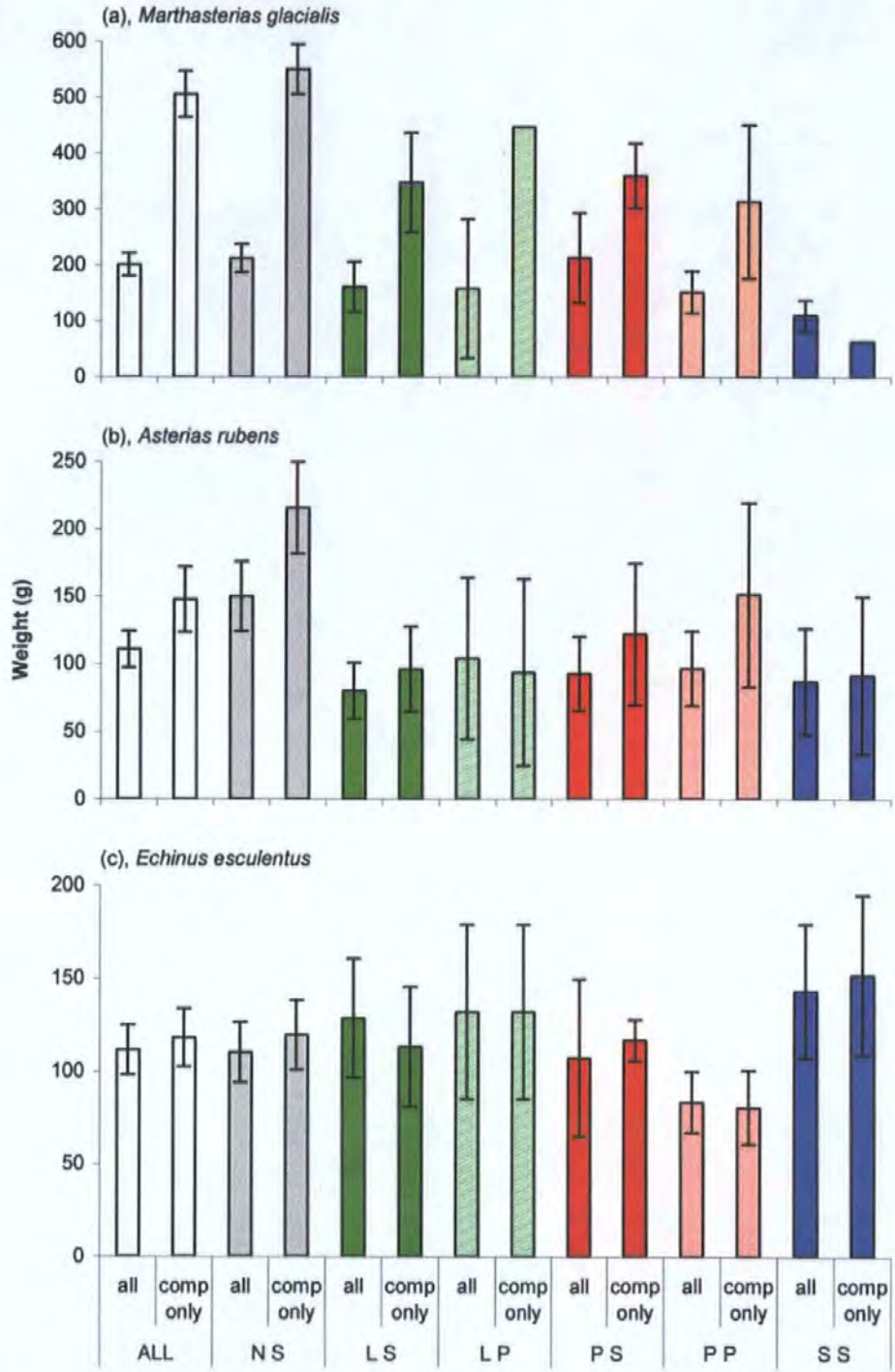


Figure 5.20. Weight (g) and (generally) 95 % C.I. of all examples of species and only complete specimens of (a), *Marthasterias glacialis*, (b), *Asterias rubens*; and (c), *Echinus esculentus*, according to port and type of trawling. No confidence intervals are shown for Looe pair and Salcombe trawled complete *M. glacialis*, ($n = 1$); 50 % C.I. are used for Looe pair trawled, complete Plymouth single trawled and complete Salcombe trawled *E. esculentus*, ($n = 2$). 66 % C.I. are used for other Salcombe *E. esculentus* ($n = 3$).

According to Figure 5.20 the largest complete *M. glacialis* were recorded from the west of the region with size (as weight) decreasing towards the east. In the classification of ‘all’ on Figure 5.20 are those *M. glacialis* for example which were complete and those which

comprised a central disk and four arms, a central disk and three arms etc down to the occurrence of single arms.

Newlyn again recorded the largest *A. rubens* though it is much harder to argue that to the east size of complete examples of this species became smaller. As far as the difference between the average of the complete and the 'all' category are concerned *A. rubens* seemed to be far more robust than *M. glacialis*. Taking the average weight of ~ 500 g for an average complete *M. glacialis* then the average 'all' weight (200 g) would suggest that many are damaged being generally found as two-armed starfish. However, the average complete weight of *A. rubens* was ~ 147 g and the average weight of the 'all' category was ~ 110 g suggesting that if damaged *A. rubens* was likely to still be three quarters complete or had lost only one (or two) arms.

In several cases on Figure 5.20, complete only averages were smaller than all examples. This was due to there being many examples of relatively small specimen.

The τ correlations between % complete starfish and number of predators was significant such that the % complete starfish decreased as the number of predators increased both for *A. rubens* $\tau = -0.410$, $n = 51$; $P = 0.001$ and *M. glacialis* $\tau = -0.421$, $n = 55$; $P < 0.001$, though the species of predators differed in that here neither *H. araneus* nor *S. endeca* were encountered.

5.4 Discussion

5.4.1 Patterns in trawled assemblages between ports and type of trawling

As was shown on both Figure 5.3 and Table 5.2, and Figure 5.4 and Table 5.3 the Newlyn hauls were quite distinct from all the others, and the Salcombe hauls were more similar to

the Plymouth pair hauls than the others for analysis of the full sample. The next highest similarity was to the Looe single boat hauls. Including the split of type of trawling for Looe and Plymouth was useful as while it did not improve the overall explanation of the data through ANOSIM global R -value, it revealed that the greatest similarity was between single boat samples from Looe and the pair boat samples from Plymouth. There was no temporal overlap between these though Table 3.5 shows that 9 of the top 10 species by rank-order were the same.

The overall picture portrayed by the full sample was unsurprisingly well retained when the fish-only part of the sample was analysed with a strong (and significant) similarity between the Looe and Plymouth samples and a similarity (though not significant) between Looe and Salcombe. Including the type of trawling again helped to explain the situation, however the generally lower ANOSIM pair-wise R -values between the full sample and the fish parts of the sample strongly suggests that there were components of the non-fishes (excluded here) which contributed to the strength of the similarity between hauls according to port. This similarity and difference between the full and fish only part of the sample points at a similar pattern of inter-annual species distributions since the Looe single boat samples were collected mostly in 1998 while all the Plymouth single and 75 % of the Plymouth pair-boat samples were collected in 1999 with 25 % of the latter being taken in March 2000.

In analysing the non-fish part of the sample, the similar overall pattern was evident although it appeared that this part showed less overall dissimilarity. There were not particularly high similarities between single and pair trawling for Looe (perhaps due to temporal differences, (see Table 3.2) but possibly also due to differences in environmental factors (see Chapter 7) but the single and pair trawled samples from Plymouth were much more similar. There also appeared to be a geographical gradient here with the Salcombe hauls being more similar to the Plymouth ones than those from Looe, although this could

alternatively be due to the temporal spread of the sampling as the Salcombe based hauls were collected more closely in time with the Plymouth rather than the Looe samples.

Table 5.17 summarises the global R -values.

Table 5.17. ANOSIM global R statistic for parts of the sample (full, fish only, and non-fish) by all ports and all ports and type of trawling, and only Newlyn samples. Non-fish for only Newlyn samples is presented after the removal of the outlying haul 5.

| factor | part of sample | | |
|----------------------------------|----------------|-----------|----------|
| | full sample | fish only | non-fish |
| all ports | 0.672 | 0.612 | 0.404 |
| all ports (and type of trawling) | 0.671 | 0.596 | 0.429 |
| only Newlyn samples | 0.498 | 0.317 | 0.466 |

In Table 5.17, the fishes were nearly as good a descriptor of the overall pattern as for the full sample (having nearly as large global R statistic). Just as importantly, for the full and the fish only parts of the sample port is a better descriptor than port and type of trawling. Only in the non-fish part of the sample does type of trawling improve discrimination, though it has been shown that they are important in revealing patterns within the single- and pair-boat samples.

The Newlyn samples maintain the pattern described for the other ports between the full sample and the fish only although uniquely the non-fish were a better descriptor overall than the fishes only.

The location of the Newlyn trips suggested that the skipper has favourite areas to fish and despite the compact nature of most of the trips, the samples from Newlyn were statistically separate. This was more apparent from the full sample rather than the fishes. The non-fish were also quite separate though it was only after removing the shell fish species that seasonality in the samples was evident; samples taken during the third quarter of the year were most similar and this was reflected in their geographical similarity. Trips taken during the second quarter of the year were geographically distant.

5.4.2 Degree of disturbance to the trawled areas

There was little difference in the W -test statistics between the non-fish and the full samples, although for the non-fish analysis (Figure 5.11) there was still a considerable effect due to the dependence on the single most dominance species. This was despite the methods in PRIMER-E (Clarke & Warwick, 2001a) employing the improvements proposed by Clarke, (1990). This feature was not apparent when examining the full sample so by this measure analysis of the full sample seemed more complete, therefore the aim in extending the assessment from the non-fish to include the fishes was successful.

There was a smaller spread in the W -test statistics according to port and type of trawling and quarter of the year between the full sample (Figure 5.16) when compared to the non-fish only part of the sample (Figure 5.12, page 131, above), though these figures appear similar overall. That the W -test statistic (and thus relative degree of apparent disturbance) differed was evident from the frequency histogram of the two data sets as shown in Figure 5.16.

Despite overall $W \approx 0.2$ it should be noted, that there was bound to be a degree of size selection in the collection of the data in that the material was sampled by a net. Although almost all samples were collected from an 85 mm codend mesh (with the exception of the Looe pair samples where an 86 mm mesh was used, Table 2.1) it was more likely to be in the application and operation of the gear that there were differences rather than its makeup, though the small differences in the ground gear may also be important. This was reflected in the apparent though not significant difference (shown visibly in Figure 3.5, page 66, above, though tested in Table 3.6, page 64, above) between single and pair trawling. The ground gear of the pair trawl was simply two single ground gears connected together, though the action of the sweeps may be significant in the species composition of the non-fish material rather than its abundance. Thus, perhaps the absolute value of the W test statistic should be treated with a degree of caution, as it might be an overestimate.

Figure 5.13 and Figure 5.17 generally support the assertion that ICES area VIIe appeared to be more disturbed in the west than the east. This was supported in that the areas trawled by the boats from Looe and Plymouth overlap to an extent, in terms of type, but less so in terms of port, (see Figure 3.1, page 47, above). Thus supposing that the operation of the boats from Looe and Plymouth (and to a lesser extent from Salcombe) was similar then the similarity of the *W*-test statistic between single and pair boat trawling (Figure 5.13) for all fishing types was due to the location of trawling rather than the type of fishing.

However, the areas trawled by boats from Newlyn and Salcombe were quite different (see Figure 3.1, page 47, above). There was a particular density in the position of the Newlyn based hauls that was not evident in those from Salcombe, with (apart from the southern most trip from Newlyn, (Figure 3.1) many hauls from Newlyn being made in a relatively small area. It is of course not known whether had so many hauls been taken from boats operating out of Salcombe as from Newlyn then the same concentration would have been evident, but the few Salcombe vessels do not operate at the same scale, (usually operating day trips) when compared to the Newlyn boats (operating for several days at a time). At a fleet level the further offshore trawls from Salcombe are also areas fished by other boats and gear types, particularly beam trawlers from Brixham (Boon, 1992).

Clarke & Warwick, (2001a) suggest that reference to spatial or temporal control sites is not required though is desirable. This is not required since the two curves act as 'internal controls', though is desired from good experimental practice. Comparison with other studies is always open to error due to differences in methods. While Kaiser *et al.*, (2000) used a variety of beam trawl and anchor dredges to study the IPA area near Salcombe, thus spatially relevant here, these authors plot ABC curves though do not quote *W*-test statistics. The authors also standardised their data and determined biomass by drying to a constant weight, which was not possible in this study. Blanchard *et al.*, (2004) used a beam trawl to survey areas off the French Atlantic coast and determined ABC

curves from number and wet weight as here. Both sets of results support the original theory (Warwick, 1986) though the difference in gear types makes direct comparisons difficult.

Furthermore in a demersal fisheries context, differences in resulting *W*-test statistics may reflect changes in the relative abundance of large and small species in assemblages, and/or changes in size composition (Yemane *et al.*, 2005). There were two important ways this may be manifest in this study.

- 1 The lack of representation of small or infaunal species due to the method of sampling.
- 2 The particular representation of scavenger species amongst the invertebrates which often tend to be large; thus repeat trawling whilst causing a greater level of disturbance might actually be represented by a higher *W*-test statistic.

Both of these present interesting challenges. The first requires a better understanding of the poorly understood (Austen *et al.*, 2002) relationship between biodiversity and community stability across the sediment water interface. The second might be examined from simulating theoretical assemblages or additional experimental work as this effect has been demonstrated experimentally (Savage *et al.*, 2001) albeit in brief though intense periods of disturbance rather than the suggested chronic disturbance here. This may also establish greater confidence in ranges of *W*-test statistics to describe more than the three typical ecosystem states of undisturbed moderately disturbed or grossly disturbed.

In this study, a size spectra analysis suggested it was valid to expand the ABC analysis from the non-fish material to the full sample (thus including the fish species was biologically relevant). Figure 5.14 (on page 134, above) did show characteristic bimodal distributions for the invertebrates though typically these peaks are classified (Ramsay *pers com*) as meiofauna and macro (epi-) fauna and the size range as shown in Figure 5.14 do not encompass values of ESD this small. The meiofaunal peak presented by Schwinghamer, (1981) was a \log_2 ESD of -3, which corresponds to a wet weight of approximately 1.1 μg , and his peak of macrofauna is a \log_2 ESD of 4, which corresponds to

a wet weight of approximately 2.3 g. Instead the peaks present on Figure 5.14 suggest the split into large numbers of macroinvertebrates and fishes as described with the smaller peak representing a mixture of epiphytic organisms (e.g. *Crepidula fornicata*, *Galathea intermedia* and *Pisidia longicornis*) as well as large numbers of hydroids. The trough on Figure 5.14 represented the tailing off of numbers of hydroids and the gradual increase in numbers of decapods as values of ESD increased.

The curve for the full sample on Figure 5.14 was both more amenable to description and valid in terms of the ABC curves for scientific as well as statistical reasons (in that it more closely approximated a normal distribution). Analysis according to both the non-fish part of the sample and the full sample appeared to be valid for assessing the degree of disturbance and each of these analyses generated similar results overall. However, including the fish species masked subtleties only present in the non-fish data and it is recommended that where possible (where non-fish material is also recorded in sampling) it is important to retain the ability to examine these data separately.

5.4.3 Interpretation of the fish community data to understand the relationship between species

5.4.3.1 Ray species

In absolute terms rays made up a relatively small proportion of the contents of the sample (~ 1.2 %) nevertheless, employing a direct comparison with literature values their hypothesized sensitivity to fishing of four of these species was the same in the study area here to the central and north-western North Sea. Data gathered in this study has enabled a further three species to be provisionally ranked according to their sensitivity to fishing.

The inconsistency between the abundances of the ray species in this study with the order described by Walker & Hislop, (1998) may be due to the sample size being too small

here or could be due to differences in local species abundances. The study area described in Walker & Hislop, (1998) was the central and north-western North Sea which only extended as far south as 51°N. Rees *et al.*, (1999) showed substrate (and other environmental and biological conditions and communities) to be quite different between the North Sea and the English Channel with the western English Channel being most similar in terms of substrate and benthic biodiversity to the west coast of southern England and Wales (Rees *et al.*, 1999, figures 7 & 8). Stehmann & Bürkel, (1984) point out that the ray species described here generally “feed on all kinds of benthic animals,” though Wheeler, (1978) reports marked differences between preferences in both diet and favoured habitat which might account for differences in distribution which will affect local abundances and species composition. Further analysis on habitat preferences of the *Raja* *sp* is contained within Chapter 8 (between page 246 and 247, below).

5.4.3.2 Predator prey interactions

A relatively simple sample presence based analysis of those species that commonly predate *P. maximus* has revealed some interesting features. It appeared that *A. rubens* while not ubiquitous generally co-occurred with *P. maximus*. This is consistent with this predators known scavenging behaviour (Ramsay *et al.*, 1998). That *Pagurus* spp. were not especially common in the samples may be due to their small size. Ramsay *et al.*, (1996) found that *P. bernhardus* was more responsive to the effects of fishing, in that it migrated into and took better advantage of the disturbance caused by beam trawling than *P. prideaux* although both species have similar dietary characteristics. This is consistent with the relative abundance of the two species in this study where *P. bernhardus* ranked 81 while *P. prideaux* ranked 124 and this pattern may be due to repeat trawling rather than natural abundance. Kaiser *et al.*, (2005) describes a limiting though subtle effect of fishing in that it causes damage to empty whelk shells that are preferred by hermit crabs. As

shown in Table 3.4 *Buccinum undatum* ranked 61 though was only occurred in 4 samples (mostly Plymouth pair trawls) and no empty shells were recorded for this species.

The presence of *Liocarcinus* spp. in the trawl samples was similar in abundance to that of *A. rubens*. Both decapod crustaceans and *A. rubens* are themselves highly susceptible to mortality induced by fishing, especially if damaged (see section 5.3.3.3) and while *A. rubens* are more transient in their residence in recently trawled areas decapods are generally a more attractive prey item to other species (Groenewold & Fonds, 2000; Bergmann *et al.*, 2001; Bergmann *et al.*, 2002).

5.4.3.3 Impacts on the Echinodermata

The difference between the size of 'complete' and 'all' *M. glacialis* and *A. rubens* was relatively consistent across the study areas in that there were consistently larger difference in these categories for *M. glacialis* than *A. rubens* according to Figure 5.20. This suggests that while *A. rubens* might make a reasonable indicator of disturbance due to fishing in some areas (Kaiser, 1996; Ramsay *et al.*, 2001), where it is present (such as the west of the UK) *M. glacialis* may prove to be more sensitive; just as the distributional use of species to indicate disturbance has also been extended to *Arctica islandica* L (Rumohr & Krost, 1991; Witbaard & Klein, 1994; Witbaard *et al.*, 1997). However while the biology of *A. rubens* has long been understood (Vevers, 1949), Verling *et al.*, (2003) point out that "...despite the reputation of *Marthasterias glacialis* as a ubiquitous asteroid and a voracious predator, it has been the subject of surprisingly few quantitative ecological studies." This may compromise its utility as an indicator, until there is a better understanding of its ecology.

Although there was a significant negative correlation between the relative proportion of complete specimens of *M. glacialis* and *A. rubens* and the number of predator present in the sample, it was not know if the number of predators was exhaustive. Also, it is not suggested (as it is not known) whether a particular predatory species has a

preference for either *M. glacialis* or *A. rubens* or whether they were coincidentally present and predating other species. It would appear however, that *A. rubens* suffered a greater rate of arm attrition (as described as a decrease in the % of complete specimens) than *M. glacialis* as predator numbers increased in the samples.

In this respect, *A. rubens* may again prove to be less suitable as a measure of disturbance than *M. glacialis* since the effect of predators may confound the effect of disturbance.

E. esculentus only occurred in the top 95 cumulative % for Newlyn (Table 3.5). Nevertheless, 'all' (Figure 5.20, lower) *E. esculentus* encountered were only marginally smaller (5 % by weight) than those which were complete. This is not surprising since *E. esculentus* are quite fragile (Macdonald *et al.*, 1996) and damaged *E. esculentus* are likely to quickly be predated therefore there was a greater potential bias in that damaged urchins are under-represented.

Chapter 6

6 Within and between sample taxonomic diversity

6.1 Introduction

Descriptions of the samples so far have followed two broad areas. Firstly, by the rank-order of species across all the samples (analyses related to Table 3.1), and then according to their port and type of trawling, (analyses related to Table 3.2). This analysis focused only on the more abundant fish and non-fish species and consequently did not examine the influence of rarer species. Secondly, by the relatedness of the full sample (or its components) in terms of port and type of trawling (Chapter 5). Chapter 5 also examined the degree of disturbance of the fished locations and several species level effects within the fish community data.

This Chapter deals with the taxonomic diversity of the samples, both in general and according to their port and type of trawling and completes the Sample Theme, Aim 1 (see Figure 1.4, page 17, above). The outcome is an assessment of whether the sampled assemblages display meaningful patterns in biodiversity in space or through time, and whether these patterns are in keeping with the outcomes as described in Chapter 3 and Chapter 5. Relationships between the biodiversity and other aspects (such as substrate and other environmental features) are explored in Chapter 7 and Chapter 8.

6.1.1 Background to measures of biodiversity

The concept of biodiversity has expanded away from the ‘number of species per unit area’ or measures of their abundance. UNEP, (1992) defined biodiversity as: “the variability among living organisms including...marine and other ecosystems and ecological complexes to which they belong: this includes diversity within species, between species and diversity of ecosystems”. Van der Spoel, (1994) defined biodiversity as “the sum of taxonomic, or numerical diversity, and the ecological, genetic historical and phylogenetic diversity.” The increased complexity required of biodiversity assessment has increased the complexity of measures of assessment.

Warwick & Clarke, (2001 p210-211) make the case for taxonomic *distinctiveness* as a “means of weighting species in respect of priorities for conservation” and taxonomic *distinctness* which is an assessment of the “properties of an assemblage and measure[s] features of its overall taxonomic spread. Comparisons are made of one assemblage with another, with the primary motivation of environmental assessment and monitoring of biodiversity change...” Whilst taxonomic *distinctiveness* measures (e.g. Root weight and Phylogenetic diversity) look appealing, Warwick & Clarke, (2001) suggest that these methods have not had any success in generating ‘priorities’ for conservation of marine resources, though recently their use has gained greater acceptance in terrestrial conservation (Keith *et al.*, 2005). Taxonomic *distinctness* measures, such as average taxonomic distinctness (AvTD, Δ^+ , see below) however, are more widely tried and tested in the marine realm (Hall & Greenstreet, 1998; Leonard *et al.*, 2006) and have been shown (Salas *et al.*, 2006) to be most useful in assessing ecological status.

6.1.1.1 Average taxonomic distinctness (AvTD, Δ^+)

The average taxonomic distinctness (AvTD, Δ^+) of a species assemblage (derived from a sample) is the average taxonomic distance apart of all its pairs of species, which satisfies

the more modern (UNEP, 1992; Van der Spoel, 1994) definitions of biodiversity in that it conveys more information about the sample than traditional diversity indices, and importantly is applicable to situations where the sample size changes. Comparatively higher values of Δ^+ derive from less perturbed communities in later stages of succession and comprise a wider range of more distinct species belonging to an increased number of taxonomic groups, (Warwick & Clarke, 2001).

It is also possible to establish a species or group's potential or importance for conservation only employing taxonomic *distinctness* measures through removing the group under scrutiny from the dataset and examining how the taxonomic *distinctness* measure (e.g. Δ^+) changes. The individual importance of taxonomically relevant constituent parts of the sampled dataset is examined in this way in section 6.2.3.

6.1.1.2 Variation in taxonomic distinctness (VarTD, Λ^+)

As shown in Figure 3.1, (page 47, above) the trawls covered about 12 nm and thus each sample includes a degree of habitat heterogeneity (see Figure 4.4, page 79 and Figure 4.5, page 82, above). This is likely to influence diversity patterns, which may mask anthropogenic effects. Clarke & Warwick, (2001b) suggest that under anthropogenic disturbances the species that tend to disappear first are those of higher taxa that are relatively species poor. The remaining species are then from a smaller number of groups which tend to be relatively more species-rich. It is possible for this species removal to occur without affecting Δ^+ (see Clarke & Warwick, 2001b, Fig 2), though it will affect the 'evenness' of the distribution of taxa across the hierarchical taxonomic tree. The measure that describes this evenness is the variation in taxonomic distinctness (VarTD, Λ^+); which is the variance in taxonomic distances in the tree and can be thought of as an index of the complexity of the hierarchical tree, (high Λ^+ = high complexity and uneven taxonomy).

6.1.1.3 Advantages and interpretation of AvTD (Δ^+) and VarTD (Δ^+)

The strong advantage of taxonomic *distinctness* measures is their ability to produce indices that are not sample-size dependent. Thus, while the sample size in this study did not vary according to changes in port or type of trawling (being a fixed volume, see Figure 3.3 page 61 and Table D.1, page 351 below) the proportion of the haul sampled did (see Table 3.6, page 64, above and Figure 3.5). Despite the fact that the species accumulation curve (Figure 3.2, page 59, above) seemed no less complete than for other studies which employ techniques where the sampling methods, the sample size and the habitat are carefully controlled, in trawl surveys it is inevitable that the area covered by the gear and the amount it retains will vary. This makes the use of traditional biodiversity measures, based on the number of species present of no value, as these indices are very sample size dependent (Warwick & Clarke, 2001, Figure 1) and therefore taxonomic distinctness measures are particularly appropriate to trawl sampling.

Another advantage of calculating taxonomic distinctness is that it is possible to test whether a species list from one location has the same or similar structure as the overall 'master' list of the region. Comparing the value of taxonomic distinctness for the specific location (sample) to the region thus allows an estimation of whether the biodiversity of the location is above or below the level that is expected (for the region), against the null hypothesis that a location is proportionally as biologically diverse as the region.

This is manifest in plots of Δ^+ values against the number of species in a sample. Plots of Δ^+ against the number of species in PRIMER-E v5 include the data and a theoretical mean Δ^+ value (derived from a large number of simulated random selections of sub-lists of numbers of species). A flat ($\beta = 0$) slope of the theoretical mean Δ^+ value confirms the unbiased nature and therefore comparability of Δ^+ value for widely differing degrees of sampling effort (of species number). Also present on the plots generated by PRIMER-E, v5 are upper and lower 95 % probability limit for Δ^+ values from a single sub-

list of specified size from the master list (for the number of species in each sample). Samples possessing Δ^+ values between the upper and lower 95 % limits of Δ^+ are within the null region of the plot and (for the number of species present) the sample has an expected level of diversity compared to the region. Plots of VarTD (Λ^+) against the number of species are also assessed for departure from expected values in the same way. Δ^+ and Λ^+ can be assessed separately however, Warwick & Clarke, (2001) suggest their combination is a statistically robust summary of taxonomic relatedness pattern and PRIMER-E, v5 can generate combined plots of Λ^+ against Δ^+ complete with various levels of probability limits.

In addition to the overall description (Δ^+ in section 6.1.1.1, and Λ^+ in section 6.1.1.2) Clarke & Warwick, (2001b) suggest that low Δ^+ , and low to normal Λ^+ were indicative of degraded locations and normal Δ^+ and high Λ^+ represented pristine conditions, although the latter assertion was from relatively few sampling events and has not been validated more widely.

In Clarke & Warwick, (2001b) high Λ^+ values were generated for nematode populations from a pristine location in the Isles of Scilly although it is suggested that the lack of estuaries greatly restricted fine substrates offshore, which in turn precluded species that favour soft habitat types. The resulting taxonomic tree was highly uneven and generated high Λ^+ values for this location. More recently Mouillot *et al.*, (2005) found that coastal lagoons with higher levels of eutrophication possessed higher levels of Λ^+ as the unevenness resulted from the complexity of the taxonomic tree. It is therefore equally important to determine the cause of the evenness in addition to its extent as this is important for understanding the consequences.

Rogers *et al.*, (1999) generated Δ^+ for coastal fish communities around the UK, and their methods form the basis of those used here. Clarke & Warwick, (1999) investigate the weighting of branch lengths, which tends to alter the magnitude of Δ^+ and Λ^+ though both measures are qualitatively robust (see Appendix I for an analysis here).

The sampling and analysis theories do not lead to an intrinsic relationship between Δ^+ (or Λ^+) and the number of species (since $\beta = 0$ of the theoretical mean Δ^+ value with increasing number of species) though this does not prevent there being an observed relationship. An observed positive correlation between Δ^+ and the number of species implies an assemblage structure where large communities are more ‘averagely distinct’ (Clarke & Warwick, 2001a, p 17-9) than small ones. The relationship between Λ^+ and the number of species can similarly be investigated as can apparent correlations on combined plots of Λ^+ against Δ^+ (Clarke & Warwick, 2001b).

In section 6.1.1, the advantages and disadvantages of calculating taxonomic *distinctiveness* measures were described. In order to determine the ecological implications of targeting a particular taxonomic collection through taxonomic *distinctness* measures, the contribution of higher order taxonomic levels can be scrutinized by exploring the effect that removing the particular taxonomic group had on the resulting Δ^+ value. This is the subject of 6.2.3. Conducting this analysis has implications on the scheme of choice for branch weighting and this is discussed in Appendix I.

6.2 Methods

Biodiversity measures of average taxonomic distinctness, (AvTD, Δ^+) and variation in taxonomic distinctness (VarTD, Λ^+) were calculated by combining the master data aggregation file (of taxonomy) and sample data (the site species biomass matrix) using the *Taxdtest* routine in PRIMER-E (Clarke & Warwick, 2001a). Both matrices included all anthropogenic material (litter as a single category) as well as all the algae. The sample dataset was the biomass site (as sample) species matrix initially introduced within the methods section of Chapter 5, (section 5.1.3). Appendix H describes the conversion of the species list in Appendix C, from Picton & Howson, (1999) into the master data aggregation

file and Appendix I for a description of how the chosen method of branch length weighting. The *Taxdtest* routine also includes the power transformation needed to remove skew.

Three types of analysis were examined.

6.2.1 Analysis of average taxonomic distinctness (Δ^+) and variation in taxonomic distinctness (Λ^+)

Firstly, Δ^+ for the full group of samples was calculated; this was then examined according to port and type of trawling. Next, followed a similar though separate analysis of Λ^+ . Values of Δ^+ and Λ^+ were then brought together for further analysis.

Trends in Δ^+ and Λ^+ against the number of species and Λ^+ against Δ^+ , (as well as the significance of the relationships) were examined through appropriate correlations. The Anderson Darling (A-D test) was used to examine whether the Pearson product moment (r) or more conservative (Dytham, 1999, p158) Spearman's rank-order (r_s) correlation was most appropriate to investigate the trend.

Rogers *et al.*, (1999) and Warwick & Clarke, (2001) show that differences in factors (in this case the port and type of trawling) can be explored by one-way ANOVA. However, here the grouped Δ^+ values according to port and type of trawling do not always approximate normal distributions and Dytham, (1999 p192) includes, as an assumption of all ANOVA tests that the data are normally distributed, (though it is really the equality of variance in the samples and approximation of normality of the residuals which are more important). The advantage of applying an ANOVA is that its *post hoc* test (for example, Fisher's Least Significant Difference test) identifies where is or are the significantly different group or groups. In applying the slightly more conservative, non-parametric Kruskal-Wallis (K-W) test *post hoc* testing is not directly possible according to Dytham,

(1999 p108) though this can be explored by examining the summary statistics. Zar, (1999) suggests using Dunn's Test for Multiple Comparisons. Additionally, the numbers of samples varied according to port and type of trawling (as well as when considering other factors) and some of the categories have low frequencies, which further strengthening the case for the more conservative K-W test.

6.2.2 Seasonality in the taxonomic distinctness of the samples

Figure 5.1 (page 110, above) shows the Newlyn samples were collected at similar times of subsequent years and over relatively small geographical area. Additionally each of these trips included a large number of samples (see Table 3.2, page 49, above). This analysis explores the degree to which there was a degree of seasonality in the samples for the same time of each year. The analysis was undertaken firstly on the Newlyn samples (in a similar manner to that presented in section 5.3.1.2) then across the wider spatial and temporal range of the Looe, Plymouth and Salcombe samples.

6.2.3 Contribution of higher taxonomic levels to biodiversity

While sections 6.2.1 and 6.2.2 were self-explanatory in nature, this was a very much more complex investigation. As a basis Rogers *et al.*, (1999) show the usefulness when interpreting regional differences in fish distribution to identify which taxa have contributed most to patterns in average taxonomic distinctness. In this study, the taxonomy was far wider such that in addition to examining the fishes the taxonomic contribution of invertebrate phyla was examined.

6.2.3.1 Fishes (by order)

In investigating the importance of fish groups, the following 15 categories (see Table 6.1) were used.

Table 6.1. Categories of fishes (as orders) for contribution of higher order taxonomic levels to biodiversity. Category 4 is the benchmark category.

| sample category # name | category name | detailed description of composition species or groups removed |
|---------------------------|---|--|
| 1 full | the full and complete sample | none |
| 2 non fish | only the non-fish part of the sample | no super class GNATHOSTOMATA |
| 3 fish + shellfish | the fishes + the shellfish. Super class GNATHOSTOMATA, (sub classes TELEOSTEI and ELASMOBRANCHII) plus the shellfishes. (family Loliginidae, <i>Cancer pagurus</i> , <i>Aequipecten opercularis</i> and <i>Pecten maximus</i> and family Octopodidae) | all other non-fish groups (see Table 3.4, page 54, above) |
| 4 fish – shellfish | the fishes without the shellfish. Super class GNATHOSTOMATA (or the sub classes TELEOSTEI and ELASMOBRANCHII). | without the shellfishes, (Squids; family Loliginidae, crabs; <i>Cancer pagurus</i> , scallops; <i>Aequipecten opercularis</i> and <i>Pecten maximus</i> ;family Octopodidae and Sepiidae) |
| 5 fish (no gur) | only the fishes without the gurnards. | order SCORPAENIFORMES, <i>Agonus cataphractus</i> , <i>Aspitrigla cuculus</i> , <i>Aspitrigla obscura</i> , <i>Eutrigla gurnardus</i> , <i>Trigla lucerna</i> and <i>Trigloporus lastoviza</i> |
| 6 fish (no herr) | only the fishes without the herrings | order CLUPEIFORMES, <i>Alosa</i> sp, <i>Clupea harengus</i> , <i>Engraulis encrasicolus</i> , <i>Sardina pilchardus</i> , and <i>Sprattus sprattus</i> |
| 7 fish (no per) | only the fishes without the perches | order PERCIFORMES, <i>Ammodytes tobianus</i> , <i>Callionymus</i> sp, <i>Dicentrarchus labrax</i> , Labridae (unspecified wrasses), <i>Mugil</i> sp, <i>Mullus surmuletus</i> , <i>Scomber scombrus</i> , and <i>Trachurus trachurus</i> |
| 8 fish (no ple) | only the fishes without the flatfishes | order PLEURONECTIFORMES, <i>Arnoglossus imperialis</i> , <i>Arnoglossus laterna</i> , <i>Lepidorhombus whiffiagonis</i> , <i>Limanda limanda</i> , <i>Microstomus kitt</i> , <i>Platichthys flesus</i> , <i>Pleuronectes platessa</i> , <i>Scophthalmus rhombus</i> and <i>Solea solea</i> |
| 9 fish (no dor) | only the fishes without the dories | order ZEIFORMES, <i>Capros aper</i> and <i>Zeus faber</i> |
| 10 fish (no gad) | only the fishes without the gadoids | order GADIFORMES, <i>Gadus morhua</i> , <i>Melanogrammus aeglefinus</i> , <i>Merlangius merlangus</i> , <i>Merluccius merluccius</i> , <i>Micromesistius poutassou</i> , <i>Molva molva</i> , <i>Pollachius pollachius</i> , <i>Trisopterus luscus</i> , and <i>Trisopterus minutus</i> |
| 11 fish (no ang) | only the fishes without the anglerfishes | order LOPHIIFORMES, <i>Lophius budegassa</i> and <i>L. piscatorius</i> |
| 12 fish (no sal) | only the fishes without the salmonids | order SALMONIFORMES, <i>Osmerus eperlanus</i> |
| 13 fish – elasm | only the teleost fishes without the elasmobranchs | sub-class ELASMOBRANCHII, i.e. without orders CARCHARHINIFORMES and RAJIFORMES (see 14 and 15) |
| 14 fish (no d&h) | only the fishes without the dogfish and smooth hounds | order CARCHARHINIFORMES, <i>Mustelus asterias</i> , <i>Scyliorhinus canicula</i> and <i>Scyliorhinus stellaris</i> |
| 15 fish (no ray) | only the fishes without the rays | order RAJIFORMES, <i>Raja brachyura</i> , <i>R. clavata</i> , <i>R. microcellata</i> , <i>R. montagui</i> , <i>R. naevus</i> , <i>R. radiata</i> and <i>R. undulata</i> |

Category 1, 2 and 3 describes the full sample and assess the contribution of the full sample made from the fishes, and the shellfish. In terms of the analysis of the fishes, category 4 (highlighted on Table 6.1) was the benchmark category. This is the fishes without the shellfishes. All the subsequent (higher numbered) categories were derived from this one. Categories 5 to 15 were created by removing the various orders of fishes in turn. Some of these orders contain few species (category 12 only removed one species) while others contain many more; there were nine Pleuronectiformes species and ten Elasmobranchii species. The species belonging to each order is included in the description of each category (Table 6.1) and each order was 're-added' before the next was removed therefore the Δ^+ values on Figure 6.10 (page 187, below), between categories 5 and 15 are for the removal of these groups of species alone. Resultant Δ^+ values could then be compared to Δ^+ from the full sample.

6.2.3.2 Non-fishes (invertebrates) (by phyla)

Expanding the removal of taxonomic groupings into the non-fish part of the sample was undertaken in a similar manner. These categories are described in Table 6.2.

Table 6.2. Categories of non-fishes (as phyla) for contribution of higher order taxonomic levels to biodiversity. Category 4 is the benchmark category.

| sample category | | detailed description of composition | |
|-----------------|----------------------------------|---|--|
| # | name | category name | groups or phyla removed |
| 1 | full | the full and complete sample (as category 1 for Table 6.1 | none |
| 2 | non-fish | only the non-fish part of the sample | no super class GNATHOSTOMATA), as category 2 for Table 6.1 |
| 3 | non-fish - shell fish | non-fish part of the sample - the shellfishes | without the shellfishes, (Squids; family Loliginidae, crabs; <i>Cancer pagurus</i> , scallops; <i>Aequipecten opercularis</i> and <i>Pecten maximus</i> ; family Octopodidae and Sepiidae) |
| 4 | non-fish - anthro, litter, angio | non-fish part of the sample | without anthropogenically derived material and also non-resident flowering plant material (though includes the shellfishes) |
| 5 | non-fish - algae | the non-fish part of the sample | without the algae (phyla CHLOROPHYCOTA, CHROMOPHYCOTA and RHODOPHYCOTA) |
| 6 | non-fish - Cnidaria | the non-fish part of the sample | without the phylum CNIDARIA |
| 7 | non-fish - Mollusca | the non-fish part of the sample | without the phylum MOLLUSCA |
| 8 | non-fish - Crustacea | the non-fish part of the sample | without the phylum CRUSTACEA |
| 9 | non-fish - Echinodermata | the non-fish part of the sample | without the phylum ECHINODERMATA |
| 10 | non-fish - Annelida | the non-fish part of the sample | without the phylum ANNELIDA |
| 11 | non-fish - Bryozoa | the non-fish part of the sample | without the phylum BRYOZOA |

Category 1, 2 and 3 for the non-fish analysis describes the full sample and assess the contribution of the full sample made from the fishes, and the shellfish. One difference between the categories on Table 6.2 and Table 6.1 was that there were too many species in each of the categories on Table 6.2 to list them all here as was done for the fishes (Table 6.1, above), though the complete species list is shown in the aggregation file (Appendix C, Table C.1, page 348 and Table C.2, page 349, below). Again, category 4 was the benchmark for the non-fish analysis and similarly to the analysis of the fish part of the sample each group (typically phyla here) was re-added before the next one was removed and the Δ^+ values calculated.

6.3 Results

6.3.1 Analysis of Δ^+ and Λ^+

6.3.1.1 Average taxonomic distinctness (Δ^+)

Figure 6.1 show a plot of Δ^+ against number of species.

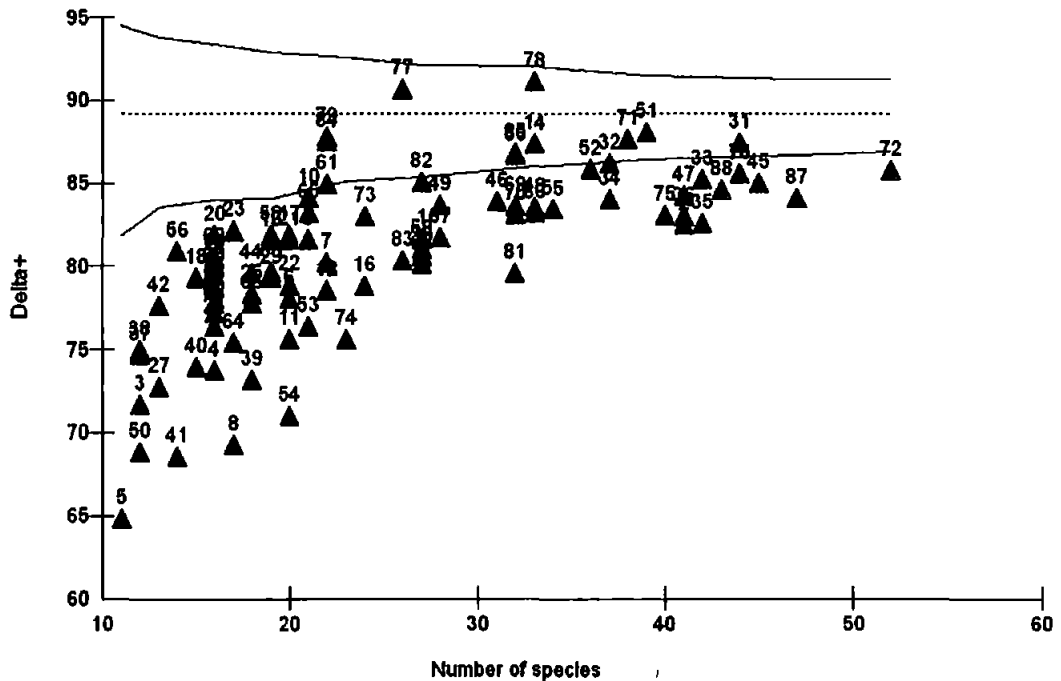


Figure 6.1. Average taxonomic distinctness values, (Δ^+) plotted against the observed number of species for all the samples. The dashed line indicates the simulated mean Δ^+ value for 1,000 selections of a random number of species from the master list of 188 species. Intervals within which the 95 % of the simulated Δ^+ lie (the expected range of Δ^+ for a given number of species) are constructed for each sub-list (random sample) and represented as a probability funnel (continuous lines).

Only 10 out of the 88 samples lie within the 95 % probability limit around the theoretical mean. The rest were below the lower limit and no samples were above the upper limit. Thus, the majority of the samples were from disturbed locations. The average $\Delta^+ = 81$ from a theoretical mean of ≈ 89 . The distribution of the Δ^+ with number of species did not approximate a normal distribution according to the A-D test, ($A^2 = 0.793$, $n = 88$, $P = 0.038$) although the positive relationship between Δ^+ and number of species was very highly significant according to the Spearman's rank-order correlation ($r_s = 0.779$, d.f. = 87,

$P < 0.001$). This suggests that across the full range of the sites the samples with greater species richness were from the less disturbed locations.

Figure 6.2 breaks down the overall pattern presented in Figure 6.1 into the categories of port and type of trawling.

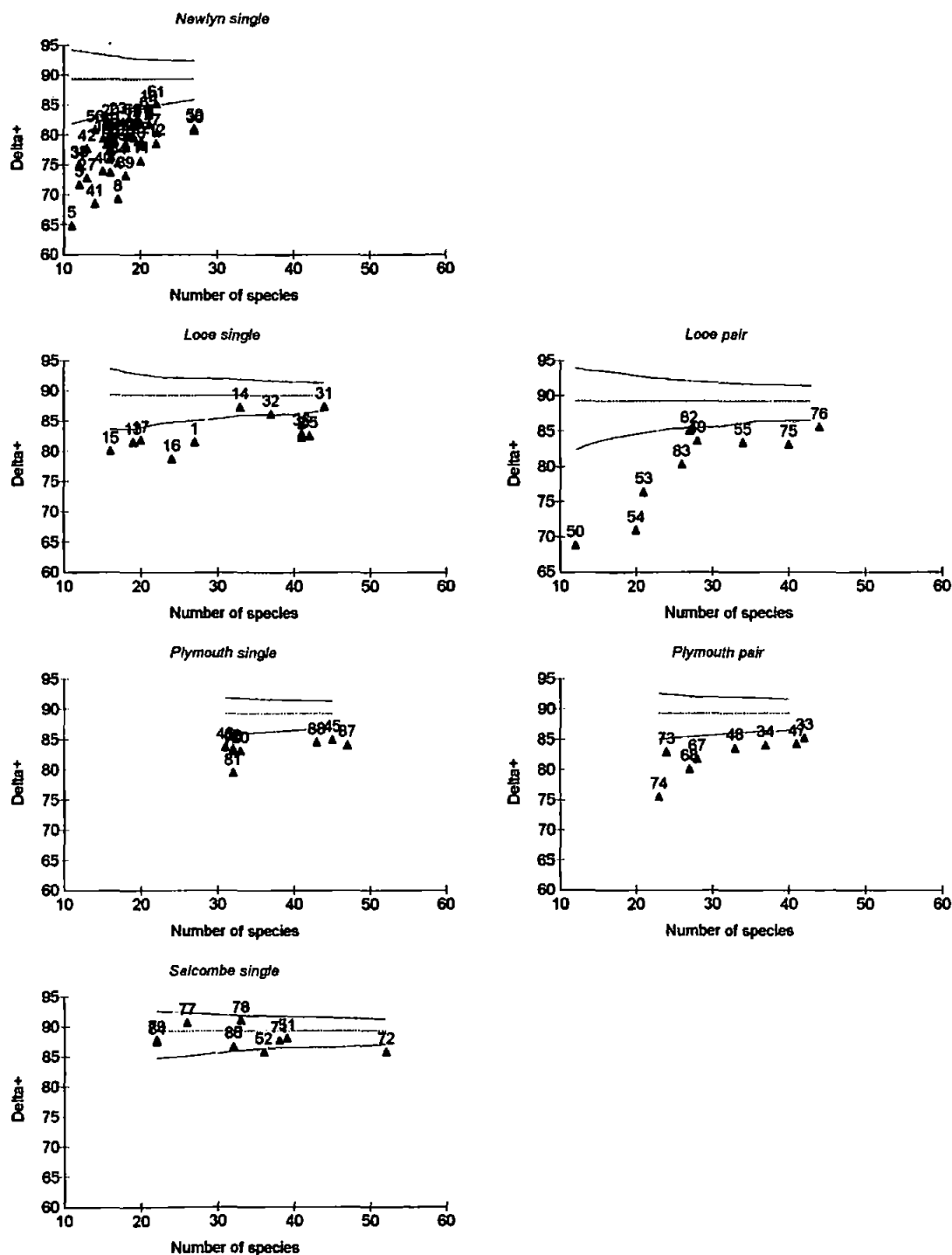


Figure 6.2. Average taxonomic distinctness values, (Δ^+) plotted against the observed number of species for the full sample according to port and type of trawling. Here the order of the plots shows the single boat trawling on the left and their pair boat counterpart on the right. The dashed line indicates the simulated mean Δ^+ value for 1,000 selections of a random number of species from the master list of 188 species. Intervals within which the 95 % of the simulated Δ^+ lie (the expected range of Δ^+ for a given number of species) are constructed for each sub-list (random sample) and represented as a probability funnel (continuous lines). Note that the same axes have been used here as on Figure 6.1.

Figure 6.2 shows a gradual increase average Δ^+ from west to east of the region according to the samples. This was most pronounced as low Δ^+ values for Newlyn (average $\Delta^+ =$

77.9), which stand out as being species poor and all were below the lower 95 % probability limit. The highest Δ^+ value were from Salcombe (average $\Delta^+ = 87.8$). There was a plateau for Looe and Plymouth though the geographical trend continued; average Δ^+ value according to port were Looe = 81.4 and Plymouth = 82.8. Also noteworthy was the fact that the pair trawled samples have lower average Δ^+ values (though also show more variation) than the single boat trawled samples. The average pair trawled Δ^+ value = 81.0 against the average single boat value for Looe and Plymouth = 83.2 and across all ports = 83.1. All but 2 of the Salcombe samples and 3 of the most species rich Looe single boat samples on Figure 6.2 were within the 95 % probability limits, though none of the other were.

Not all of the Δ^+ values according to port and type of trawling approximated normal distributions therefore these data were examined with non-parametric methods. Table 6.3 shows (according to the K-W test) the differences between (median) average taxonomic distinctness according to port and type of trawling.

Table 6.3. Kruskal-Wallis test of median (average) taxonomic distinctness (Δ^+) according to port and type of trawling, N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling. $H = 45.65$, d.f. = 5, $P < 0.001$ (adjusted for ties).

| port and type of trawling | <i>n</i> | median | average rank | Z |
|---------------------------|----------|--------|--------------|--------|
| N S | 42 | 78.86 | 28.1 | - 5.76 |
| L S | 11 | 82.52 | 55.1 | 1.48 |
| L P | 9 | 83.12 | 43.7 | - 0.10 |
| P S | 8 | 83.80 | 61.0 | 1.92 |
| P P | 8 | 83.28 | 53.0 | 0.99 |
| S S | 10 | 87.62 | 82.5 | 5.00 |
| overall | 88 | | 44.5 | |

The significance in Table 6.3 across the samples was explored with the *post hoc* Dunn's Test for Multiple Comparisons.

Table 6.4. Results of Kruskal-Wallis *post hoc* Dunn's Test for Multiple Comparisons (Q) of (median) average taxonomic distinctness (Δ^+) according to port and type of trawling, N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling according to 2 d.p. $K = 2.94$ and significantly different pairs are highlighted.

| | | | | | |
|-----|------|------|------|------|------|
| N S | 3.12 | 1.66 | 3.34 | 2.53 | 6.05 |
| L S | | 1.00 | 0.50 | 0.18 | 2.45 |
| L P | | | 1.39 | 0.75 | 3.31 |
| P S | | | | 0.63 | 1.77 |
| P P | | | | | 2.43 |
| | L S | L P | P S | P P | S S |

Table 6.4 shows that the average taxonomic distinctness (Δ^+) values for the Looe and Plymouth hauls (whether single or pair trawled) were not significantly different. The Newlyn samples were different to all the other single boat samples, though not the pair samples. The Salcombe samples were different to the Looe pair and Newlyn samples.

Many of the clusters on Figure 6.2 show strong positive correlations between Δ^+ and number of species for Newlyn, Looe pair trawled samples and (to a lesser extent) Plymouth pair trawled samples. Table 6.5 shows the Spearman's rank-order correlations by port and type of trawling.

Table 6.5. Value and significance of Spearman's rank-order correlation (r_s) between average taxonomic distinctness (Δ^+) and number of species according to port and type of trawling.

| port and type of trawling | Spearman's rank-order correlation (r_s) | significance (P) value | d.f. |
|---------------------------|---|----------------------------|------|
| full sample | 0.779 | < 0.001 | 87 |
| N S | 0.604 | < 0.001 | 41 |
| L S | 0.765 | 0.006 | 10 |
| L P | 0.883 | 0.005 | 8 |
| P S | 0.610 | 0.108 | 7 |
| P P | 0.929 | 0.001 | 7 |
| S S | - 0.226 | 0.454 | 9 |

The Newlyn samples show the lowest positive association between Δ^+ and the number of species but this was very highly significant. It seems likely that the larger number of samples for this port was responsible for the (comparatively) low correlation coefficient and this was visible in the cloud of points in Figure 6.2 for this port, nevertheless the

positive correlation was also highly visible. It was also apparent that the Newlyn samples were generally the most species poor having an average of only 17.5 species against the average for all the other ports of 32.2 species.

While the Looe single boat samples show a strong association (as described in Table 6.5) there was a wide range of species from these samples though the range in Δ^+ was small. These samples appear to fall into two grouping based on the number of species they contain though here the addition of species was throughout the taxonomic level rather than at the fine or coarse extremes. This cannot be said to be the case for the Looe pair trawl samples where the species poor samples have low values of Δ^+ implying the addition of species was at the coarse end of the taxonomic spectrum.

The Plymouth single boat samples mirror those already described for the Looe single boat samples both in terms of their grouping and location on the Δ^+ axis, although their clustering into the two groups was more evident. The Plymouth pair samples show similarities to the Looe pair samples in terms of their distribution though it is speculative whether the formers' species poor samples are also taxonomically poor at the finer levels.

Most of the samples described so far fall below the solid lines on Figure 6.1 and Figure 6.2 indicating that many of the samples were more taxonomically poor than might be expected by selecting species at random; and that this was indicative of degraded locations. This cannot be said to be the case for the samples from Salcombe which were unique amongst those on Figure 6.2 also in that their correlation (r_s) was negative, though not statistically significantly so. Their position on the Δ^+ axis suggests that richness was added at fine taxonomic levels that were already well represented and though not significant it is suggested that the negative (r_s) correlation indicates that as more species are added in these samples these additions continue to be new underrepresented taxonomic branches so even here the species sampling is not exhaustive as was evident from the species accumulation curves (Figure 3.2, page 59, above).

6.3.1.2 Variation in taxonomic distinctness (Λ^+)

Figure 6.3 shows the full sample data of variation in taxonomic distinctness (Λ^+) against the numbers of species in each sample across all the samples.

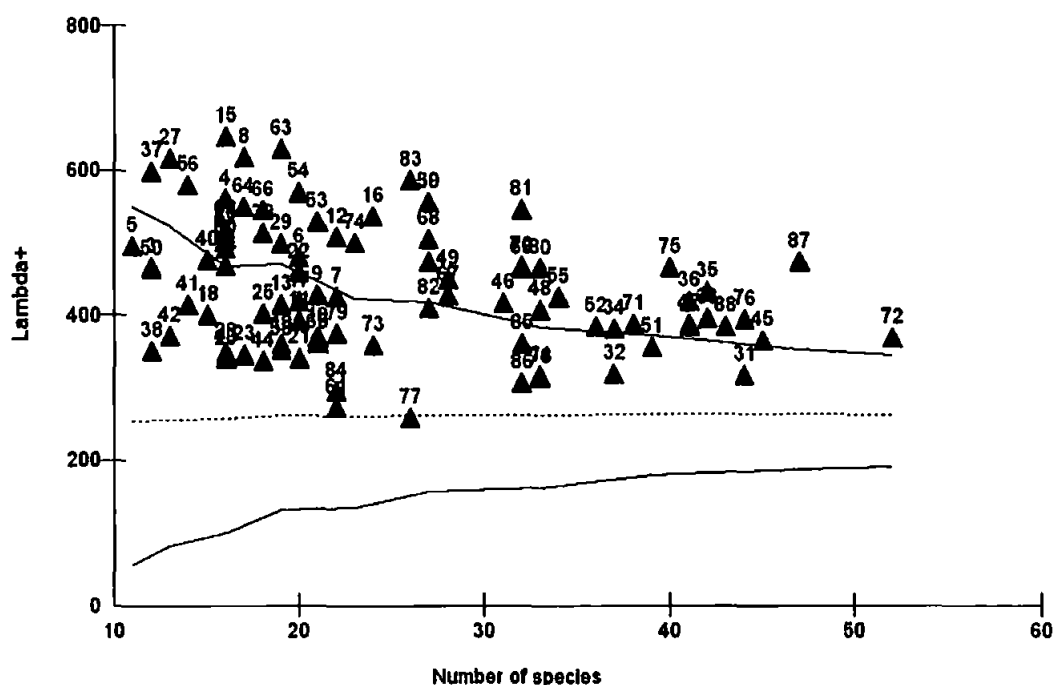


Figure 6.3. Variation in taxonomic distinctness values, (Λ^+) plotted against number of species for all of the samples. The dashed line indicates the simulated mean Λ^+ value for 1,000 selections of a random number of species from the master list of 188 species. Intervals within which the 95 % of the simulated Λ^+ lie (the expected range of Λ^+ for a given number of species) are constructed for each sub-list (random sample) and represented as a probability funnel (continuous lines).

All samples except one (# 77) were above the theoretical mean Λ^+ on Figure 6.3 and 46 samples were above the 95 % probability funnel. The theoretical $\Lambda^+ = 250$ and the actual mean was 428. This suggests that the taxonomic tree was highly irregular or complex and uneven with many underrepresented higher-order taxonomic groups. While the relationship between Δ^+ values and the number of species for all the samples was positive the equivalent relationship for Λ^+ values was negative; the Spearman's rank-order correlation (r_s) = - 0.298, d.f. = 87, $P < 0.005$. This suggests that the more even taxonomic trees also contained the largest number of species. Figure 6.4 divided the data points of

Figure 6.3 into port and type of trawling. Table 6.6 shows the value and significance of the Spearman's rank-order correlation (r_s) according to port and type of trawling. Figure 6.3 and Table 6.6 are described together.

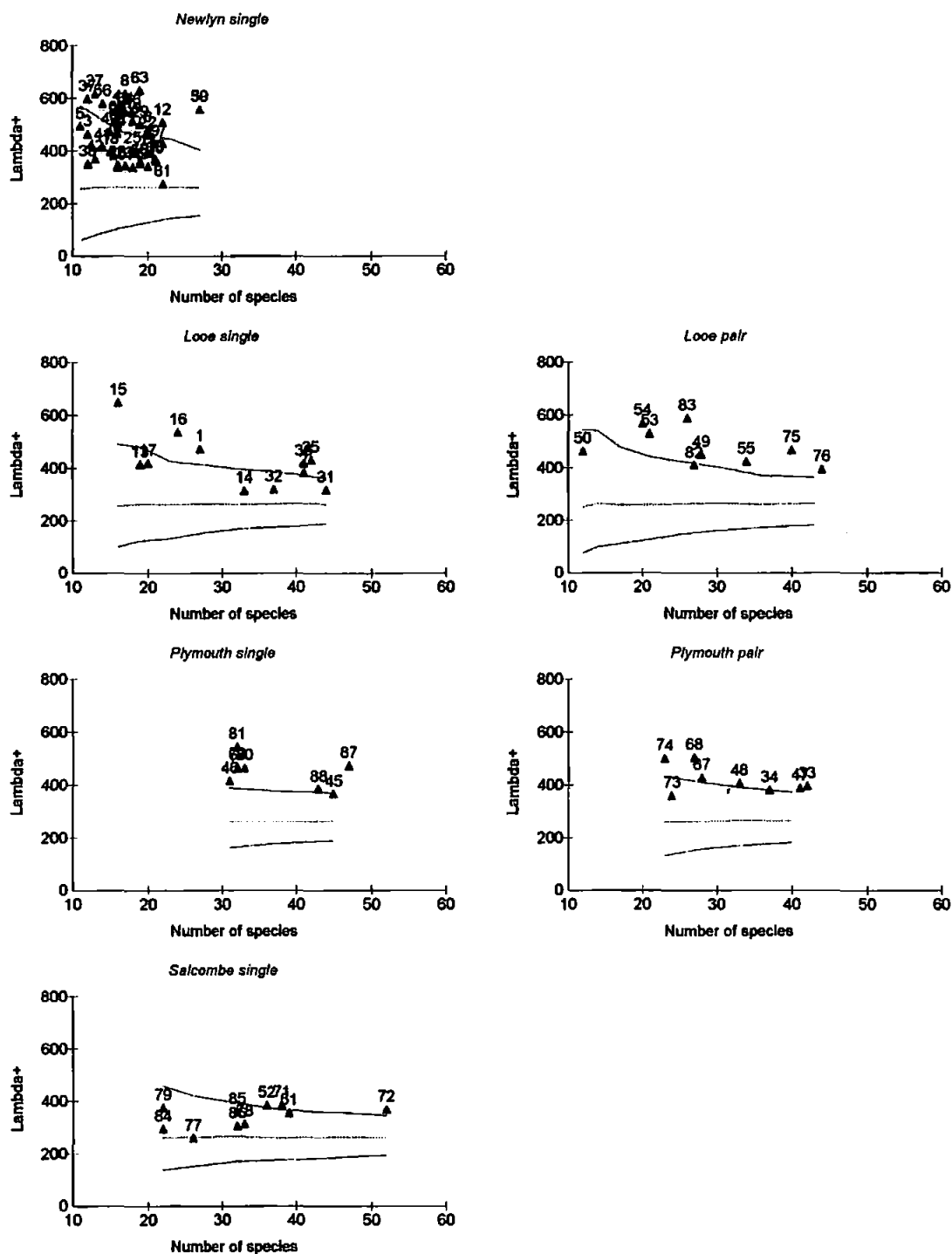


Figure 6.4. Variation in taxonomic distinctness values, (Λ^+) plotted against the observed number of species for the full sample according to port and type of trawling. Here the order of the plots shows the single boat trawling on the left and their pair boat counterpart on the right. The dashed line indicates the simulated mean Λ^+ value for 1,000 selections of a random number of species from the master list of 188 species. Intervals within which the 95 % of the simulated Λ^+ lie (the expected range of Λ^+ for a given number of species) are constructed for each sub-list (random sample) and represented as a probability funnel (continuous lines). Note that the same axes have been used here as on Figure 6.3.

Table 6.6. Value and significance of Spearman's rank-order correlation (r_s) between the variation in average taxonomic distinctness (Λ^+) and number of species according to port and type of trawling.

| port and type of trawling | Spearman's rank-order correlation (r_s) | significance (P) value | d.f. |
|---------------------------|---|----------------------------|------|
| full sample | - 0.298 | 0.005 | 87 |
| N S | - 0.118 | 0.458 | 41 |
| L S | - 0.501 | 0.116 | 10 |
| L P | - 0.583 | 0.099 | 8 |
| P S | - 0.171 | 0.686 | 7 |
| P P | - 0.357 | 0.385 | 7 |
| S S | 0.463 | 0.171 | 9 |

Table 6.6 shows that none of the Spearman's rank-order correlations for the Λ^+ values were significant according to their port and type of trawling, also and that the r_s are lower for the Λ^+ values than was the case for Δ^+ .

The Newlyn samples have a consistently high value of Λ^+ with 18 out of the 42 samples being above the 95 % probability funnel. Though not too clear from Figure 6.4 the hauls away from the main sampling area (sample numbers 3 through to 12, see Figure 5.1, page 110, above) lie around the middle of the cluster on Figure 6.4, (average Λ^+ values ~ 475).

The single and pair boat samples from Looe appear quite similar on Figure 6.4 and both have similar correlation coefficients (Table 6.6); so too did the Plymouth single and pair samples though the latter had a smaller range of species and lower correlation coefficients. Despite these samples containing many more species than the Newlyn samples, the Λ^+ values are higher than the 95 % probability funnel.

Moving further east, the association between Δ^+ and the number of species for the Salcombe samples was previously uniquely negative (Table 6.5). Here (Table 6.6), the association between Λ^+ and the number of species was uniquely positive. Furthermore all but three samples appear to be within the 95 % probability funnel.

Only from the Looe and Salcombe single boats were there more samples within the probability funnel than above it, so overall there was a consistent pattern separately from Δ^+ and Λ^+ .

Table 6.7 shows the results of the K-W test applied to Λ^+ according to port and type of trawling.

Table 6.7. Kruskal-Wallis test of (median) variation in taxonomic distinctness (Λ^+) according to port and type of trawling, N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling. . $H = 16.81$, d.f. = 5, $P < 0.001$ (adjusted for ties).

| port and type of trawling | <i>n</i> | median | average rank | Z |
|---------------------------|----------|--------|--------------|--------|
| N S | 42 | 468.1 | 49.4 | 1.72 |
| L S | 11 | 419.4 | 40.7 | - 0.52 |
| L P | 9 | 463.8 | 56.9 | 1.54 |
| P S | 8 | 464.9 | 49.0 | 0.52 |
| P P | 8 | 401.7 | 41.3 | - 0.38 |
| S S | 10 | 358.1 | 15.9 | - 3.76 |
| overall | 88 | | 44.5 | |

The values of Z on Table 6.7 appears to show that only the Salcombe samples (based on the Λ^+ values) are significantly different from the combined Plymouth and Looe samples.

Table 6.8 shows the permutation results of the *post hoc* Dunn's Test for Multiple Comparisons.

Table 6.8. Results of Kruskal-Wallis *post hoc* Dunn's Test for Multiple Comparisons (Q) of (median) variation in taxonomic distinctness (Λ^+) according to port and type of trawling, N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling according to 2 d.p. $K = 2.94$ and significantly different pairs are highlighted.

| | | | | | |
|-----|------|------|------|------|------|
| N S | 1.01 | 0.80 | 0.04 | 0.82 | 3.73 |
| L S | | 1.41 | 0.70 | 0.05 | 2.22 |
| L P | | | 0.64 | 1.26 | 3.49 |
| P S | | | | 0.60 | 2.73 |
| P P | | | | | 2.01 |
| | L S | L P | P S | P P | S S |

Table 6.8 shows that the Λ^+ values according to port and type of trawling for the Looe and Plymouth were all not significantly different. Also, the Newlyn samples can be added to this pool. The importance of this fact is that while the Newlyn samples were less species and taxonomically rich, or diverse, overall they were not significantly more uneven than

the pool of Looe and Plymouth sampled areas. The Salcombe samples were only significantly different to the Newlyn and Looe pair samples.

6.3.1.3 Combination of Λ^+ and Δ^+

The wider implications of these results are presented later though it is useful to examine how the combined values of Λ^+ and Δ^+ varied. Figure 6.5 shows the plot of expected and actual values of Λ^+ against Δ^+ for all of the samples.

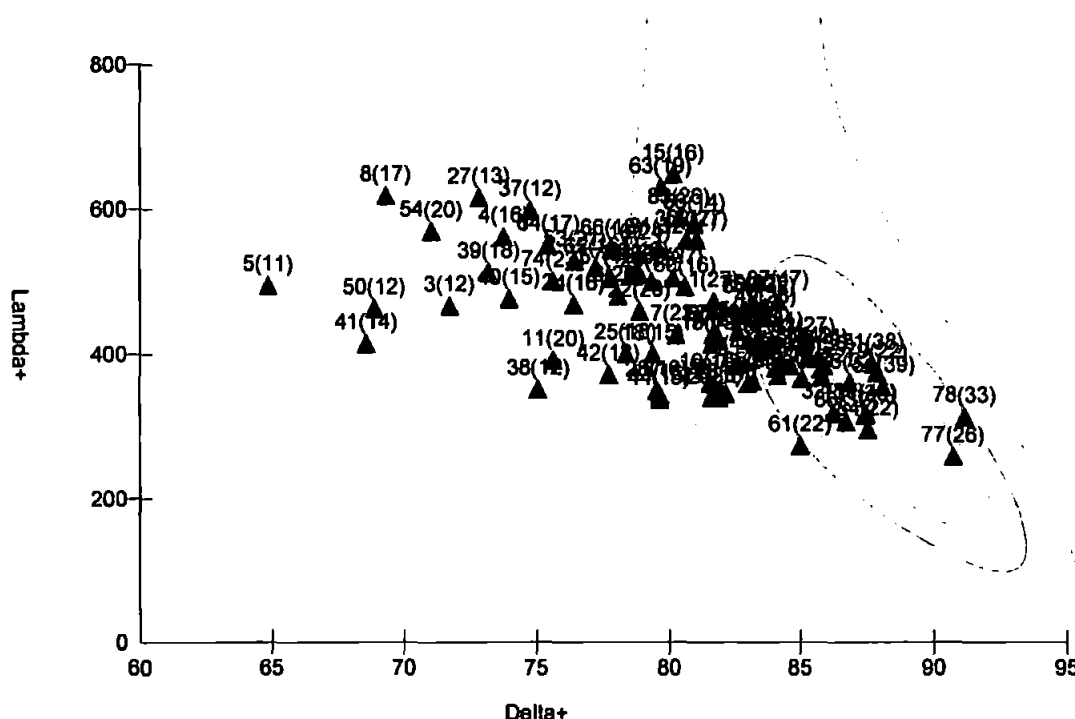


Figure 6.5. Variation in taxonomic distinctness (Λ^+) against average taxonomic distinctness (Δ^+) for all ($n = 88$) of the taken samples (green triangles, labelled with sample number and number of species) and probability of null or expected values. The inner yellow region is 60 % and each outer region is 10 % lower. The same axes ranges are used as on Figure 6.1 and Figure 6.3.

As expected the majority of the cloud of points on Figure 6.5 represent lowered levels of Δ^+ and elevated levels of Λ^+ , and only 8 out of the 88 hauls lie within the 50 % probability region of expected values. Figure 6.5 also does show the strongly negative association between the two variables. As above the Spearman's rank-order correlation was used as both Δ^+ and Λ^+ do not always approximate a normal distribution), $r_s = -0.627$, d.f. = 87, P

< 0.001 between the full sample of Δ^+ and Λ^+ values. On Figure 6.5, only those samples with the higher Δ^+ and lower Λ^+ values are close to the expected range of these variables, which would represent taxonomically diverse and even samples. Figure 6.6 breaks down Figure 6.5 into port and type of trawling to show which subset more closely approximates the expected distribution between Δ^+ and Λ^+ values.

trawling. Only 2 of the Newlyn samples (5 %) were within the 20 % of expected values. 3 (27 %) of the Looe single and 4 (44 %) of the Looe pair samples were within the similar 20 % though the 'tail' of these samples away from the null region is also interesting. The single boat samples were more uneven though not less species rich while the pair samples were species poor though not more uneven. This supports the assertion that the pair trawls were sampled from less structurally complex habitats with lower overall species richness though the sample size was small. The Plymouth samples describe a similar trend of overall Δ^+ and Λ^+ values and appear to share the same relationship in their 'tail' though this is less obvious. Finally Figure 6.6 shows that the Salcombe samples were all within their 20 % expected range such that they were composed from a broad and well constructed sub-list of the master species list (high Δ^+ values) and the branches of the taxonomic tree were evenly weighted (lower Λ^+ values). The (non-parametric) correlations between Δ^+ and Λ^+ for the Salcombe samples was negative though this association was particularly "poor" (Table 6.9); the reason being the data cluster closest to the null region.

Table 6.9. Value and significance of Spearman's rank-order correlation (r_s) between the variation in taxonomic distinctness (Λ^+) and average taxonomic distinctness (Δ^+) according to port and type of trawling.

| port and type of trawling | Spearman's rank-order correlation (r_s) | significance (P) value | d.f. |
|---------------------------|---|----------------------------|------|
| full sample | - 0.627 | < 0.001 | 87 |
| NS | - 0.473 | 0.002 | 41 |
| LS | - 0.827 | 0.002 | 10 |
| LP | - 0.767 | 0.016 | 8 |
| PS | - 0.738 | 0.037 | 7 |
| PP | - 0.643 | 0.086 | 7 |
| SS | - 0.358 | 0.310 | 9 |

The deviation from the samples, (according to port and type of trawling) comprising a well constructed sub-list of the master species list (high Δ^+ values) and the branches of the taxonomic tree being (relatively) evenly weighted (lower Λ^+ values) increases with

distance from the Salcombe areas of sampling and region populated on Figure 6.6. This is borne out by the 'tail' of decreasing Δ^+ and increasing Λ^+ values in the Plymouth, then Looe then Newlyn samples. All of these associations are also negative and all except that for the Plymouth pair trawled samples are significant (see Table 6.9).

6.3.2 Seasonality in the biodiversity of the samples

42 of all the samples were from Newlyn. Except for the second quarter 1998 hauls, which were well south of both The Isles of Scilly and the tip of Cornwall most of the hauls from Newlyn were from a small geographical area between Cornwall and the Isles of Scilly, as shown in Figure 3.1, page 47, above. Figure 6.7 shows these in their individual trips and shows plots of (actual and expected) Λ^+ against Δ^+ values and also in which quarter of the year they were sampled.

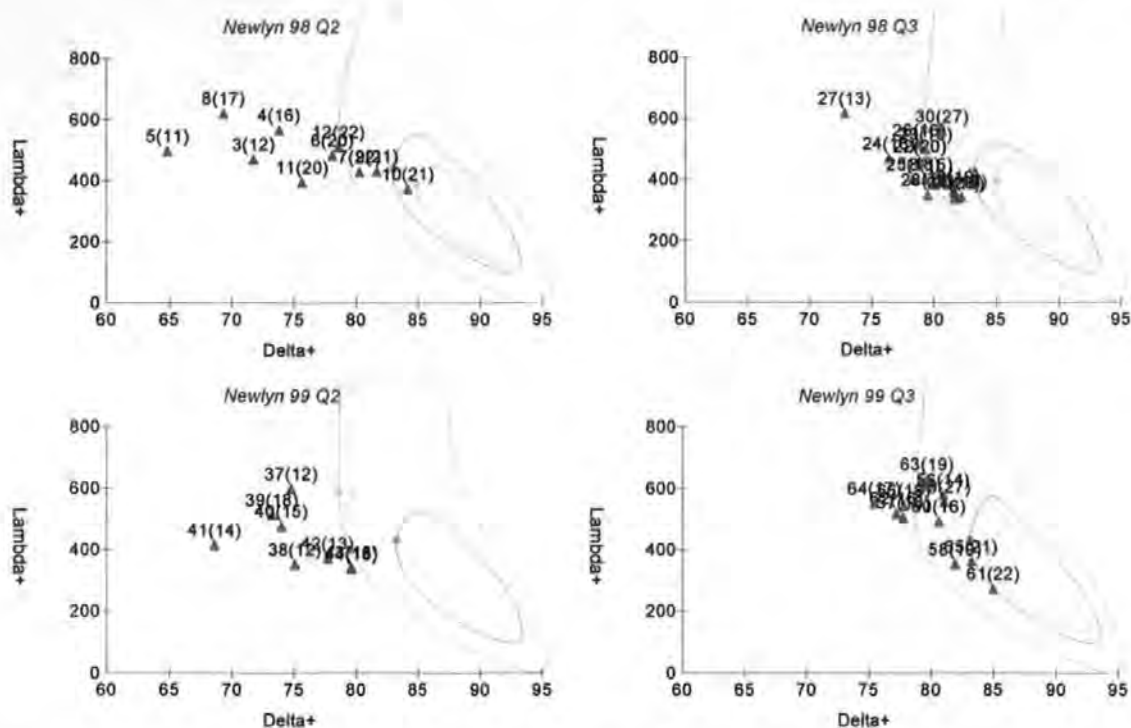


Figure 6.7. Variation in taxonomic distinctness (Λ^+) against average taxonomic distinctness (Δ^+) for all of the Newlyn collected samples (green triangles, labelled with sample number and number of species) according to year and quarter of the year, and probability of null or expected values. The regions are: 98-Q2 10, 20, 30 %, 98-Q3 10, 20, 30 %, 99-Q2 10, 20 %, 99-Q3 10, 20, 30 %. The same axes ranges are used as on Figure 6.1 and Figure 6.3.

It would appear that those Newlyn trips taken later in the year (Q3) show both an average taxonomic distinctness and variation in taxonomic distinctness closer to the expected or null values, (where the data is similar in nature to the Salcombe based hauls on Figure 6.6). The Newlyn sample Δ^+ values were highly significantly different between quarters 2 and 3 (pooling years) according to a Mann-Whitney test ($W = 82$; $P = 0.001$), though not between years (pooling quarters) $W = 499$, $P = 0.919$. Λ^+ values were neither significantly different between quarters 2 and 3 (pooling years) $W = 375$; $P = 0.770$ nor between years (pooling quarters) $W = 476$; $P = 0.649$, according to Mann-Whitney tests, ($n = 42$ in all cases).

Figure 6.8 shows the plot of Λ^+ against Δ^+ for the pool of the Looe, Plymouth and Salcombe samples which were sampled across 4 quarters of the year from 1998 to 2000.

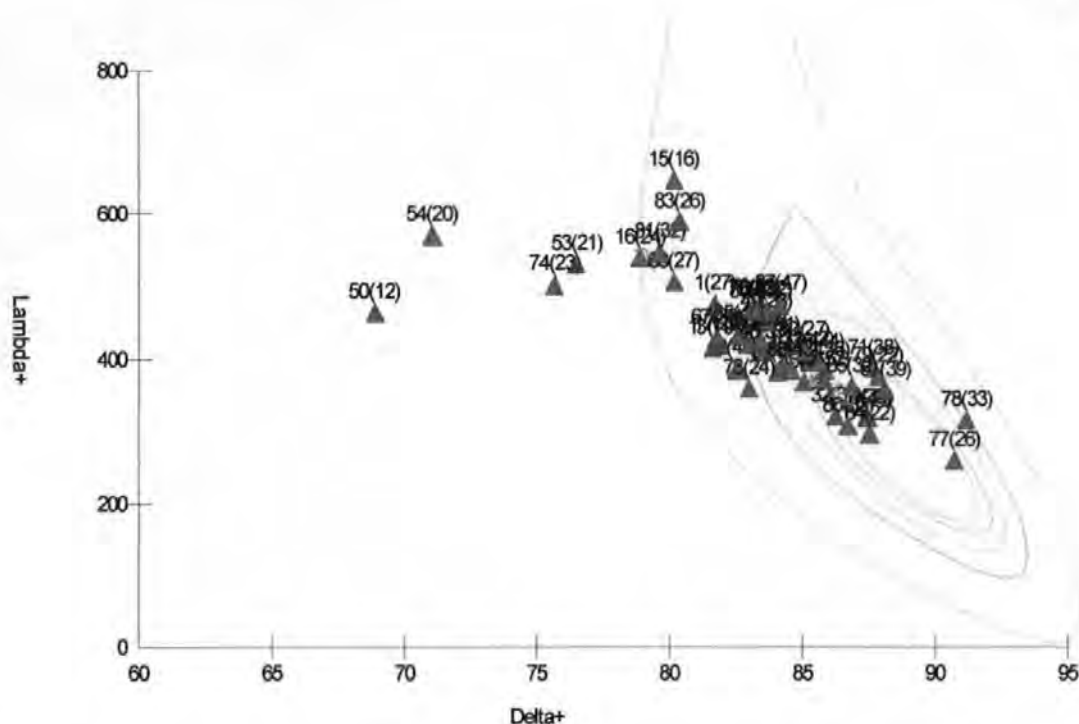


Figure 6.8. Variation in taxonomic distinctness (Λ^+) against average taxonomic distinctness (Δ^+) for the pool of Looe, Plymouth and Salcombe samples (green triangles, labelled with sample number and number of species) showing the probability of null or expected values. The regions are: 10 to 60 %. The same axes ranges are used as on Figure 6.1 and Figure 6.3.

Figure 6.8 shows a much smaller range in Δ^+ values for the majority of the Looe, Plymouth and Salcombe samples than was evident for the Newlyn samples (Figure 6.6, top left). The data are also generally closer to the null (or expected) range and this is borne out by the fact that the highest null level for the whole of the Newlyn samples was 30 % (Figure 6.6, top left) whereas Figure 6.8 includes values up to 60 %, and that 29 (63 %) of samples were within the 20 % null region. Figure 6.9 shows the pool of Looe, Plymouth and Salcombe samples according to the quarter of the year in which the samples were taken.

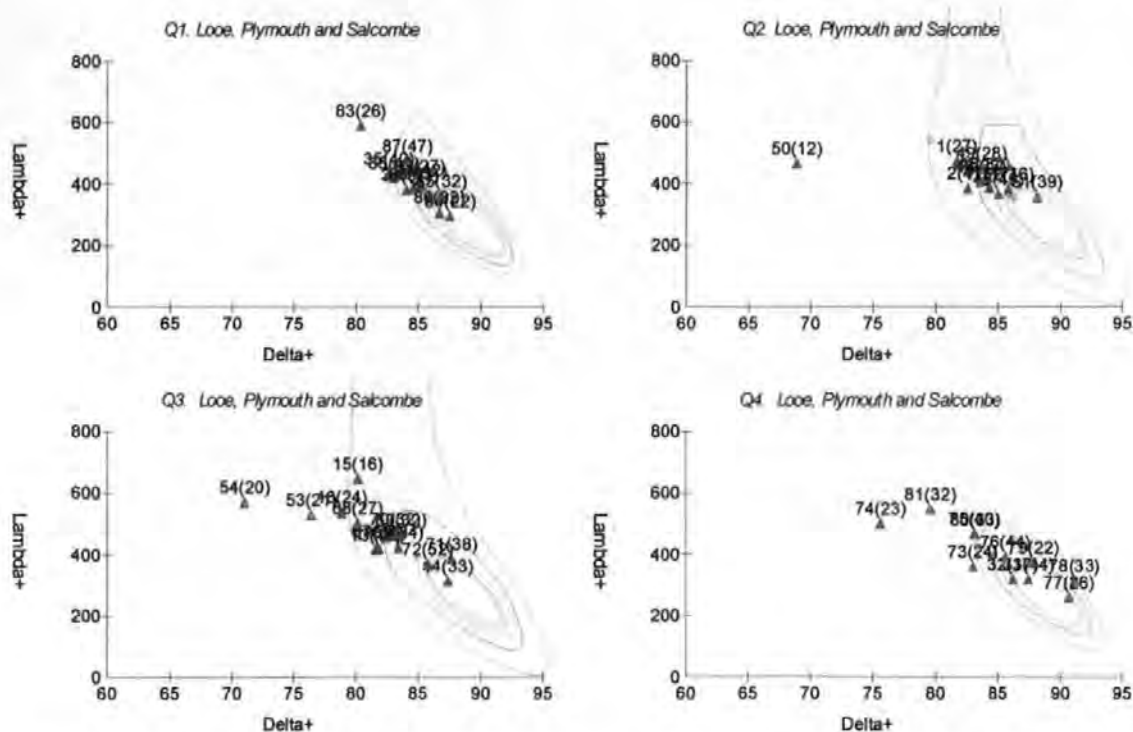


Figure 6.9. Variation in taxonomic distinctness (Λ^+) against average taxonomic distinctness (Δ^+) for the pool of Looe, Plymouth and Salcombe samples (green triangles, labelled with sample number and number of species) according to quarters of the year showing the probability of null or expected values. The regions are: Q1, 20, 30, 40, 50 %; Q2, 10, 20, 30, 40, 50 %; Q3, 10, 20, 30, 40, 50, 60 %; Q4, 20, 30, 40, 50 %. The same axes ranges are used as on Figure 6.1 and Figure 6.3.

The first feature to notice from Figure 6.9 is that (compared to Figure 6.7) the samples from Looe, Plymouth and Salcombe do not exhibit the same shift of increasing Δ^+ values from earlier to later in the year. This is borne out by the results of a Kruskal-Wallis test of pooled Looe, Plymouth and Salcombe Δ^+ values between the four quarters of the year, which are shown in Table 6.10.

Table 6.10. Kruskal-Wallis test of pooled average taxonomic distinctness (Δ^+) values from Looe, Plymouth and Salcombe by quarter of the year. $H = 5.47$, d.f. = 3, $P = 0.140$.

| quarter of the year | n | median | average rank | Z |
|---------------------|----|--------|--------------|-------|
| 1 | 11 | 72.07 | 27.7 | 1.20 |
| 2 | 10 | 70.46 | 21.9 | -0.43 |
| 3 | 14 | 68.31 | 17.5 | -2.01 |
| 4 | 11 | 72.42 | 28.4 | 1.38 |
| overall | 46 | | 23.5 | |

The H value for the K-W test in Table 6.10 was not significant and the average ranks shown are not greatly different. A *post-hoc* Dunn's test (Table 6.11) shows where these non-significant differences were least and greatest.

Table 6.11. Results of Kruskal-Wallis *post hoc* Dunn's Test for Multiple Comparisons (Q) of pooled average taxonomic distinctness (Δ^+) values from Looe, Plymouth and Salcombe by quarter of the year to 2 d.p. $K = 2.64$ and there are no significantly different pairs.

| | | | |
|---|------|------|------|
| 1 | 1.00 | 1.86 | 0.12 |
| 2 | | 0.79 | 1.11 |
| 3 | | | 2.02 |
| | 2 | 3 | 4 |

Although not significant the more temporally distant quarters (quarters 1 and 3, and quarters 2 and 4) were more dissimilar than adjacent quarters (including quarters 1 and 4 where the difference is the smallest) although the largest differences were between the third and fourth quarters' samples.

6.3.3 Contribution of higher taxonomic levels to biodiversity

6.3.3.1 Fishes (by order)

Figure 6.10 shows the average Δ^+ value for the full sample according to the sample categories described in Table 6.1 (page 164, above) and according to port and type of trawling.

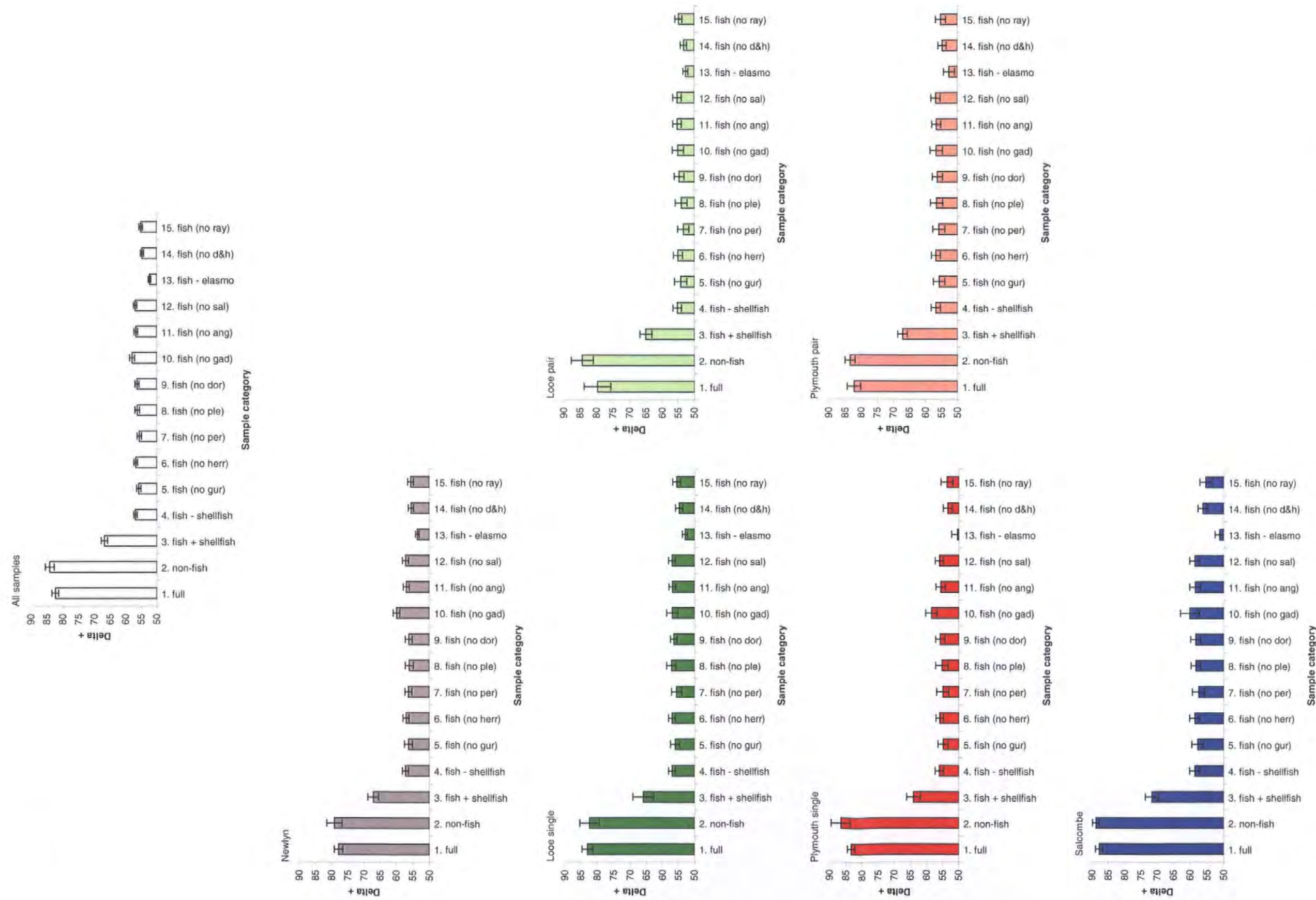


Figure 6.10. Average taxonomic distinctness (Δ^+) values (and 95% CI) for the fish based sample categories (see Table 6.1, page 164, above for descriptions of categories) across all samples and by port and type of trawling.

The category 1 Δ^+ values on Figure 6.10 according to port and type of trawling were the same as those on Figure 6.2 (mean $\Delta^+ = 80.76$) and have the general increase, west to east, in Δ^+ values ($\Delta^+ \text{ N S} = 77.9$; $\Delta^+ \text{ S S} = 87.8$) and with the single boat samples being higher than the similarly based pair trawl samples, as shown in 6.3.1.

The Δ^+ values for the non-fish part of the sample (category 2 on Figure 6.10) were higher on average than for category 1 (except for Looe single boat samples where the Δ^+ value decreased by -0.64) though the differences were not generally large; the average increase in Δ^+ values between category 1 and 2 = 1.78.

There was a marked drop in Δ^+ values between categories 2 (average $\Delta^+ = 84.14$) and 3 (average $\Delta^+ = 66.83$). Category 3 was the fishes and the shellfish species. The largest levels of variability (as 95 % CI) were in categories described so far. This was due to some of these samples having very few of the groups making up these categories.

The plateau on Figure 6.10 between categories 4 and 15 was created by removing various orders of fishes in turn (see Table 6.1, above). Removing the six gurnard species, category 5, (which contributed significantly to the sample biomass) has lowered the Δ^+ values by -1.01 on average and (due to their near ubiquity) this reduction was fairly uniform across all ports and types of trawling.

The removal of the eight species of Perciformes, category 7 (which were not so abundant, though still very important, within the sample) reduced the average Δ^+ value by -1.23 though this order was most significant to the Looe samples (average Δ^+ value reduced by -1.65) and least to the Newlyn ones (average Δ^+ value reduced by -0.87) compared to category 4.

Removal of the nine Pleuronectiformes species (category 8) produced generally small negative changes in the Δ^+ values (average decrease -0.60) except for the Looe single boat hauls where the removal produced a positive change in the Δ^+ values. This order was the most important for Newlyn (Δ^+ value reduced by -1.17) and Looe pair samples where Δ^+ was reduced by -1.26 .

The taxonomic importance of the two species of dories, category 9, (though only *Zeus faber* was commonly recorded; *Capros aper* being both rare and absent from the Plymouth and Salcombe samples) is shown in that their exclusion produced a drop in Δ^+ value of ~ -0.55 though the Newlyn samples produced the largest reduction (Δ^+ value reduced by -1.00). The anglerfishes (category 11) were similar to the dories in that one species *Lophius piscatorius* was commonly recorded (only absent in Looe pair trawl samples) while the other species *L. budegassa* was only recorded in the Looe single boat samples. Nevertheless the exclusion of the order LOPHIIFORMES only resulted in a decrease in Δ^+ of ~ -0.19 .

Exclusion of the species poor Clupeid (category 6) and Salmonid (category 12) groups was not particularly important as these only decreased the Δ^+ values by -0.09 and < -0.01 respectively from the benchmark Δ^+ values of category 4.

Removal of the gadoids (category 10), had (after the Perciformes, category 7) the largest effect of any of the teleost fish groups (with an average increase in Δ^+ values = 1.03), and this was most noticeable for the single boat samples. These values were N S = 2.75 , L S = -0.07 , L P = 0.22 , P S = 2.48 , P P = -0.20 and S S = 1.45 . Gadoids were generally the targeted group though there are also several discard species amongst this order. Figure 6.10 shows that exclusion of this group also produced the largest range in Δ^+ values as expressed in their CI values. The elevated Δ^+ values that resulted from the exclusion of gadoids, for some ports and types of trawling, indicate the taxonomic similarity of this group within the sample.

All these differences in Δ^+ values for the removal of the orders of the teleost fishes are small when compared to the removal of the elasmobranchs (category 13). An average reduction in Δ^+ values of -4.56 from category 4, though -7.25 for the Salcombe based samples. The levels of variability (as 95 % CI) were not even for category 13 with low variability for Newlyn and Looe hauls (2.76 %) and higher variability for Plymouth and Salcombe hauls (4.76 %). This reflects the relative distribution of species according to the

ports and types of trawling. Also, the reductions in Δ^+ values were much larger for the single boat trawls (Δ^+ reduced by - 5.14) than the pair boat trawls (Δ^+ reduced by - 3.40) which may reinforce the habitat preference of this group as a whole (see Chapter 8). According to the Δ^+ values the removal of the order Carcharhiniformes (category 14) was greater (Δ^+ down by - 2.17) than the order Rajiformes (category 15), where the average Δ^+ value was reduced by - 1.18.

6.3.3.2 Non-fishes (invertebrates) (by phyla)

In addition to examining the removal of various orders of fishes the taxonomic range in this study was sufficiently wide to allow a similar exclusion exercise to be carried out on the non-fish part of the sample. Figure 6.11 shows this.

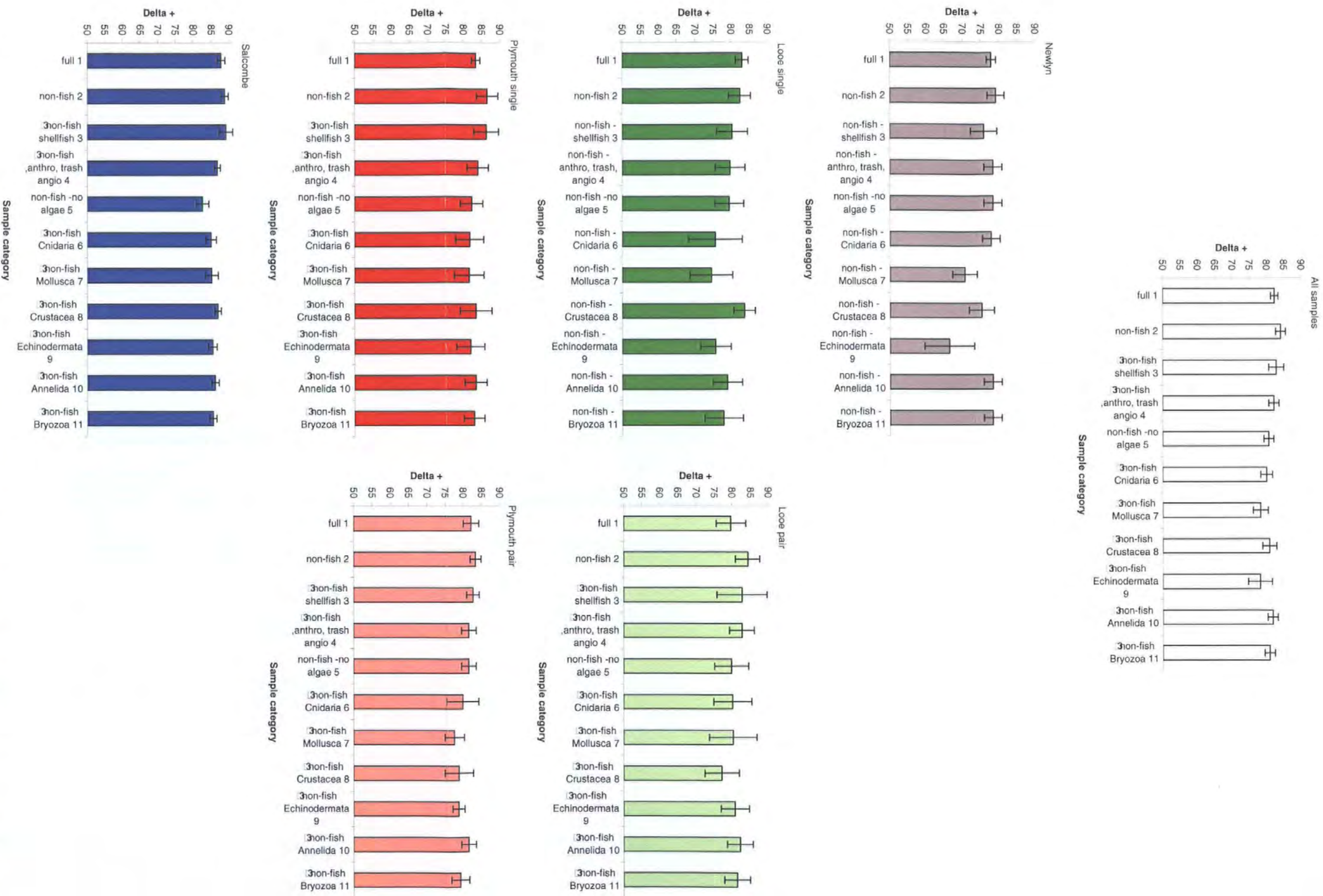


Figure 6.11. Average taxonomic distinctness (Δ^+) values (and 95 % CI) for the non-fishes based sample categories (see Table 6.2, page 166, above for descriptions) across all samples and by port and type of trawling.

The first feature to notice on Figure 6.11 (above) is the general trend in Δ^+ values for the six categories of port and type of trawling. With a few exceptions (described later), there was more constancy for the Plymouth and Looe based samples where Δ^+ values range between 75 and 85. The Δ^+ values for the Salcombe based samples are generally higher (with Δ^+ values between 80 and 90) representing more finely filled taxonomic branches. Conversely, the Newlyn samples have lower Δ^+ values (generally between 70 and 80). These represent taxonomic branches that are not so well filled towards their tips (species) but are well populated at their coarser end.

The variability expressed as 95 % CI was generally lower for the Salcombe and Plymouth samples (± 2.33) and higher for the Looe and Newlyn ones (± 3.93) and across all the categories the single boat samples were more variable than equivalent single boat samples though there are exceptions to this general situation.

Next, Figure 6.11 shows the general trend in Δ^+ values for categories 1 and 2. These were described above for Figure 6.10, (page 187, above). The variability of categories 1 and 2 were also as described above.

The removal of the shellfish species (category 3) only had a minimal effect on the Δ^+ values (increasing them by ~ 1.25) and while the variability of these samples remained relatively unchanged from those of category 2 the variability was greater for Newlyn and Looe pair trawled samples. The increase in the Δ^+ values was due to the relatively small taxonomic range of the shellfish species. The removal of category 4 was carried out because it can be argued that these removed groups were not so important to the overall picture of taxonomic distinctness or range. Here category 4 was again the benchmark non-fish part of the sample in the same way that category 4 was the benchmark fish part of the sample as it is the category from which exclusion (here at the phylum level) were taken. Importantly, the two-benchmark categories were quite different in that for the fish part of the sample the Δ^+ values were at the bottom of the plateau while for the non-fish part of the sample there is no such distinction. This marked difference shows the fundamental reason

for sampling both the fish and the non-fish material. Here, for the non-fish part of the sample, category 5 (the non-fish material without the algae) could be classed as another possibly unimportant group however the effect of its removal was most noticeable in the Salcombe samples; Δ^+ values decreased by -4.15 , compared to category 4.

Removal of the phylum CNIDARIA (category 6) reduced the average Δ^+ values by -2.14 when compared to the benchmark of category 4. There was only a relatively small taxonomic range of Cnidarian species from the Newlyn samples resulting in a decrease in Δ^+ values by -0.59 . The largest decrease in Δ^+ values resulting from the exclusion of the Cnidarians was in the Looe based samples, (-3.34 overall), though they had a greater diversity in the single (Δ^+ reduced by -5.21) rather than pair boat samples (Δ^+ reduced by -3.41). There was a peak in variability (as 95 % CI in the Looe (single particularly) and Newlyn hauls.

The other two phyla whose removal did not result in large reductions in Δ^+ values were the Annelids (category 10, Δ^+ down by -0.40 on average) and the Bryozoans (category 11 Δ^+ down by -1.26 on average), compared to category 4.

The removal of the Molluscan, Crustacean and Echinoderm Phyla (categories 7, 8 and 9 respectively) created some very large reductions in the Δ^+ values as shown in Figure 6.11. The averages reductions were -3.89 (category 7), -1.30 (category 8) and -3.99 (category 9) from the benchmark category 4, although there were marked differences according to port and type of trawling.

Amongst the molluscs are important species of shellfishes and their significance was reflected in the removal of this category resulting in a Δ^+ value of 70.71 for the Newlyn samples (Δ^+ reduced by -7.70) though there were also reduction -4.56 for Looe single and Plymouth pair trawled samples.

Removal of the crustaceans resulted in a greater decrease in Δ^+ values for the pair boat compared to the single boat samples, though the situation is complex. The changes (compared to category 4) were L S = 4.00 , L P = -5.58 , P S = -0.51 and P P = -2.71 . The

Δ^+ values for Newlyn was reduced by -3.12 though this removal had little effect on the Salcombe samples (where the average Δ^+ value was increased by only 0.15) compared to category 4.

The largest single decrease in any of the non-fish with the removal of an invertebrate phylum (according to port and type of trawling) was for the removal of Echinoderms for the Newlyn samples (Δ^+ down by 11.93 , $\Delta^+ = 66.47$) which is towards the range of Δ^+ values found in the fish analysis. This removal also generated the largest amount of variability (± 6.80). The variability for all these categories was again larger for the Newlyn and Looe samples than the others.

6.4 Discussion

6.4.1 Analysis of average taxonomic distinctness (Δ^+) and variation in taxonomic distinctness (Δ^+)

The strength of examining the biodiversity of the samples using the indices of taxonomic distinctness is that the results are not dependent on sample size. This is particularly important when the number of sampling opportunities cannot be tightly controlled and the operation of the various vessels meant that different numbers of samples could be collected. These measures also work well between different studies. Here they enabled the detection of subtle differences between operations from different ports and using single and pair trawling gear where, though it was not the intention to alter the size of the sample, inevitably the area trawled and the amount of material retained by the gear varied greatly and meant that comparisons using other indices of assessment may be flawed. These methods are no longer in their infancy though it is only with their wider application that their strengths and weaknesses can be explored.

One of the features of Δ^+ is its robustness to alteration by manipulating either the taxonomic groups sampled, or the resolution to which the taxonomic tree is taken. Therefore, altering the former might have altered the magnitude of the values of Δ^+ , which being from the kingdom level are much larger than reported by Rogers *et al.*, (1999), (who examined only fish) though would not have altered the position of the probability funnel to include more samples. However in order to be comparable between studies it is suggested that the same coarse level of kingdom is always used and that where the removal and reintroduction of taxa is undertaken the compromise of even (fixed) branch lengths is preferable to assigning values based on the master species list, (see Appendix I for more details). It is also recommended that it is sensible to report differences in Δ^+ due to removal of taxonomic groups relative to the benchmark category.

The positive correlation in Figure 6.1 described a situation where added richness came from filling in more species at coarse taxonomic levels that were not already present. In other words, completely 'new' taxonomic branches were added and those already present were not added to as equally. Values of Δ^+ which fall below the 95 % funnel usually represent samples from localities which have a lower than expected taxonomic spread (Clarke & Warwick, 1998). Thus, it would appear that many of the samples collected here could be described as being from taxonomically impoverished locations, or that this might be an artefact of the collection of these samples. The ambivalent nature of this statement can be offset against the species accumulation curves (Figure 3.2, page 59, above) though it is recognised that trawl gear may not be an ideal method of sampling all benthic species whether or not they are fishes. Nevertheless, the disturbed indication of the Newlyn samples was also supported by the ABC in Chapter 5.

Values of Λ^+ are more difficult to interpret than those of Δ^+ , (see Clarke & Warwick, 2001b) however variation in taxonomic distinctness reflects the degree of evenness of the taxonomic tree within the sample. Low Λ^+ values represent taxonomically even sites, for example, a list in which all species are from different families but the same

order. Λ^+ increases as the number of intermediate taxonomic levels increases (for the same value of Δ^+). For example a site with a higher Λ^+ might have several different orders represented only by a single species, but also some genera which are very species rich, (see Clarke & Warwick, 2001b, figure 2). The ecological implication of this is that sites with higher Λ^+ may not be so resilient to disturbance. In a study of eutrophication in lagoons on the French Mediterranean coast Mouillot *et al.*, (2005) found that as the stress level increased taxonomic lineages were constrained by the environment and Λ^+ values were higher. It is possible that here similar constraints are being imposed by disturbance or loss of habitat.

The high Λ^+ values from the Newlyn samples shows that the taxonomic tree of the species in these samples was more uneven than might be expected, within the size range of organisms retained in the trawl. The exact size range retained within the samples was explored in Chapter 5, (specifically in relation to Figure 5.14, page 134, above). Nevertheless, the link between higher Λ^+ values and environmental impact may be supported by the relatively small geographical extent of the sampling effort, (Figure 3.1, page 47, above) and the anecdotal information from the boat skipper and crew that this was a favourite area in which to fish. The hauls away from the main sampling area (sample numbers 3 through to 12 on Figure 3.1) were in the middle of the cluster on Figure 6.4 (top left), which suggests that further offshore areas may well overall be similarly disturbed as portrayed by measures of biodiversity, though more sampling would be required to carry this assessment further. Nevertheless, their greater depth does not appear to have protected them from being equivalently impacted to the more closely inshore (and shallower) areas.

The Looe single boat samples on Figure 6.4 roughly divided into the more species rich, and more taxonomically even inshore samples and the less species rich, and taxonomically uneven samples collected south of Eddystone Rocks, (see Figure 3.1, page 47, above and Figure 4.4, page 79, above). The pair trawl samples from Looe were not similarly distributed in terms of their taxonomy although further offshore samples are

roughly more species poor. The pattern in the Plymouth samples was more similar to the Looe pair samples though while it does not seem possible to divide these into offshore/inshore or taxonomically even/uneven sites from these samples, the Plymouth sites appear less impacted overall.

The position of the Salcombe samples within the 95 % probability funnel for Δ^+ values on Figure 6.4 suggests that the taxonomy contained in these samples was more even and these samples were from less environmentally impacted sites. It is suggested that the proximity of these sites to the Inshore Potting Agreement's temporarily closed areas (see Blyth *et al.*, 2004, Fig 1) may be responsible. Significantly, samples 77 and 84 were within the temporarily closed areas and while these samples were not the most species rich, they did possess the lowest Δ^+ values for Salcombe and only one other haul had a lower Δ^+ value than #84. It is unlikely that the close proximity of some of these samples to the shore cannot alone be responsible (although > 12 m vessels are prohibited from fishing within 6 nm of both Devon and Cornwall, Anon, 1993b) as although other samples close to land were relatively taxonomically even they were generally more species rich. Blyth *et al.*, (2004) examined the implication of the seasonal closure on the waters around Salcombe and found that longer closed areas had increased numbers of both attached and free species and in sampling close to the temporarily closed areas and the Salcombe samples. Here the Δ^+ generally decreased with increasing distance from Salcombe.

Also noteworthy was the fact that the pair trawled samples had lower average Δ^+ values (though also show more variation according to Figure 6.2 than their single boat trawled samples, thus there may be consistent features of the gear arrangement that make single boat trawling better at capturing the greater range of taxonomy than from pair trawling. However, it might also be that the single boats were trawling in more structurally complex areas where there was likely to be a greater range of habitats and therefore a greater taxonomic range. Nevertheless, this strengthens the case for the west to east geographical distribution of increasing average taxonomic distinctness (Δ^+) values, which

was evident from Figure 6.2. In addition, perhaps, that the Newlyn samples share some of the gear-related features (mentioned above) of the pair trawled samples. Interpreting the average Λ^+ values Figure 6.3 was more complex however almost all of the samples have a Λ^+ value well above the theoretical mean of ≈ 260 with about half of the samples (according to Figure 6.3) have Λ^+ values above the simulated 95 % probability funnel.

Here, the relatively high Λ^+ values (above the mean and also often above the 95 % confidence region) was interpreted as a result of environmental impact (Warwick *pers com*) rather than as an example of a pristine ecosystem limited in its habitat diversity (Clarke & Warwick, 2001b) because of the diversity in the substrates and tide of the region (see Table 4.1, page 80, and Table 4.2, page 84, respectively). The only possible corollary for the case presented in Clarke & Warwick, (2001b) (in that the samples could have been collected from pristine locations) was that despite the variable nature of the habitats the collection of the samples through trawling generated a size-selection bias thus the generated Λ^+ was biased towards being irregular and complex in that the sampling has missed parts of the biodiversity. While it is inevitable that some (especially small sized) diversity components were missed in the sample collection this argument is ameliorated by both the large number of species encountered (Figure 3.2, page 59) and their broad size distribution (Figure 5.14, page 134). Furthermore, the idea that the taxonomically more uneven nature of the samples (greater Λ^+) is representative of disturbance rather than of low diversity but pristine habitat is supported by the generally good correlation with low Δ^+ values. Finally, the disturbance interpretation is supported by the generally negative correlation between Λ^+ and numbers of species such that only the most species rich samples possessed Λ^+ values approaching or within the null region except for the Salcombe samples that appear to be from considerably less disturbed locations.

The plots of Λ^+ against Δ^+ (Figure 6.5 and Figure 6.6) were particularly useful as considerable additional information is available which was undetectable from comparing the examining each independently. After bringing together the Δ^+ and Λ^+ values the (r_s)

correlations of the single boat samples (Table 6.9, page 181, above) were greater (and more negative) than those of similarly based pair trawled samples suggesting that there was a consistent gear-related feature in the distributions of the Δ^+ and Λ^+ values. This is shown in Figure 6.6 in that the 'tail' described above is skewed towards similar Δ^+ and increased Λ^+ values for the single boat samples (though this is more evident from Looe than Plymouth) and decreasing Δ^+ though more stable Λ^+ for the pair trawled samples. Again, this is more evident in the samples from Looe than from Plymouth. This supports the above assertion that the pair trawled samples in the 'tail' are from species (or taxonomically) poorer sites (or that this was a feature of their collection) and the similar single boat samples were from more heavily impacted locations though their taxonomy remains more complete. Finally, the 'tail' samples from Looe and Plymouth are predominantly those further offshore (see Figure 3.1, page 47, above). The distance offshore of these locations brings them into the operating range of beam trawlers however; with this data set, it is not possible to take this idea further.

The management implications of assessing Δ^+ and Λ^+ of trawl samples has yet to be fully realised, though the above described advantages of the techniques lend themselves to these data types and sources. The planned EU Marine Strategy Directive sets out a requirement to achieve "‘Good Environmental Status’ (GEnS) of the marine environment by 2021," (COM, 2005, p5). Laffoley *et al.*, (2006) sets out to define GEnS considerations though missing from this list is an assessment of taxonomic diversity (Δ^+) and resilience to disturbance (Λ^+). It is hoped that a taxonomic index can complement the others that have been proposed.

6.4.2 Seasonality in the taxonomic diversity of the samples

That most of the hauls from Newlyn were from a small geographical area between Cornwall and the Isles of Scilly (Figure 3.1, page 47, above) and those away from this area show similar features means it was unlikely that the patterns observed on Figure 6.7 result from spatial distribution. Instead, the cause might be physical or biological in nature. Some possible seasonality in the samples from Newlyn was demonstrated, within the scope of this dataset, in that those collected in the earlier part of the year (Q2) were shown to have significantly lower Δ^+ values than those in Q3. This suggests that these samples have a fairly coarse taxonomic spread comprising major groups and that later in the year additional fine taxonomic resolution is added though the evenness of these samples did not change. In an experimental colonization study Arntz & Rumohr, (1982) found a seasonal oscillation in species diversity and it is possible that the same pattern was detected here.

The feature of seasonality of increasing Δ^+ values (for similar Δ^+ values) is not evident from the much wider temporally and spatially sampled area of pooled Looe, Plymouth and Salcombe samples. Instead, for the pool of non-Newlyn samples higher Δ^+ values were found at the beginning and end of the calendar year. Despite the sampling period spanning three years that more temporally distant quarters (quarters 1 and 3, and quarters 2 and 4) were more dissimilar than adjacent quarters (including quarters 1 and 4 where the difference was the smallest) suggests that there may be a marked change between these periods which has been detected in the taxonomy of the samples, though here the difference between adjacent quarters may be linked to the level of biological activity rather than the level of taxonomic distinctness.

It is possible that the pair and single boat samples for Looe particularly mirror the seasonality apparent in the Newlyn samples.

6.4.3 Contribution of higher taxonomic levels (fish orders and non-fish phyla) to biodiversity

Interpreting the fish part of the sample the small differences between the category 1 and 2 on Figure 6.10 suggests that the removal of the fishes was barely detectable on taxonomic distinctness grounds in that this group (or the super class GNATHOSTOMATA branch of the full 188 species within the taxonomic tree) was reasonably evenly populated when compared to its appropriate non-fish part. The explanation for this is due to the twin facets of the equivalent taxonomic fineness of the fish and non-fish parts of the sample but also the choice of Kingdom as the 'ground level' for the taxonomic tree.

The large drop in the Δ^+ values between categories 2 and 3 on Figure 6.10 was unsurprising since in category 3 much of the taxonomic tree has been removed leaving only the sub classes TELEOSTEI and ELASMOBRANCHII, the commercial crab species (*Cancer pagurus*), a few cephalopods (squids, and octopus) and the King and Queen scallops. The Δ^+ values are lower because most of the connectivity is at the super-class level with only a little across phyla. Nevertheless, the Salcombe samples again possessed the richer fine level of taxonomy of the fishes and shellfish as the Δ^+ value = 71.62 against the average for this category, of 66.83. The taxonomic relevance of the shellfish is revealed when comparing category 3 with category 4 (where the average Δ^+ value = 56.82). Category 4 is only the teleost and elasmobranch fishes though again the Salcombe based hauls have the highest fine taxonomic resolution (highest Δ^+ value = 58.61).

Despite different magnitudes in Δ^+ values (due largely to the extension here of the classification into coarser groupings) Rogers *et al.*, (1999) discuss similar findings for the removal of the elasmobranchs and other groups and demonstrate, as here, that the exclusion of similarly numerically sized components can have greatly different effects on taxonomic distinctness and that "In the event of perturbations caused by either human

impact or changing environmental conditions Tilman, (1996) claims that the taxonomic range of an assemblage will be important for maintaining the stability of the ecosystem,” (Rogers *et al.*, 1999, p 780).

In terms of the fish species the results from this study are in broad agreement to those gathered by Rogers *et al.*, (1999). It is important for ecological stability to retain taxonomic richness, especially derived from the elasmobranches, but also made up from the other species rich target groups (such as the Pleuronectiformes and Gadoids).

Although category 5 of the non-fish analysis might be relatively unimportant, it shows that while still too deep to naturally include algal species, it is likely that these groups were sampled because of either human or natural disturbance closer inshore.

The Cnidarians (removed in category 6) are a very diverse group though the majority of the species sampled were Hydroids belonging to the families Plumulariidae and Sertulariidae. These are species-rich families of erect colonies (Cornelius, 1995) prone to being caught in mobile gear and it is likely that the single boat trawling in more variable habitats was responsible for the greater reduction in Δ^+ values caused by this phylum's exclusion.

All of the Annelids sampled (removed in category 10) were Polychaetes for which trawl gear is not a very ideal method of sampling, though this group was most significantly caught from Salcombe.

The most abundant Bryozoans (removed as category 11) were *Cellaria* spp. which was quite ubiquitous by port and type of trawling except from Newlyn, though far more commonly encountered when pair trawling than when single boat trawling. Unique to the Newlyn samples and the only bryozoan in these samples was *Pentapora fascialis*. This large colonial animal is described in Hayward & Ryland, (1996, p 657) as being 'locally quite common.' Pätzold *et al.*, (1987) analysed the rate of growth (and longevity) of this species showing the large specimens were quite old – a 20 cm diameter colony being at least 3 years old and Stebbing, (1971) described larger colonies which were at least 12

years old. The lack of *P. fascialis* except in the Newlyn samples may be due to several reasons. It could be the lack of suitable hard substrates to which it attaches. However, there are areas of hard substrate close to or within areas sampled by the Looe, Plymouth or Salcombe boats. Alternatively the life history characteristics of this species coupled with events of fishing disturbance may mean it is simply too rare to have been encountered. According to the National Biodiversity Network (NBN), (Anon, (2004) the distribution of *P. fascialis* is restricted to around The Isles of Scilly, the Eddystone Rocks, and along the coast from the Plymouth Breakwater through Bigbury Bay to Salcombe. This study found *P. fascialis* from other areas suggesting that the National Biodiversity Network lists are not complete but also that *P. fascialis* is not recorded in the area covered by boats operating from Looe, Plymouth and Salcombe despite the outcrops of hard substrate that suggests its distribution may be restricted by the activity of fishing.

The alterations of Δ^+ values for the removal of the molluscs (category 7) and crustaceans (category 8) are particularly influential since all the crustaceans were within the order Decapoda level, while the molluscs were from three classes and ten orders. The preferred habitat, feeding and behavioural ecology of decapod crustaceans is extremely complex (Ingle, 1996, p20-28) and while it is difficult to know why this group, as a whole, was under represented in the Salcombe samples, despite the Salcombe sample generally being the most species rich they retained the fewest (6) decapod species. It is suggested that the reason may be due to the dominance of the edible *Cancer pagurus* filling the niches that might otherwise be occupied by other species. According to port and type of trawling the others were N S = 10; L S = 9; L P = 9; P S = 9; P P = 24.

That the largest fall in any of the non-fish Δ^+ values was due to the removal of the echinoderms from Newlyn, which shows the importance of this group to this area. This was also reflected in the variability (± 6.80). Removal of the Echinoderms for other ports and types of trawling were as important in terms of reducing the Δ^+ value as the removal of category 6; phylum Cnidaria. The removal of the phylum Mollusca for the non-Newlyn

samples was more important in taxonomic distinctness terms reducing the Δ^+ values by 3.13.

Warwick & Clarke, (1993) suggest that the relative numbers of species in the four major taxa of marine macrobenthos generally following the sequence polychaetes > molluscs > crustaceans > echinoderms. After pollution or disturbance, they are reduced in the reverse sequence: echinoderms > crustaceans > molluscs > polychaetes. Figure 6.11 showed how the action of these removals in isolation would affect the taxonomic diversity (according to Δ^+). Figure 6.12 shows the effect of these removals in sequence.

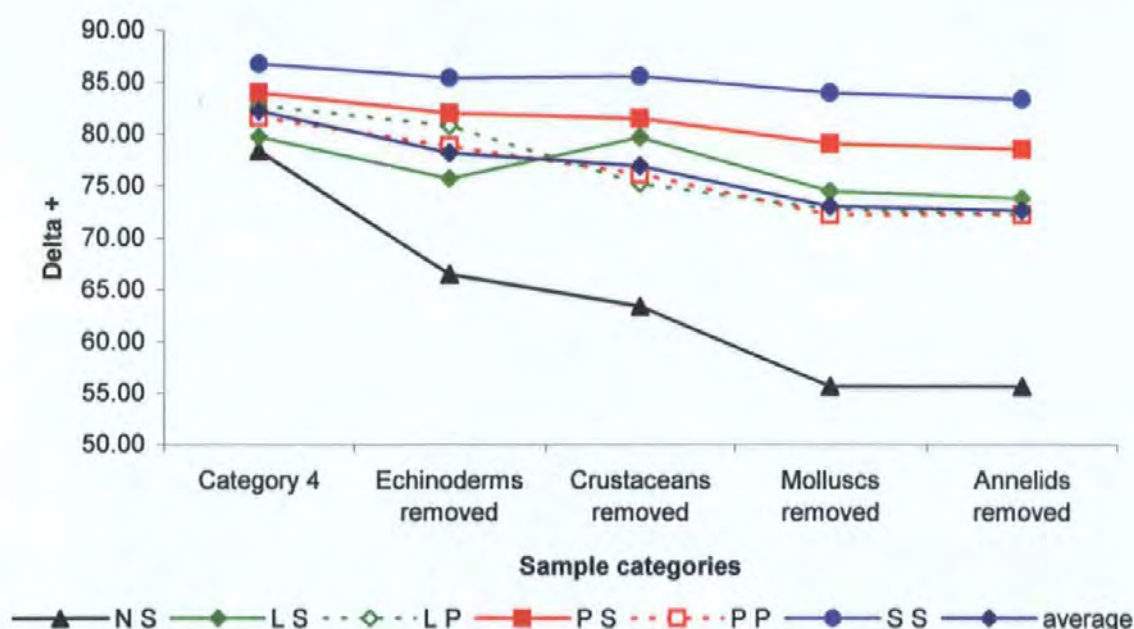


Figure 6.12. Effect of sequential removal of Echinoderms, Crustaceans, Molluscs and Annelids on average taxonomic distinctness (Δ^+) of category 4, (benchmark non-fishes).

It is clear from Figure 6.12 that the removal of selected phyla would be most significant for the location of the Newlyn samples. Therefore it would appear that although possessing relatively low levels of overall biodiversity (according to Δ^+) the locations of sample collection might be suitable for monitoring the occurrence of echinoderm species (particularly) as this group was both relatively species-rich and important for maintaining biodiversity.

Expanding the assessment of Δ^+ to include the non-fish species contained in the sample is a novel approach and it highlights the importance of maintaining species-rich aggregations in terms of conserving biodiversity and the fate in terms of distinctiveness if taxonomic groups are lost. It also highlights the validity of sampling the non-fish material in that it contributes to a much greater range of taxonomic distinctiveness than present in just the fish species alone. This points towards assessing fishing grounds according to a much wider biodiversity perspective than can be gathered either from the analysis of landed fish, caught fish or the intermediate compromise offered by examining stomach contents, although it would be highly beneficial to complement the methods employed here with a suitable fishery independent (or complementary) investigations. While useful here Somerfield *et al.*, (2006) concluded that analysis at the phylum level was rather too coarse to be useful in detecting differences between sites of dredging and disposal around the UK. It is expected that an even clearer and more useful picture can be gathered by examining these data at a finer resolution or by functional groups.

Analysis of this type also has a perceived role in determining taxonomic or functional compartments of quality assessment of environmental status (GEnS) as described by the indices of Laffoley *et al.*, (2006), and the analysis presented in Figure 6.12 is a first step.

Regardless of the taxonomic groups included in samples it is recommended that the broadest range of classification is used in order that the generated biodiversity measures can be comparable between studies. In this study 15 of the total 24 taxonomic levels, catalogued by Picton & Howson, (1999) were used. Five of those not used (numbers 7, 8a, 15, 17 and 18a) are extremely infrequently employed, being reserved for the crustaceans. Where classification is carried through to species levels is it necessary also to make into a species those coarser levels where classification stopped. It is also necessary to fill in the gaps between those taxonomic levels used for a particular species or group, and it is

recommended that this filling process also occurs in the same direction of only increasing taxonomic level.

Chapter 7

7 The relationship between the samples and abiotic data

7.1 Introduction

In keeping with the thoughts of Clarke & Ainsworth, (1993) the derived, abiotic information (see Chapter 4), and biotic or sample data have been analysed separately (see Chapter 5 and Chapter 6). This was both for the whole dataset and by spatial and temporal groups and according to fish and non-fish components of the sample and it is apparent that there was some commonality in the patterns derived. The advantage of examining these separately is that avoids the circularity of deciding whether the abiotic factors are responsible for the biota or *vice versa*.

Many previous studies have established that there is a strong relationship between sediments and fish and non-fish fauna (Gray, 1974; Basford *et al.*, 1990; Snelgrove & Butman, 1994; Taylor, 1998; Rees *et al.*, 1999) and it is important to establish whether the abiotic factors are useful predictors of the biotic distributions. This Chapter compares those derived distributions to determine which factors might drive patterns in the sample assemblages.

Chapter 8 takes the relationship between the environmental and biotic data further examining individual species for their degree of expected association with particular individual or groups of substrates and together these Chapters (with the initial description

of the abiotic data in Chapter 4) address the Environment Theme of Aim 2 (see Figure 1.4, page 17, above).

7.2 Methods

At its simplest relating the biotic and abiotic data involves a procedure whereby two similarity or dissimilarity matrices are compared by computing a correlation coefficient between the two matrices, (Mantel, 1967, cited in Clarke & Warwick, 2001a). This procedure (e.g. *RELATE* in PRIMER-E Clarke & Warwick, 2001a) and Matrix comparison in NTSYS-pc (Rohlf, 1988) can compare any two similarity based matrices, only requiring that the cells within the matrices have the same labels. A more informative approach is to compare a suitably transformed biotic similarity matrix with an iterative selection of abiotic factors, to see which individual or combination of factors best explains the observed biological data. PRIMER-E (Clarke & Warwick, 2001a) offers the *BIO-ENV* and *BVSTEP* routines, which are essentially similar analyses, only differing in that *BVSTEP* circumvents the exponential escalation in the number of abiotic variables and as such reduces the computation time where there are many abiotic factors.

7.2.1 Abiotic data sets

Prior to running the analysis the full suite of abiotic factors was reduced to those which were truly features of the environment. The redundancy analysis described in Chapter 4 demonstrated that minimum and maximum maximum tidal strength could be removed as the influence of these factors were adequately explained by including the average maximum tidal strength only.

Also, the preliminary analysis in section 4.3.1.4 showed that whether the hauls were collected during the day, the night or the twilight was not a good descriptor of the sample, (see Table 4.7, page 89, above), therefore the D/N/T factor was not included in this analysis.

The following factors were included:

- Characteristics of water: av.m.t.s., (average maximum tidal strength); r.m.t.s., (range of maximum tidal strength), (see Table 4.2, page 84, above); depth (see Figure 4.8, page 95, above);
- Characteristics of the substrate: S, (sand); mS, (muddy sand); (g)S, (slightly gravely sand); gmS, (gravely muddy sand); gS, (gravely sand); G, (gravel); msG, (muddy sandy gravel); sG, (sandy gravel) and R, (rock), (see Figure 4.4, page 79, and Table 4.1, page 80, above).

Therefore, the source matrix was the same 88 sites and 12 factors generated in section 4.3.3. In generating the similarity matrix, the abiotic factors were standardised to allow for the different units of measure and the derived similarity matrix was based on non-transformed, normalised Euclidian distances. Chapter 4 describes the potential bias when so many of the abiotic data sets are presence/absence in nature. It was decided to maintain the same analysis method for the abiotic data so that the comparability of the analysis here with that in Chapter 4 was evident.

7.2.2 Biotic data sets

As described in Chapter 5 the similarity matrix for the biotic data was generated from the full 88 site (sample) and 190 species (group) matrix of biomass according to each species in each sample by non-standardised, double square root transformation using the Bray-Curtis measure (see Appendix G, starting on page 369, below). Divisions of the sample according to the fish or non-fish species were in keeping with Table 3.4, (page 54, above).

7.2.3 Analysis

The first analysis examined the overall correlation between the similarity matrices for the full abiotic and biotic data sets using *RELATE* in PRIMER-E (Clarke & Warwick, 2001a). Next the *BIO-ENV* analysis was performed. When presenting these and subsequent results the best single factor was reported and then the best combinations (as two, then three etc) of factors which improved the fit to a maximum. Following this further best combinations were generated until the quality of the fit decayed back to the level of the initial single factor.

The full sample was then divided into the fish and non-fish species (Table 3.4) to determine how well patterns with each were predicted by the abiotic factors, as above.

The global *R*-values of the full species, fish only and non-fish ANOSIMs in section 5.3.1.1 decreased in the order described and this was the case whether only by port or also included type of trawling (see Table 5.17, page 147, above). Several reasons for this trend were described in Chapter 5 although a major cause was the low abundance of many species. In sample datasets where the size frequency distribution is strongly right skewed Field *et al.*, (1982) and Clarke & Warwick, (2001a) advise the selection of the most dominant species to remove some of the apparent noise in the data and generate more robust *BIO-ENV* outcomes. In this analysis, four subsets of data were chosen:

- The 60 species that possessed the greatest abundance. Across all the samples this represented $\approx 30\%$ of all the species (Table 3.4, page 54, above) and according to port (inferable from Table 3.5, page 56) this represented all but the tail of the very least abundant species).
- Those species that separately contributed at least 5, 10 and 20 % of the total abundance by weight.

Previous analysis in section 5.2.1 (see Figure 5.3, page 116, above) showed that the characteristics of the samples from Newlyn were qualitatively different from the other ports, and this was apparent, but less clearly so for the abiotic factors (Figure 4.6, page 90, above). It was therefore important to determine if a similar situation was evident in the relationship between the biotic data and abiotic factors. This was achieved by generating a *BIO-ENV* for the Newlyn samples and another for the combined Looe, Plymouth and Salcombe ones and comparing the resulting correlation coefficients. Before examining only the Newlyn samples substrates of mS and gmS were removed as these were not present in these samples, and in order to run the comparative analysis on the Looe, Plymouth and Salcombe samples the categories of msG and G had to be removed.

7.3 Results

7.3.1 Full samples – all factors

The comparison of similarity matrices for the biotic and abiotic matrix comparison by *RELATE* generated a relatively poor Spearman's rank-order correlation of $r_s = 0.215$. Overall, for the full sample and the full suite of abiotic factors the best single abiotic descriptor was the presence of sand as shown in Table 7.1.

Table 7.1. *BIO-ENV* output as ρ (correlation coefficient) for the best single factor to the best (highlighted) multiple combination, then declining back down to the level provided by the best single factor for the full sample. The factors are described on page 209, above.

| # | ρ | factors | | | | | | | | | |
|---|--------|-----------|----------|-----|------|-----|-----|-----|-----|----|--|
| 1 | 0.327 | S | | | | | | | | | |
| 2 | 0.397 | av.m.t.s. | S | | | | | | | | |
| 3 | 0.406 | av.m.t.s. | S | msG | | | | | | | |
| 4 | 0.402 | av.m.t.s. | S | msG | sG | | | | | | |
| 5 | 0.395 | av.m.t.s. | r.m.t.s. | S | msG | sG | | | | | |
| 6 | 0.385 | av.m.t.s. | r.m.t.s. | S | gS | msG | sG | | | | |
| 7 | 0.372 | av.m.t.s. | r.m.t.s. | S | gmS | gS | msG | sG | | | |
| 8 | 0.347 | av.m.t.s. | r.m.t.s. | S | (g)S | gmS | gS | msG | sG | | |
| 9 | 0.323 | av.m.t.s. | r.m.t.s. | S | (g)S | gmS | gS | G | msG | sG | |

Table 7.1 shows that the combination of abiotic factors which best predicted biotic similarity was sand, muddy sandy gravel and the average maximum tidal strength. The decay of the correlation coefficients generally was because of the increase in noise due to the addition of extra substrates. As shown in Figure 4.6, (page 90, above) sand was the principal component of axis 1 and divided the samples according to Newlyn and the other ports (Figure 4.7(a)). The ANOSIM in Table 5.2 (page 117, above) which showed the split of the biotic data also showed the separation into the Newlyn and other ports so the outcome in Table 7.1 was not surprising. Depth did not figure in any of the top combinations, (its first inclusion was with ten factors). Table 7.1 also shows that the *BIO-ENV* yielded a better result than correlating the similarity matrices. Nevertheless, the *BIO-ENV* output as described in Table 7.1 was rather crude in that it attempted to produce an overall picture across different components of the sample, and different geographic areas. This is borne out in the inclusion of muddy sandy gravel which Figure 4.7(h) shows was only present in one Newlyn sample though this substrate was situated at the extreme end of the 'arch' and therefore may have had an undue influence on the selection in the *BIO-ENV*. A breakdown of the full analysis is given in the following sections.

7.3.2 Fish component

The comparison of similarity matrices for the fish only component and all the abiotic factors generated a Spearman's rank-order correlation of $r_s = 0.253$, which was marginally higher than generated for the full sample. Table 7.2 shows the *BIO-ENV* for fish-only component.

Table 7.2. *BIO-ENV* output as ρ (correlation coefficient) for the best single factor to the best (highlighted) multiple combination, then declining back down to the level provided by the best single factor for the fish only part of the sample. The factors are described on page 209, above.

| # | ρ | factors | | | | | | | | | |
|---|--------|-----------|----------|-----|-----|------|-----|-----|-----|----|--|
| 1 | 0.324 | S | | | | | | | | | |
| 2 | 0.405 | av.m.t.s. | S | | | | | | | | |
| 3 | 0.422 | av.m.t.s. | S | msG | | | | | | | |
| 4 | 0.420 | av.m.t.s. | S | msG | sG | | | | | | |
| 5 | 0.419 | av.m.t.s. | r.m.t.s. | S | msG | sG | | | | | |
| 6 | 0.402 | av.m.t.s. | r.m.t.s. | S | gmS | msG | sG | | | | |
| 7 | 0.385 | av.m.t.s. | r.m.t.s. | S | gmS | gS | msG | sG | | | |
| 8 | 0.367 | av.m.t.s. | r.m.t.s. | S | mS | gmS | gS | msG | sG | | |
| 9 | 0.345 | av.m.t.s. | r.m.t.s. | S | mS | (g)S | gmS | gS | msG | sG | |

Again sand was the best single factor in Table 7.2 and the best overall explanation ($\rho = 0.422$) was the combined three factors of average maximum tidal strength, sand and muddy sandy gravel. The best, combined correlation coefficient for fish only was slightly better than for the full sample suggesting that removing non-fish material removed complexity. Table 5.8, (page 124, above) showed a very strong similarity between the fishes and the full sample to the pattern in Table 7.2 and Table 7.1 was as expected.

7.3.3 Non-fish component

The comparison of similarity matrices for the non-fish biotic part of the sample and all the abiotic factors generated a very low and negative Spearman's rank-order correlation of $r_s = -0.042$. Table 7.3 shows the results of the *BIO-ENV* for the non-fish material.

Table 7.3. *BIO-ENV* output as ρ (correlation coefficient) for the best single factor to the best (highlighted) multiple combination, then declining back down to the level provided by the best single factor for the non-fish part of the sample. The factors are described on page 209, above.

| # | ρ | factors | | | | | | | |
|---|--------|-----------|----------|------|------|----|----|--|--|
| 1 | 0.184 | S | | | | | | | |
| 2 | 0.227 | S | gS | | | | | | |
| 3 | 0.221 | S | gS | sG | | | | | |
| 4 | 0.217 | av.m.t.s. | S | gS | sG | | | | |
| 5 | 0.206 | av.m.t.s. | S | (g)S | gS | sG | | | |
| 6 | 0.188 | av.m.t.s. | r.m.t.s. | S | (g)S | gS | sG | | |

Sand was again the best single abiotic factor, though the correlation was not as good as in either of the previous two analyses. The best, combined set was for the two factors of sand and gravely sand. Despite the correlation coefficient being low, these substrates were the two most important in the first axis of the PCA (see Figure 4.7(a) and (b)). The low correlation may be because, while sand was a good descriptor for the sample sites between Newlyn and the other ports, in this analysis the factors associated with the tidal velocity were not so important. This at first may appear rather surprising since it might be expected that the tide would have had an important impact on the non-fishes, as they were more benthic in habit than many of the fish species. The influence of the tide diminishes with depth however, and here the substrates (sand and gravely sand) were more important for describing the non-fishes. This strengthens the case that the fishes were in fact more distinctly distributed with reference to particular abiotic factors (which will be further examined in Chapter 8) while the non-fishes were more ubiquitously distributed according to the substrate factors, which is supported by the very low correlation values. However, the portrayal of both tidal factors on Figure 4.7(j) and (k) were most important across the second axis so it is possible that the low correlation was due to these factors cancelling out.

7.3.4 Most dominant species and examination by port

The best single set of factors according to various parts of the sample and combinations of samples by ports is shown in Table 7.4.

Table 7.4. *BIO-ENV* output as the best ρ (correlation coefficient) and set of abiotic factors for various parts of the sample and groups of samples according to ports (full = all the samples; N = Newlyn; L-P-S = Looe and Plymouth and Salcombe; and individual ports). Factors are the best overall combination and are described on page 209, above.

| parts of sample | features | port | | | | | |
|-----------------|-------------------|---------------------------------|----------------------------|---------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|
| | | full | N | L-P-S | L | P | S |
| all | ρ factors | 0.406 av.m.t.s., S, msG | 0.334 msG, sG | 0.266 r.m.t.s., sG | 0.398 av.m.t.s. | 0.334 av.m.t.s., r.m.t.s., sG | 0.651 (g)S |
| fish | ρ factors | 0.422 av.m.t.s., S, msG | 0.373 msG, sG | 0.303 r.m.t.s., sG | 0.384 av.m.t.s. | 0.302 av.m.t.s., r.m.t.s., sG | 0.593 (g)S |
| non-fish | ρ factors | 0.227 S, gS | 0.152 av.m.t.s. | 0.068 r.m.t.s. | 0.207 r.m.t.s., sG | 0.251 depth, (g)S, gS | 0.243 av.m.t.s., r.m.t.s., sG |
| $n = 60$ | ρ factors | 0.395 r.m.t.s., S, msG | 0.342 msG, sG | 0.296 r.m.t.s., sG | 0.405 av.m.t.s. | 0.369 r.m.t.s., gS | 0.654 (g)S |
| $n = 5\%$ | ρ factors | 0.407 r.m.t.s., S, msG | 0.349 msG, sG | 0.306 r.m.t.s., sG | 0.423 av.m.t.s. | 0.334 av.m.t.s., r.m.t.s., sG | 0.702 av.m.t.s., r.m.t.s. |
| $n = 10\%$ | ρ factors | 0.411 av.m.t.s., S, msG | 0.387 S, msG, sG | 0.258 av.m.t.s., r.m.t.s. | 0.284 av.m.t.s. | 0.282 gS, sG | 0.755 av.m.t.s., r.m.t.s. |
| $n = 20\%$ | ρ factors | 0.390 r.m.t.s., S, gS, sG | 0.375 av.m.t.s., msG | 0.205 av.m.t.s., r.m.t.s. | 0.395 av.m.t.s., r.m.t.s., sG | 0.302 depth, gS, sG | 0.666 av.m.t.s., r.m.t.s. |

In selecting the top 60 species from across the full sample the best correlation was slightly lower than from across the full sample, which was surprising. The two substrate groups remained unchanged though the average maximum tidal strength was substituted for the range. Figure 4.7(j) and (k) (page 93, above) showed that these two factor were similarly distributed so the substitution was not surprising. Selecting only those species that contributed to 5 and 10 % of the biomass (36 and 26 species respectively) across the full sample improved the correlation and the substrate types remained the same. Expanding this to those (17) species which contributed 20 % of the biomass probably was too coarse. Nevertheless the substrates of sand, gravely sand and sandy gravel had the largest eigenvectors overall.

Examining only the Newlyn samples showed a similar pattern to that for the full sample overall in respect of the correlation coefficients in Table 7.4. Again, the fishes dominated the full sample and there was a switch between modified gravels for the full sample and fishes and average maximum tidal strength for the non-fishes.

Across the other ports Looe, Plymouth and Salcombe combined the pattern in the correlation coefficient was similar to the Newlyn and full samples though selecting only those species which contributed 5 % of biomass best described the combined pattern in the *BIO-ENV*. This was most likely due to the variability and species richness in these samples in that fewer species dominated the samples to the same extent. There were 31, 21 and 11 species, which comprised 5, 10 and 20 % respectively of the biomass. The greater spatial extent of all these samples was perhaps responsible the correlation coefficients being lower overall and for tidal factors being important, especially as species number decreased. While sand was important as a separator into the Newlyn and non-Newlyn samples its relative ubiquity in the non-Newlyn samples means that it was not useful for examining within this group, similarly depth was not important since depth was relatively constant in these samples. Sandy gravel was the most important substrate and this reflected the inshore/offshore split of these samples so while there may have been other con-specific factors the split was manifest in this substrate.

Individually Looe and Plymouth have higher correlation coefficients than they did when combined with Salcombe. Average maximum tidal strength was most important for Looe. This was probably due to the Looe samples being placed along the second PCA axis on Figure 4.6 and Figure 4.7. While slightly sandy gravel and sandy gravel were largely responsible for this axis (s)G was quite common in the Looe samples (Table 4.1, page 80, above) therefore sG was a more important discriminating factor. The Plymouth correlation coefficients were similar in pattern to those from Looe. Again, tidal influences were important as the Plymouth samples were also distributed along the second PCA axis on Figure 4.6 and Figure 4.7, though substrates were also important. In addition, these substrates were important Eigenvectors on the second PCA axis. Depth was important for the non-fishes and those species that contributed to 20 % of the biomass.

The Salcombe samples had the highest correlation coefficient from any of the analyses in as shown in Table 7.4. The Salcombe samples were in the lower part of Figure

4.6, therefore any abiotic factor that was well divided along second PCA axis would be important. This explains why slightly gravely sand was important. Figure 4.5 (page 82, above) shows that the Salcombe samples were in a region of high tidal strength and as the sample size was reduced the tide has been a greater influence.

7.4 Discussion

Many of the BIO-ENV correlations were low though were within the range produced from other studies, (Giberto *et al.*, 2004, Table 6; Hernández Arana *et al.*, 2005, Table 7; Lu, 2005, Table 3). In addition, this method is far superior to manually selecting factors, generating similarity matrices and testing their degree of relatedness.

Overall, it would appear that where the samples were taken from a small geographical area substrates are more important than tide as variables that correlate more closely with biotic data, and *vice-versa*. The exception to this was around Salcombe, which was the most heterogeneous. Depth plays a rather surprisingly small part in describing any of the variation, possibly due to the generally similar depths over which the samples were taken, (see Figure 4.8, page 95, above).

It is possible that for the purposes of examining the combined influences of the contents of the sample and its principle environmental correlations, the division of the sample into the two (fish or non-fish) categories is rather arbitrary. Instead, examining the influence of the most dominant species (regardless of their classification) was particularly useful. Where $n = 60$ are retained the correlations were similarly as good as the full sample suggesting that this reduction is a reasonable way of better resolving the overall pattern. Restricting the retained number of species still further to species which each contribute at least 5% of the biomass of the sample, ($n \approx 40$, but varies on a case-by-case basis) further improved the correlation coefficient and the most important factors were

generally the same. Where the cut-off is raised to those species contributing at least 10% of the biomass of the sample ($n \approx 25$, but again varies on a case by case basis) the fit was generally better still; higher than the case for the full sample but not better than for the fish only part of the sample. Finally where only the species which contribute at least 20% of the sample are retained ($n \approx 15$, but again varies on a case-by-case basis) the fit between the abiotic and biotic factors is generally worse than where $n = 60$, and the best abiotic factors are similar to those for the sub-sample where $n = 5\%$.

Above it was suggested that the division of the sample data into the fish and non-fish part of the sample might not be very valuable in terms of describing the relationship between the abiotic and biotic factors. This is reinforced by the fact that the fish (generally) made up such an overwhelmingly large component of the sample, (on average 95% by weight). However when comparing the *BIO-ENV* correlation coefficients for the fish and non-fish parts of the sample with the full sample and the most important 60 species it is evident that the fish species were more closely tied to particular substrates (or groups of substrates and tidal regime thereof) than the non-fish part of the sample. Therefore, the non-fish part of the sample seems to have a greater general distribution, or alternatively a distribution that is not as constrained by abiotic factor as monitored here. The reason for this is that many of the commonly occurring invertebrate species which contribute to much of the non-fish species were found across many samples. This is likely to be due to the extensive nature of the fishing footprint in the area and from a biological point of view the generalist, predominately scavenging, lifestyle adopted by many of the most commonly sampled and thus abundant (epifaunal) species. In order to examine this further it is proposed to analyse these data by functional groups of invertebrates, though the work developed in Chapter 8 (when this is expanded to describe the invertebrates) may shed light on the lack of strong relationships in this *BIO-ENV*, (as there, the substrates are classified different according to the full, fish and non-fish parts of the sample for one analysis).

The substrate type of rock was shown to be not well described within the PCA plots, Figure 4.6 and Figure 4.7 (above) though it was the most important factor in the third axis of the PCA. Rock did not feature as important in the *BIO-ENV* either. Many of the *BIO-ENV* outcomes were strongly influenced by the same patterns that were evident in the PCA (due to the standardisation and normalisation of the data) though it was also apparent how the biotic data was important. Neither in this analysis nor that in Chapter 4 was the factors of the substrate and variables of the tide and depth weighted as to their 'real' influence as this is not known. The significance of rock in determining the relationship between fishes and the substrate is one small part of Chapter 8.

Chapter 8

8 Relating the fish species and the substrate

8.1 Introduction

The previous Chapter examined the relationship between the biotic (fish and non-fish) and abiotic (environment and substrate) data and while it showed which of the environmental data were best correlated with which components of the abundance data this analysis was limited to examining the relationship for ports, major compositional parts of the sample or the most dominant species present. This Chapter takes the Theme 2 analysis further by examining the relationship between particular species and substrates.

The last decade has seen the emergence of and attempts to comply with the Essential Fish Habitat (EFH, Benaka, 1999) provisions of the Sustainable Fisheries Act in the United States (Baird, 1999); a process which will probably further develop in the UK with the progress towards a Marine Bill (DEFRA, 2006). In attempting to define EFH it is necessary to understand first the association between fishes and their habitat. Here the aim is to establish whether the occurrence of particular fish species is consistent with where the literature suggests that they are found in terms of the substrate over which they were trawled and to augment this knowledge where possible. This analysis deals with the association amongst adult specimens. It does not include species' spawning activities and

early development, which while a relatively small proportion of fishes life histories (Cushing, 1975) are nevertheless important in determining entire EFHs.

The analysis is also limited to the fishes because their literature sources are both more mature and comprehensive. FishBase (Froese & Pauly, 2003) and Wheeler, (1978) were consulted for relevant information and the latter was generally more comprehensive. In keeping with the instructions of Froese & Pauly, (2003): "...data taken from FishBase [are] cited by main or data reference of the respective record to give due credit to the original authors."

This Chapter also prepares the ways to begin describing the relationship between non-fish species and the substrates with which they are associated as part of the *post hoc* (Class 3) analysis (see Figure 8.3, page 235, below). The analysis for these relationships is not included in this study because despite much work examining the presence of local species, perhaps best represented by MBA, (1957) its current form (MarLIN) only includes detailed substrate information for 110 species (Tyler-Walters *pers com.*).

Studies have identified the relationship between species and the substrate, particularly with the flatfishes (Gibson & Robb, 1992; Rogers, 1992, and see Pleuronectiformes references between pages 254 and 256, below). Habitat complexity (which is a function of surface topography and sessile epifauna that grows on it, (Kaiser *et al.*, 1999) seems more important however, in the survival of round fishes (Gotceitas *et al.*, 1995; Borg *et al.*, 1997; Thrush *et al.*, 2002). Thus, the advantage of extending the analysis to include the non-fish species will enable this relationship to be better understood.

The encountered fish species (see Table 3.3, page 51, above) exist on a continuum between those with a strong attraction for a particular substrate or group of substrate types and at the other extreme those species without, or possessing only a very superficial affinity for the sea floor in general or specific substrate types in particular. FishBase (Froese & Pauly, 2003) and Wheeler, (1978) suggest some fishes are understood to have an intelligible and logical relationship with one or more types of substrate. At the high-

affinity end of the continuum are species whose occurrence would be expected over particular substrate types and which would not be expected to occur if this substrate or substrates were not co-occurring with the passage of the fishing gear. Obviously this depends on the type, rigging and deployment of the gear, though for the range of otter or pair-trawls sampled here, high affinity species include the small eyed ray *Raja microocellata* "...particularly common on sandy grounds," (Wheeler, 1978) and the lesser sand eel *Ammodytes tobianus* as "...always found close to clean, rather fine sand..." There are also many species that might be described as strongly benthic but found over a range of substrate types. These include cod (*Gadus morhua*) which Wheeler, (1978) described as "...widely distributed in a variety of habitats..." In the middle of the continuum are those species with a passing preference to a particular substrate or ranges of substrates since features in their behavioural or feeding ecology might predispose them to be present over some substrate or groups of substrates. Into this category fall the great majority of the typically benthic fishes. Reference to the collective sources of FishBase, (Froese & Pauly, 2003) and Wheeler, (1978) revealed statements such as: "...both in mid-water...and inhabits sandy as well as muddy bottoms," for whiting, *Merlangius merlangus*. "It occurs close to the bottom and in mid-water," for poor cod *Trisopterus minutus*, and "pelagic to benthopelagic, mostly close to shore over hard bottoms," pollack *Pollachius pollachius* respectively from Cohen *et al.*, (1990), and obviously only the benthic portion of these species ranges' can be examined here. Finally, those species with the lowest benthic affinity are generally pelagic and this includes species such as mackerel *Scomber scombrus*, and herring *Clupea harengus*.

There is general agreement between the collective references contained in FishBase, (Froese & Pauly, 2003) and Wheeler, (1978) though there are conflicts, for example John Dory *Zeus faber* was described by Kailola *et al.*, (1993) "...found in areas close to the sea bed," while Wheeler, (1978) described this species as "...inshore...though exceptionally...reported close to the surface."

Species abundance in samples acts to modify this continuum of expected presence or absence of fishes' affinity with substrate presence or absence. At one extreme are species such as the red gurnard *Aspitrigla cuculus* and the lemon sole *Microstomus kitt*, which were nearly ubiquitously caught. Any expected association with a particular substrate or groups of substrates is likely to be masked by these species' capture over most of the substrate types. However the former species is described as being "...found on a variety of different sea-beds, usually on sand, or sand and gravel, but also on mud and even rocks," and the latter as "...liv[ing] on a wide range of bottoms from mud (exceptionally), and sand, gravel, even rocky grounds..." (both from Wheeler, 1978) and as these are frequently occurring substrates, this may account for their commonness. At the opposite extreme are fishes that were rarely encountered, such as the hooknose *Agonus cataphractus* or bass *Dicentrarchus labrax*. These species may have been truly rare or under represented in trawling gear because of their small size, or there may be other features of trawling which might significantly under represent them in the haul. These factors include those associated with species which might be more pelagic in nature, or which are able to extend their range into brackish water.

Given that a continuum exists in the affinity of species to the substrate, and that this continuum may be modified by a species' expected abundance, a sequential two-part question was therefore proposed in undertaking this analysis.

1. Are there patterns in the distribution of species, which are associated with the patterns in the substrate?
2. If so, where these occur are they in keeping with the expectation presented from the literature?

8.2 Methods

The first part of the analysis was to identify whether an association should be expected between the presence/absence pattern of the species across the substrates. Next to identify whether this state was observed in the presence/absence pattern of the species across the substrates.

In order to undertake these analyses four areas require explanation. These are:

1. The way the substrates were classified (section 8.2.1)
2. The format for the species data (section 8.2.2).
3. The analysis method (section 8.2.3) for the substrate and species data. For the fish species there was also a validity test for species presence and a scoring system for the outcomes (section 8.2.3.2).
4. Definitions of Classes of analyses and amalgamation of fully unique substrate groups (section 8.2.4).

8.2.1 Substrate data

As explained in Chapter 4 the substrate information, which related to the trawl track was obtained by analysing the plotted path of the gear on a chart of substrate types from the British Geological Survey, (shown illustratively on Figure 4.4, page 79, above) and recording each as presence/absence. A trawl may have passed over only one or may have integrated catch from several substrate types. For example haul 55 (a pair trawled sample from Looe) passed over the single substrate type of slightly gravely sand, whereas hauls 51 and 52 (both from Salcombe) passed over slightly gravely sand, gravely muddy sand and gravely sand.

In order that the species composition of each haul can be assessed in relation to the substrate type or types passed over, the 88 tows were classified into groups, each containing a number of samples categorised by the same substrate type or types. These

groups form the basis of the analysis though subsequent groupings of these individual hauls can later be defined according to various requirements of the data and the analysis. The 88 hauls were initially classified into 27 'unique substrate groups' according to those types passed over. These are shown in Table 8.1.

Table 8.1. List of 'unique substrate groups' (based on BGS classification) showing which sediment types comprise each substrate group, their major (unqualified) substrate types, the sample numbers associated with each group and their origin in terms of port and type of trawling. See page 232 and 234 (below) for further details and description of yellow and grey highlighted groups.

| 'unique substrate group' # | substrates | major substrate type | sample number(s) | port and type of trawling |
|----------------------------|----------------|----------------------|---|-----------------------------------|
| 1 | (g)S | S | 55 | L P |
| 2 | (g)S.gmS.gS | S | 51, 52 | S S |
| 3 | (g)S.gS | S | 11, 12, 16, 22, 23, 39, 78 | N S |
| 4 | (g)S.G.sG.R | SGR | 44 | N S |
| 5 | (g)S.gS.G.sG | SG | 37 | N S |
| 6 | (g)S.gS.G.sG.R | SGR | 30 | N S |
| 7 | (g)S.gS.sG | SG | 18, 25, 26, 27, 28, 42, 63 | N S |
| 8 | (g)S.gS.sG.R | SGR | 57 | N S |
| 9 | gS | S | 77, 84 | S S |
| 10 | gS.G.sG | SG | 3, 6, 7, 8, 9, 19, 38, 58, 59, 60, 62, 66 | N S |
| 11 | gS.G.sG.R | SGR | 40, 41, 64 | N S |
| 12 | gS.msG.sG | SG | 24 | N S |
| 13 | gS.sG | SG | 4, 5, 10, 20, 21, 29, 43, 61, 65 | N S |
| 14 | mS.gS.sG | SG | 34, 47, 48 | P P |
| 15 | mS.gS.sG.R | SGR | 33 | P P |
| 16 | S | S | 67, 73, 74, 87, 88 | P P |
| 17 | S.(g)S | S | 13, 14, 32, 49, 50, 53, 54, 68, 72, 80 | 3xL S, 4xL P, 1xP S, 1xP P, 1xS S |
| 18 | S.(g)S.gS | S | 15, 17, 71, 79, 81, 86 | 2xL S, 1P S, 3xS S |
| 19 | S.(g)S.gS.R | SR | 85 | S S |
| 20 | S.(g)S.R | SR | 56 | N S |
| 21 | S.(g)S.sG.R | SGR | 31, 35 | L S |
| 22 | S.gS | S | 1 | L S |
| 23 | S.gS.sG | SG | 2, 45, 46, 75 | 1xL S, 1xL P, 2xP S |
| 24 | S.mS.gS.sG | SG | 70 | P S |
| 25 | S.mS.gS.sG.R | SGR | 69 | P S |
| 26 | S.sG | SG | 76, 82, 83 | L P |
| 27 | S.sG.R | SGR | 36 | L S |

The 27 'unique substrate groups' in Table 8.1 form the basis for assessing whether the presence or absence of a particular species is significantly related to the presence or

absence of a particular substrate. It can be seen that some of these were exclusive to different ports and types of trawling.

8.2.2 Species data

Species abundance was recorded as counts and weight derived from the length of each specimen. Weight of species in each haul has an inherent bias since it does not take into account the size of the organism. Thus, ten specimens of small fish might have a similar weight to one specimen of a generally large species. This bias would be removed if the analysis was based around the alternative measure of counts. This measure was acceptable for the fish species but introduces other bias when applied to the non-fish species due to the recording of colonial species, but more importantly where damaged or incomplete organisms were found. In order to apply the data to all groups avoiding these sources of bias the analysis was undertaken as the presence/absence of species against the presence/absence of substrate types.

8.2.3 Analysis of species and substrate data

This analysis compared the frequency distribution of presence/absence for each species and the frequency distribution of presence/absence of same substrate groups of which there were twenty seven at most (Table 8.1). The test of choice was the one-tailed Chi-Squared test of independence (Dytham, 1999, p61) as the analysis compared the expected and observed frequencies of species in different substrates and the hypothesis was that there was no significant difference in the presence of a species in samples based on the grouping of these samples by their substrate composition. Table 8.2 shows a simplified arrangement of the contingency table created for cod.

Table 8.2. Example Chi-squared test of independence for cod (*Gadus morhua*), based on only four substrate groups (for clarity). The highlighted box is discussed with reference to Table 8.3, (page 233, below).

| | | | | | | |
|-----------------|---------------------|---------|------|-----|-------|-------------|
| species | <i>Gadus morhua</i> | | | | | |
| observed | present | 12 | 33 | 1 | 9 | 55 |
| | absent | 22 | 8 | 1 | 2 | 33 |
| expected | present | 21.3 | 25.6 | 1.3 | 6.9 | 55 |
| | absent | 12.7 | 15.4 | 0.7 | 4.1 | 33 |
| sum of columns | | 34 | 41 | 2 | 11 | 88 |
| | | | | | | Sum of rows |
| substrate types | | S | S.G | S.R | S.G.R | |
| | Chi-squared number | 18.283 | | | | |
| | Degrees of freedom | 3 | | | | |
| | P value | < 0.001 | | | | |

Table 8.2 shows that of the 88 samples 34 were sand, S, 41 were sand and gravel, S.G, 2 were sand and rock, S.R, and 11 were sand and gravel and rock, S.G.R, thus samples were grouped according to their substrate. Cod was present in 55 samples and if there was no substrate preference, it should be present in proportion to the relative frequencies of substrates. Cod was present in many fewer sand only (S) samples (12) than expected (21.3) though more commonly than expected in sand and gravel (S.G) samples, (observed in 33; expected in 25.6). In addition, cod was more commonly found than expected in mixed sand and gravel and rock (S.G.R) than expected. These unbalanced frequencies are reflected in the Chi-squared test, $\chi^2 = 18.283$, d.f. = 3, $P < 0.001$ (Table 8.2), though it was only through examining the raw data that it was possible to comment on whether the expected association with particular substrate types were observed.

8.2.3.1 Procedure

The key to this analysis was the ways in which the substrates (Table 8.1) were classified into different amalgamation. There were 3 major Classes of these and 9 in total. These are described in section 8.2.4 (starting on page 230, below). All species (both fish and non-fish) were examined for their association with the substrates using the method described above for all the 9 substrate classifications.

The Results (section 8.3) presents these data as a summary of all species and the major components of the sample (fish and non-fish) (section 8.3.1, page 241). Also on a species-by-species basis for the fish species only (section 8.3.2, page 244).

For all the species the numbers and % of significant associations (separately where $P < 0.05 > 0.01 = *$; $P < 0.01 = **$) were calculated. The highly significant associations (where $P < 0.01$) were included given the deviation away from the ideal use of the Chi-squared test and numerous occasions where the number of expected frequencies were not ≥ 5 , therefore including these present a more stringent level of statistical significance.

The fish species (section 8.3.2) were examined in a more comprehensive manner by analysing the associations between each species and substrate presence/absence data for the same levels of significance and across the same 3 Classes (section 8.2.4):

- according to each species,
- according to the literature information, and,
- according to whether each relationship was considered valid.

8.2.3.2 The validity test for fish species presence and scoring system for outcomes

A qualifying criterion was required to assess the validity of the match between the species and substrate data. Figure 8.1 shows the frequency histogram of all the fish species based on the percentage of samples in which they were observed.

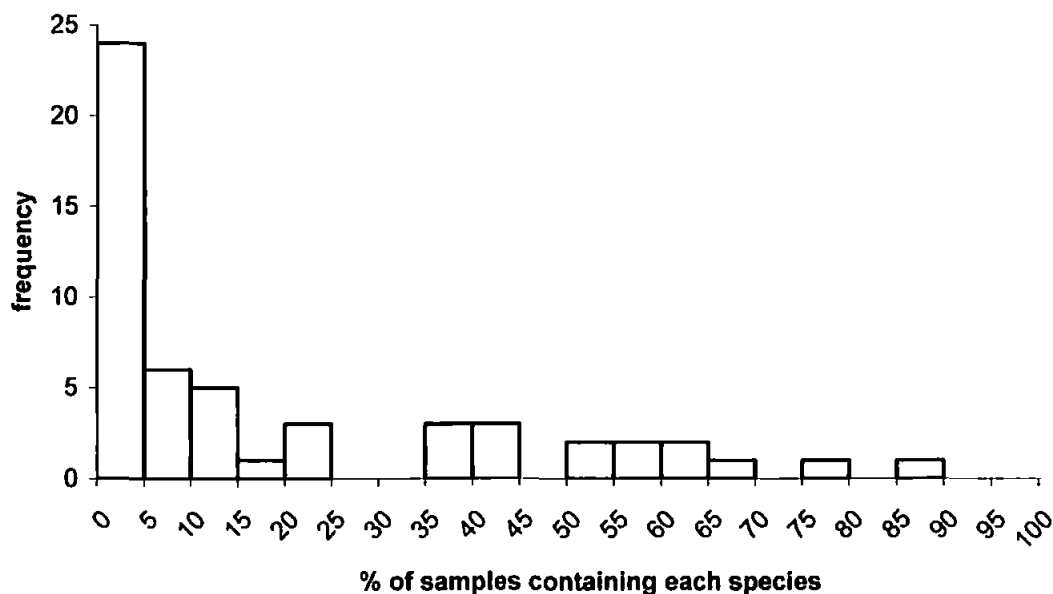


Figure 8.1. Frequency histogram of species ($n = 54$) based on the percentage of samples containing each species.

Figure 8.1 shows a typically right skewed frequency distribution. It was decided to analyse the relationship between the species and substrates for all species but treat those where the species were present in $\leq 10\%$ of samples with caution and consider these associations as not necessarily valid. There were 28 species of this type. The analysis of those species present in $> 10\%$ of samples ($n = 26$) was considered valid.

Figure 8.2 shows the scoring system for valid (with confidence) and non-valid (without confidence) decisions around whether association were expected and subsequently observed.

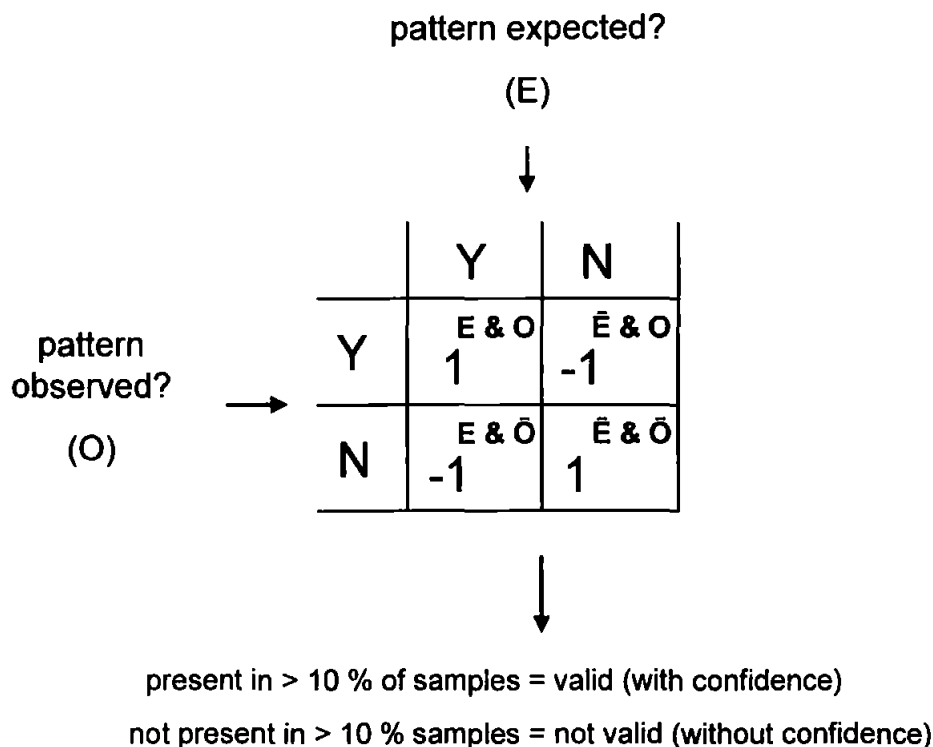


Figure 8.2. Scoring system based around expected and observed patterns of association with validity for the fish species.

The scoring system presented in Figure 8.2 shows that if an association was either expected and observed (E&O), or not expected and not observed (\bar{E} & \bar{O}) then this fish species scored a positive value. Conversely, if an association was expected but not observed (E& \bar{O}) or not expected but one was observed (\bar{E} &O) then this fish species scored a negative value. Figure 8.2 also shows this application of the validity threshold.

8.2.4 Classes of analyses and amalgamation of substrate groups

The question of how many categories of substrate to use for the analysis; that is whether to combine any or some of the 27 categories of Table 8.1 is complex. The number of categories has implications for the number of degrees of freedom for the Chi-squared test, its goodness of fit, (Burridge *pers com*) and the number of expected values in each category. Fowler & Cohen, (1996, p71) state that expected frequencies should > 5 and that

where this is not the case similar categories with low frequency of counts should be aggregated until the threshold of 5 is reached. Greenwood & Nikulin, (1996, p39) formalised this problem based on the equation of Sturges, (1926) given as:

$$r = [1 + \log n] = 1 + 2.303 \log_{10} n$$

where r = the chosen number of classes and n = the number of initial categories. This suggests the fully unique 27 groups should be amalgamated into ~5 categories. This seriously weakens the analysis since it means that around five of the unique groups must be amalgamated into each of those to satisfy this rule. Burrige (*pers com*) suggested that the number of categories appropriate for analysis was actually "...a problem which biologists worry about far more than statisticians [in that] the '5' rule errs on the side of caution – but it can be useful." Bearing this in mind, the approach taken was to carry out a suite of analyses with 'unique substrate groups' amalgamated into several different Classes according to different criteria. There were three large Classes of these, which are described below.

Class 1 – The full range

This analysis comprised the full twenty-seven fully unique groups. It was essentially an ideal situation though its interpretation was subjective as the number of expected frequencies was commonly < 5. This analysis however provided a useful 'baseline' measure against which to test the usefulness of all the other analysis methods.

Class 2 – Major substrate types

The second class of analyses were *a priori* in nature. Five of these were undertaken and in these a variety of amalgamations of the 'unique substrate groups', (Table 8.1, page 225, above) was performed. These were based on an assessment of which substrates should amalgamate well, based on their apparent similarity, as described below.

Class 2,a – Major substrate type part 1

In this analysis each of the 27 ‘unique substrate groups’ shown in Table 8.1 were classed according to their ‘major type’ and these are shown in column 2 of Table 8.1. The ‘unique groups’ were not evenly distributed into these ‘major types’: sand (8), sand and gravel (9), sand and rock (2), and sand and gravel and rock (8). Amalgamating the ‘unique groups’ into these ‘major substrate types’ produced few categories though these most closely relate to those broadly described by FishBase, (Froese & Pauly, 2003) and Wheeler, (1978).

Class 2,b – Major substrate type part 2

Due to the fact that there were only two sand and rock (S.R) major substrate types (groups 19 and 20 on Table 8.1) and that both of these were groups developed from only one sample each (number 85, from Salcombe and number 56 from Newlyn) it was decided that in the second ‘major type’ these were amalgamated with the sand and gravel and rock (S.G.R.) group. This created three major substrate types; S, 8; S.G, 9; S.G.R 10. This meant that there was a single major group holding all the samples containing rock, which might be important for habitat preference.

Class 2,c – Large categories alone

This group consists only the seven ‘unique groups’ highlighted in yellow on Table 8.1 which each contained five or more samples. Between them, they account for 56 or ~ 64 % of the all the samples and well represent the S, or S.G sites however do not at all represent those containing rock. As shown by the substrate PCA plots (Figure 4.7(i), page 93, above) rock was not well represented by the presence of other substrates.

Class 2,d – Large categories with other groupings, part 1

This comprised the seven groups which contain five or more samples (described for Class 2,c) with the addition of the remaining 32 samples amalgamated in ‘intermediate

categories' containing at least 5 samples so that similar substrate types were amalgamated together as far as possible. This was achieved by overlaying each 'unique groups' on copies of Folk's triangle (Folk, 1954, and Figure 4.1, page 71, above) and then classifying these so that each 'intermediate category' occupied similar regions of the whole triangle. Ensuring that each 'intermediate category' contained 5 samples did not ensure that the minimum number of expected frequencies for each new group exceeded 5, though it did produce a compromise between this and the number of categories. Five 'intermediate category' were produced as shown in Table 8.3 and for this analysis they were added to the 7 groups described for Class 2,c.

Table 8.3. Amalgamation (based on BGS classification) of 'unique substrate groups' (see Table 8.1) into their 'intermediate category' showing substrate composition, major substrate type, sample number and port and type of trawling.

| 'unique substrate group' # | 'intermediate category' | substrates | major substrate type | sample number(s) | port and type of trawling |
|----------------------------|-------------------------|--|--------------------------------|---|--|
| 1 2 9 22 | 8 | (g)S (g)S.gmS.gS gS S.gS | S S S S | 55 51, 52 77, 84 1 | L P S S S S L S |
| 4 5 6 8 11 | 9 | (g)S.G.sG.R (g)S.gS.G.sG (g)S.gS.G.sG.R (g)S.gS.sG.R gS.G.sG.R | SGR SG SGR SGR SGR | 44 37 30 57 40, 41, 64 | NS NS NS NS NS |
| 12 14 15 | 10 | gS.msG.sG mS.gS.sG mS.gS.sG.R | SG SG SGR | 24 34, 47, 48 33 | NS P P P P |
| 19 20 21 27 | 11 | S.(g)S.gS.R S.(g)S.R S.(g)S.sG.R S.sG.R | SR SR SGR SGR | 85 56 31, 35 36 | S S N S L S L S |
| 23 24 25 26 | 12 | S.gS.sG S.mS.gS.sG S.mS.gS.sG.R S.sG | SG SG SGR SG | 2, 45, 46, 75 70 69 76, 82, 83 | 1xL S, 1xL P, 2xP S P S P S L P |

The Chi-squared analysis for Class 2,d was undertaken on the seven groups (those groups highlighted in yellow on Table 8.1) plus the five 'intermediate categories' as shown on

Table 8.3, making 12 in total. Table 8.3 also shows how these categories were divided according to port and type of trawling.

Class 2,e – Large categories with other groupings, part 2

The aim here was to establish whether the presence or absence of rock was biologically relevant to the classification of substrates in their relation to the preference of fish species. The first 'intermediate category' (from column 2 in Table 8.3) comprised a set of samples that were from the same major substrate type of sand although the other categories were not similarly, equally comprised. While it appears sensible that the groups should be drawn from similar major substrate types it is difficult to establish exactly which samples should be amalgamated together to facilitate this. This analysis (Class 2,e) employs the same 7 groups which were highlighted in yellow on Table 8.1, above though this time the additional 32 samples are divided into two groups according to whether or not they included rock. Those 'unique substrate groups' including rock were: 4, 6, 8, 11, 15, 19, 20, 21, 25 and 26. These comprised 13 samples and were highlighted in grey on Table 8.1. Those 'unique substrate groups' not containing rock were: 1, 2, 5, 9, 12, 14, 22, 23, 24, and 26 (19 samples in total) and are not highlighted on Table 8.1. Additionally it should be noted that none of the large groups (highlighted in yellow on Table 8.1 above contain rock. Above it was shown that samples containing rock are diverse in other respects (as each type was generally few in number) and the presence of rock was not well described by the other substrate types (Figure 4.7(i), page 93, above).

Class 3

All the Class 2 methods for amalgamating the substrate groupings attempted to best represent the species preferences for particular substrates based on an *a priori* assessment of which substrate types might best describe those species that show a degree of similarity. The amalgamations of substrates must always be undertaken before the analysis is carried

out with these groups however all the Class 2 methods do not take into consideration the degree to which the species profile, or the presence and absence of all the species was apparently similar or different between the various substrate types. In addition, the Class 1 and 2 analyses made no distinction between whether the species in question were or were not fish. The Class 3 analyses reverse this. In these analyses, the species were better able to tell their own story and was termed *post hoc*. Figure 8.3 shows how the model was developed for the Class 3 analyses.

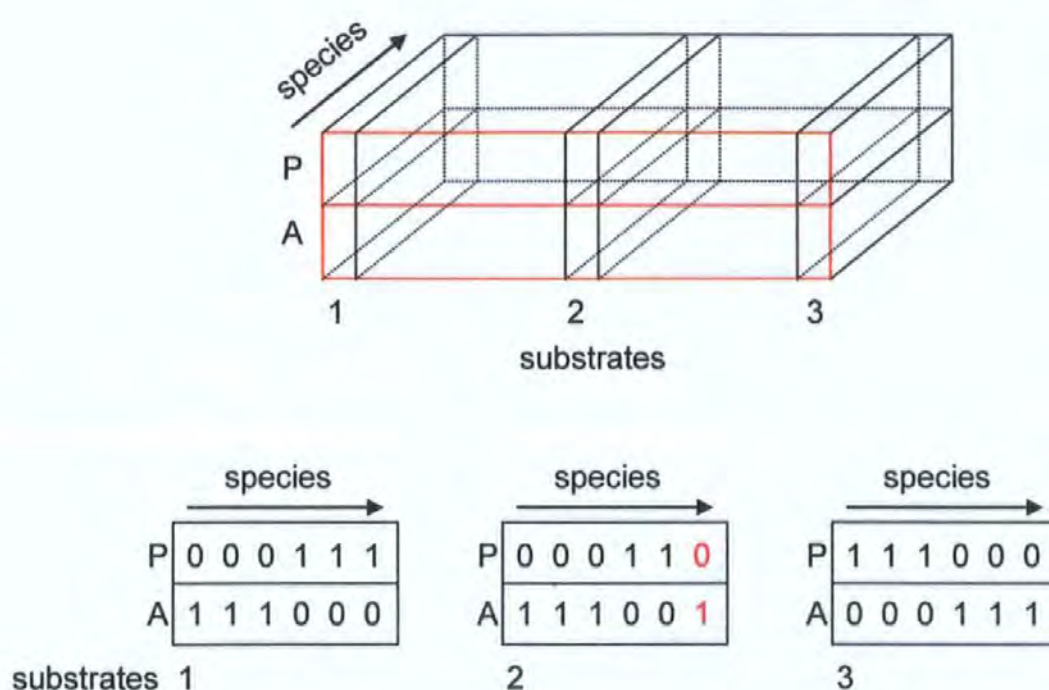


Figure 8.3. Model developed for the class 3 analyses. The top part shows the observed presence (P) and absence (A) values for a single species. The red box is equivalent to that on Table 8.2, (page 227, above) for one species across a variety of substrates. See text (below) for additional information.

The depth (or third dimension) on Figure 8.3, was generated through stacking of all the species, thus this model was built as a three dimensional matrix and the Class 3 analyses uses the profile of all the species under scrutiny compared according to substrate. Figure 8.3 (lower part) shows this. In the model, the presence and absences of all (nominally six) species were compared for substrate 1 and 2. In this example, five of the six species have the same presence and absence scores while these values were not the same for the sixth

species. The likelihood of this would be that substrates 1 and 2 could be amalgamated. This process was then repeated with additional substrate types until all the similar substrates had been identified and amalgamated. The process was then restarted with a new substrate and the species profile was compared to the others. On Figure 8.3, although the species profiles for substrates 1 and 2 were similar, the species profile of substrate 3 was markedly different and due to the presence/absence of the species substrates 1 and 2 would not group with substrate 3. The outcome of this process was that groups of substrates with similar species profiles were formed and each amalgamated group was comprised from different species profiles. Three separate analyses were undertaken for Class 3. These were:

Class 3,a – All the species, (190 species).

Class 3,b – Only the fish species, (54 species).

Class 3,c – The non-fish species, (136 species or groups).

Each of these analyses was carried out in the same manner. Several modelling methods were explored but the simplest and most amenable method was to examine the similarity percentage both in respect of contribution to average similarity within a group and average dissimilarity between groups, where the groups were the initial ‘unique substrate groups’ (see Table 8.1). This was achieved using the SIMPER routine in PRIMER-E, (Clarke & Warwick, 2001a). The SIMPER routine was run on presence/absence non-standardised values. The SIMPER dissimilarity output was converted to a similarity matrix and the similar and dissimilar species profiles according to ‘unique substrate groups’ were identified formally using a combination of cluster and non-metric multi-dimensional scaling (MDS) analyses (again in PRIMER-E, Clarke & Warwick, 2001a). Both clustering and MDS were employed as each suffers from flaws making reliance on one method alone prone to errors. These are described in turn. Cluster analysis (Figure 8.4, Figure 8.6, and Figure 8.8, below) is not best suited to organising data into groups where (like here) the groups fall along a continuum. Where the categories are along such a continuum the

outcome can often produce a dendrogram with a high degree of 'chaining.' Some chaining is evident in Figure 8.6 (below) though where an unacceptable amount was evident the dendrogram was produced by complete rather than grouped average linkage which usually reduces this. MDS plots (Figure 8.5, Figure 8.7 and Figure 8.9, below) suffer from being a two-dimensional portrayal of a higher dimensional picture. As such, objects may appear close together which may be far apart in a non-plotted dimension. The opposite can also occur where object may appear far apart on the MDS plot though if they are on a similar plane to one of the plotted dimensions their distance apart, as portrayed on the MDS plot, is truly their separation and perhaps they should be grouped together.

Figure 8.4 shows the cluster analysis plot and Figure 8.5 shows the MDS plot for Class 3,a, which was the analysis of all the species.

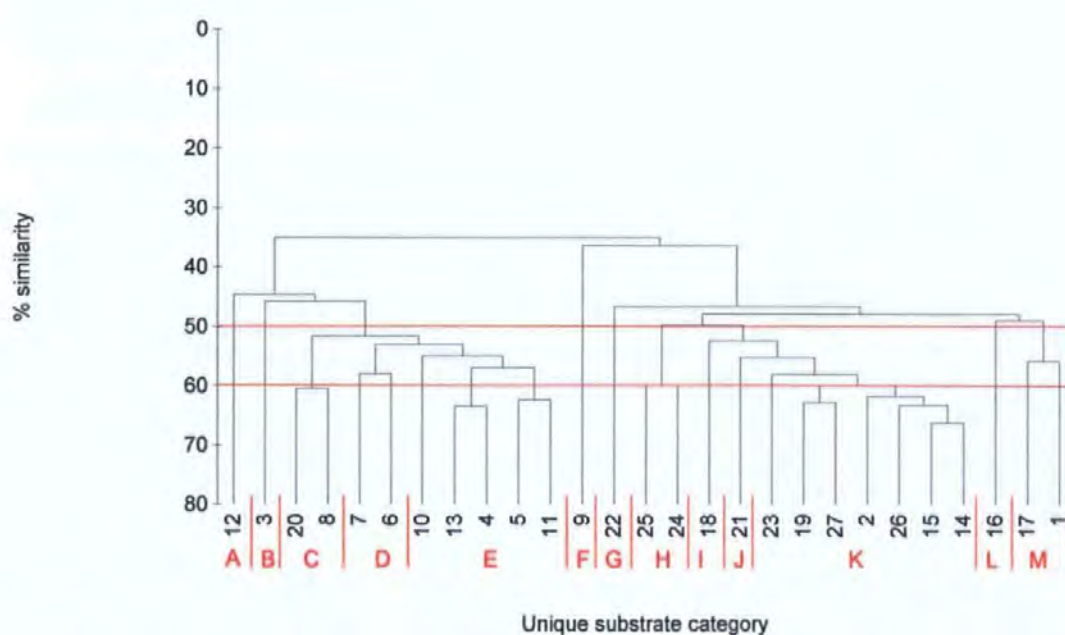


Figure 8.4. Group average-based cluster dendrogram based on percentage similarity between 'unique substrate groups' (as numbers; Table 8.1, above) of all species. Superimposed in red (as letters) are the amalgamated groupings. The relevance of the 50 and 60 % lines are given in the text.

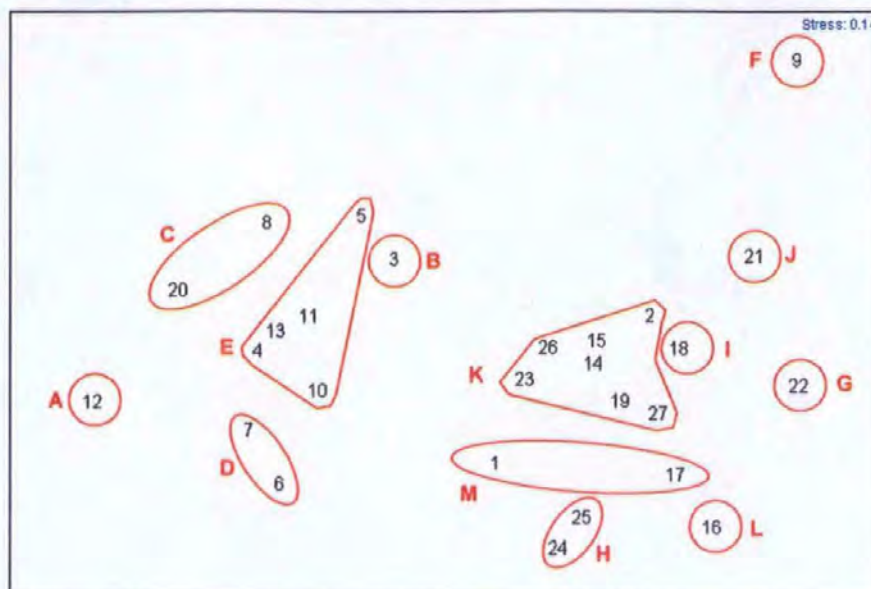


Figure 8.5. MDS plot based on percentage similarity between 'unique substrate groups' (as numbers, Table 8.1, above) of all species. Superimposed in red (as letters) are the amalgamated groupings.

Superimposed on Figure 8.4 and Figure 8.5 are the fully unique substrate groups (see Table 8.1, above) which both analytical methods amalgamate together. The rationale for making the groups was to keep separate those 'unique substrate groups' which were less than 50 % similar and generally amalgamate those more than 60 % similar. Where the cut off point between two groups fell between the 50 and 60 % similarity level reference was made to the appropriate MDS plot and the distance examined in both the 2d and 3d plot before a decision was made. The cluster and MDS analyses shown in Figure 8.4 and Figure 8.5 produced 13 amalgamated groupings.

Figure 8.6 and Figure 8.7 show the cluster and MDS plots (respectively) for the Class 3,b (fish only) part of the sample.

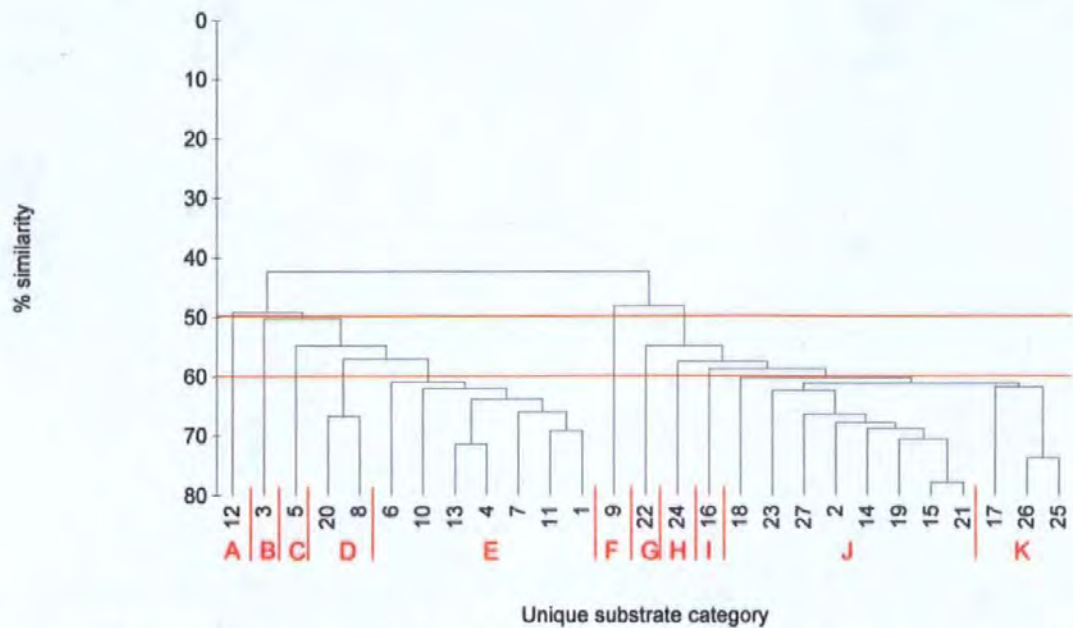


Figure 8.6. Group average-based cluster dendrogram based on percentage similarity between 'unique substrate groups' (as numbers; Table 8.1, above) of the fish only species. Superimposed in red (as letters) are the amalgamated groupings. The relevance of the 50 and 60 % lines are given in the text.

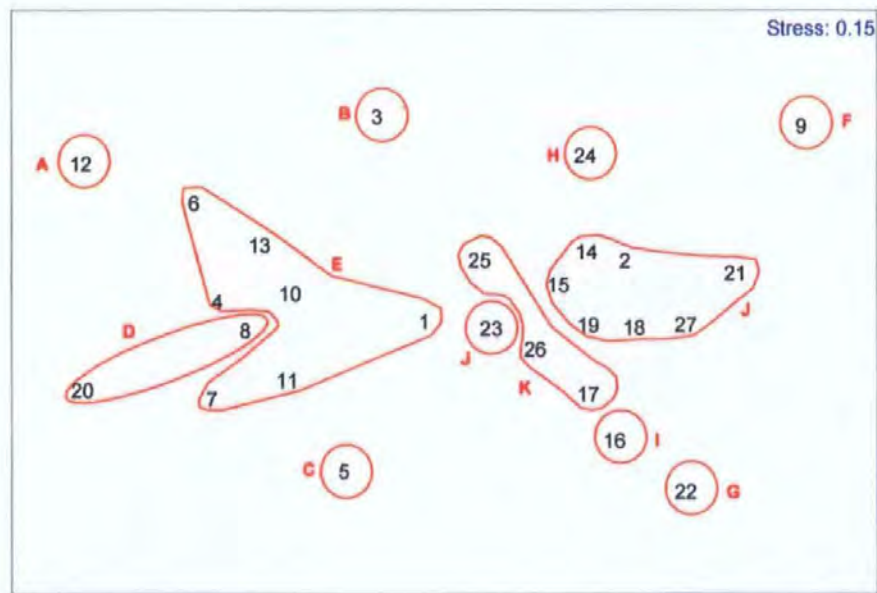


Figure 8.7. MDS plot based on percentage similarity between 'unique substrate groups' (as numbers, Table 8.1, above) of the fish species. Superimposed in red (as letters) are the amalgamated groupings.

The cluster and MDS analyses shown in Figure 8.6 and Figure 8.7 for the Class 3,b (fish only) part of the sample produced eleven amalgamated groupings. The fish-only species show an interesting example where the MDS plot (Figure 8.7) contains non-contiguous

'unique substrate groups' in the amalgamated group 'J'. It was necessary to examine the relevant cluster analysis (Figure 8.6) to determine the correct amalgamation.

Figure 8.8 and Figure 8.9 show the equivalent plots for the Class 3,c (non-fish) part of the sample.

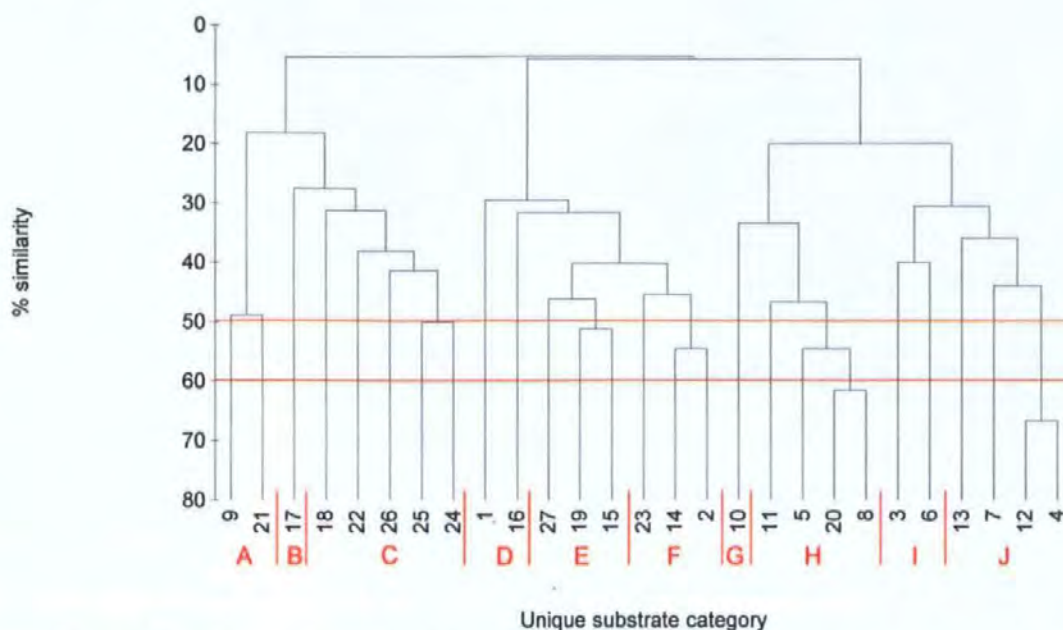


Figure 8.8. Complete linkage-based cluster dendrogram based on percentage similarity between 'fully unique substrate groups' (as numbers; Table 8.1, above) of the non-fish species. Superimposed in red (as letters) are the amalgamated groupings. The relevance of the 50 and 60 % lines are given in the text.

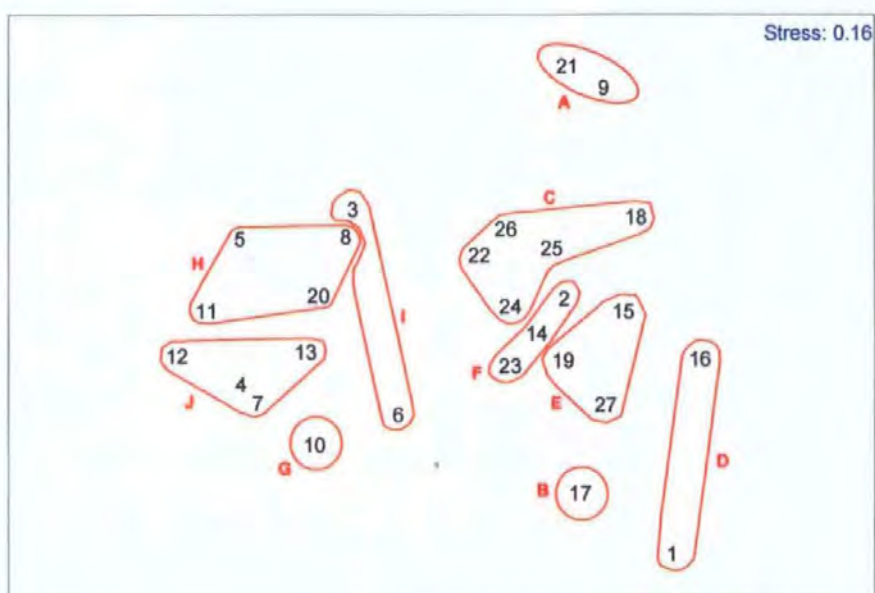


Figure 8.9. MDS plot based on percentage similarity between 'unique substrate groups' (as numbers, Table 8.1, above) of the non-fish species. Superimposed in red (as letters) are the amalgamated groupings.

The cluster and MDS analyses shown in Figure 8.8 and Figure 8.9 for the Class 3,c (non-fish) part of the sample produced 10 amalgamated groupings. The cluster dendrogram for the Class 3,c, (non-fish) part of the sample (Figure 8.8) was created using the complete linkage method as the group-average method produced too much chaining.

The Class 3 analyses were undertaken in the same way as the others (Class 1 and 2) though the categories for the Chi-squared test of independence (Table 8.2) were the amalgamated groupings (of 'unique substrate groups', Table 8.1 above), shown as red letters on Table 8.5 and Figure 8.5 for Class 3,a; and Figure 8.6 and Figure 8.7 for Class 3,b; and Figure 8.8 and Figure 8.9 for Class 3,c.

8.3 Results

As described in section 8.2.3.1 (page 227, above) the results present the data in two forms. Firstly according to all species (section 8.3.1) for the relationships between species and substrates as numbers and % of significant associations (separately where $P < 0.05 > 0.01$, and < 0.01). This is followed by the comprehensive examination of the fish species (section 8.3.2).

8.3.1 All species overview

The outcome of the 3 Classes of analysis (9 in total) are summarised in Table 8.4.

Table 8.4. The number of species and number of interactions between the presence/absence of a species and the substrate which are significant (according to the Chi-squared test of independence), where $P > 0.05$, < 0.01 and where $P < 0.01$ for the full species list, those just fish and those non-fish in nature for the three Classes of analyses. Percentages are highlighted.

| species | outcome | 1 full range (27 grp) | 2,a large cat only (4 grp) S, S.G, S.R, S.G.R | 2,b large cat only (3 grp) S, S.G, S.R + S.G.R | 2,c large cat only (7 grp) yel on Table 8.1 | Class 2,d large cat (7 grp) yel on Table 8.1) + 5 intermed | 2,e large cat (7 grp) yel on Table 8.1) +2 intermed rock or not | 3,a all | 3,b fish | 3,c non-fish |
|----------|--|-----------------------------|--|---|--|---|---|------------|-------------|-----------------|
| all | # sp | 190 | 190 | 190 | 165 | 190 | 190 | 190 | 190 | 190 |
| | # sig. sp | 66 | 26 | 23 | 39 | 50 | 40 | 61 | 57 | 67 |
| | % sig. sp | 35 | 14 | 12 | 24 | 26 | 21 | 32 | 30 | 35 |
| | # sig. sp ** (where $P < 0.01$) | 43 | 14 | 10 | 25 | 24 | 20 | 41 | 37 | 40 |
| | # sig. sp * (where $P > 0.05$, < 0.01) | 23 | 12 | 13 | 14 | 26 | 20 | 20 | 20 | 27 |
| | % sig. sp ** (where $P < 0.01$) | 23 | 7 | 5 | 15 | 13 | 11 | 22 | 19 | 21 |
| | % sig. sp * (where $P > 0.05$, < 0.01) | 12 | 6 | 7 | 8 | 14 | 11 | 11 | 11 | 14 |
| fish | # sp | 54 | 54 | 54 | 44 | 54 | 54 | 54 | 54 | 54 |
| | # sig. sp | 19 | 8 | 8 | 10 | 16 | 13 | 19 | 22 | 15 |
| | % sig. sp | 35 | 15 | 15 | 23 | 30 | 24 | 35 | 41 | 28 |
| | # sig. sp ** (where $P < 0.01$) | 10 | 5 | 4 | 7 | 9 | 7 | 14 | 16 | 12 |
| | # sig. sp * (where $P > 0.05$, < 0.01) | 9 | 3 | 4 | 3 | 7 | 6 | 5 | 6 | 3 |
| | % sig. sp ** (where $P < 0.01$) | 19 | 10 | 8 | 16 | 17 | 13 | 27 | 31 | 23 |
| | % sig. sp * (where $P > 0.05$, < 0.01) | 17 | 6 | 8 | 7 | 13 | 11 | 9 | 11 | 6 |
| non-fish | # sp | 136 | 136 | 136 | 121 | 136 | 136 | 136 | 136 | 136 |
| | # sig. sp | 47 | 18 | 15 | 29 | 34 | 27 | 42 | 35 | 52 |
| | % sig. sp | 35 | 13 | 11 | 24 | 25 | 20 | 31 | 26 | 38 |
| | # sig. sp ** (where $P < 0.01$) | 33 | 9 | 6 | 18 | 15 | 13 | 27 | 28 | 33 |
| | # sig. sp * (where $P > 0.05$, < 0.01) | 14 | 9 | 9 | 11 | 19 | 14 | 15 | 14 | 24 |
| | % sig. sp ** (where $P < 0.01$) | 24 | 7 | 4 | 15 | 11 | 10 | 20 | 15 | 21 |
| | % sig. sp * (where $P > 0.05$, < 0.01) | 10 | 7 | 7 | 9 | 14 | 10 | 11 | 10 | 18 |

Examining Table 8.4 shows that the Class 1 – The full range has 66 (or 35 %) of all the species with a significant relationship between their presence/absence and various substrate types. Class 2,a – Major substrate type part 1, and Class 2, b – Major substrate type part 2, revealed low numbers of species ($n = 26$ and 23 respectively) with a significant relationship between their presence/absence and various substrate types. Class 2,a and 2,b were the categories definable directly from the British Geological Society charts and it is likely that the four (or three) categories are too coarse to best show the relationship between the presence/absence of species and various substrate types, and this is reinforced as there were fewer numbers of significant associations for Class 2,b (three categories) than Class 2,a (four categories). Class 2,c – Large categories alone, comprised only those substrate groups which contained five or more samples. This class generated 39 significant relationships between the presence/absence of species and various substrate types though 25 species (10 fish and 15 non-fish) could not be included in the analysis since they were only present in samples not included in this Class.

Class 2,d – Large categories with other groupings, part 1, produced the highest number of species ($n = 50$) with a significant relationships between the presence/absence of species and various substrate types. The composition of the substrate groups (in addition to the large groups) in this class was aimed at best producing significant relationships between the presence/absence of species and various substrate types and this appears to have been achieved by the *a priori* amalgamation of the infrequently occurring 'unique substrate groups', (those not highlighted in yellow on Table 8.1, above). In contrast Class 2,e – Large categories with other groupings, part 2, showed that combined with the large categories featured in Class 2,c and Class 2,d the presence or absence of rock was not so important in producing significant relationships between the presence/absence of species.

The pattern of the species significance were even divided between the fish and non-fish species such that Class 2,d produced the highest proportion of significant relationship

and the presence or absence of rock was not so important in producing significant relationships between the presence/absence of species.

In all of the Class 3 analyses, the substrates and species are more able to tell their own story though the amalgamations of 'unique substrate groups' was, as with the Class 1 and 2, carried out before the analysis of relationship between presence/absence of species and substrate was undertaken. According to the numbers of significant interactions between the presence/absence of the species and the substrates (Table 8.4) all of the Class 3 analyses best approach that of the Class 1 – The full range though as expected the Class 3,b – Fish only, best explains the fish species with a significant relationship between the presence/absence of this group and the substrates in 41 % of cases ($n = 22$). Similarly, Class 3,c – Non-fish only, produced a significant relationship between the presence/absence of this group and the substrates in 38 % of cases ($n = 52$). Class 3, a – All species, performed less well overall in each of its target (fish or non-fish) groups but closely matched the Class 1 – The full range, situation. These examples on Table 8.4 are highlighted in red. The significance of these does show the utility of the Class 3 methods in that they used many fewer categories than the Class 1 method though they produced outcomes that were similar. Also, they show that the substrates should be classified separately when analysing the fish and non-fish species, and this was not carried out for Class 2.

8.3.2 Fish species analysis

The fishes are listed according to their taxonomy (class, order, family, genus and species), with the common name and three-letter species code. The 'conclusion' with each species description details whether or not an association with the presence/absence data was expected, whether significant associations were observed (* where $P < 0.05$, > 0.01 , and ** where $P < 0.01$), across the 3 Classes of analysis, whether similarities exist in terms of

expected substrate types and whether the conclusions were or were not considered valid. Citations from FishBase, (Froese & Pauly, 2003) are accredited to their main or data reference of the respective record and precede those from Wheeler, (1978) in the text.

Class Chondrichthyes, order Carcharhiniformes, family Scyliorhinidae

***Scyliorhinus canicula*, Lesser Spotted Dogfish, LSD.** FishBase (Compagno, 1984): “Found on sandy, coralline, algal, gravel or muddy bottoms...” Wheeler, (1978): “It inhabits sandy bottoms, fine gravel and even mud.” **Conclusion:** Expected over a wide range of substrates. No significant associations with presence/absence data observed. Valid as species was common (present in 65 % of samples).

***Scyliorhinus stellaris*, Greater spotted dogfish/ Bullhuss, GSD.** FishBase (Compagno, 1984): “...over rough, even rocky or coralline ground and algal-covered bottoms.” Wheeler, (1978): “It usually lives on rough or rocky grounds.” **Conclusion:** Expected over hard substrates. No significant associations observed with presence/absence data. However observed rarely (~ 1 % of samples) and expected substrates not coincident with samples, therefore conclusions were not considered valid however, lowest Chi-squared *P* value with Class 2,e which features the presence of rock.

Family Triakidae

***Mustelus asterias*, Starry Smooth Hound, SSH.** FishBase (Compagno, 1984): “Prefers sandy and gravelly bottoms.” Wheeler, (1978): “...seems to be most common on sand and gravel grounds.” **Conclusion:** Association not expected since this species preferences are coincident with general area of sampling and lack of knowledge of full extent of substrate preference. Observed rarely however (~ 2 % of samples and therefore not valid) and no significant associations observed with presence/absence data in any class but only coincident with sand or sand and gravel substrates as expected.

***Mustelus mustelus*, Smooth Hound, SMH.** FishBase (Compagno, 1984): No specific information. “Sometimes in midwater but prefers to swim near the bottom.” Wheeler,

(1978): “[As] only recently...distinguished from the more common *M. asterias*, ...[the] information compiled...could have applied to either species.” **Conclusion:** No association expected (see above) and no significant associations observed with presence/absence data in any class. Observed rarely however (1 % of samples) and only coincident with plain sand. Lack of association observed but not valid.

Family Rajidae

***Raja brachyura*, Blonde Ray, BLR.** FishBase (Brito, 1991): “Found on sand and sand-rock bottoms.” Wheeler, (1978): “It is not found in estuaries and usually young specimens only are encountered in very shallow water. It lives mainly on sandy bottoms.” **Conclusion:** Relatively common (present in 21 % of samples, therefore valid). Expected on sand and significant associations with presence/absence data for Class 1(*); 2,d(**); 2,e(**); 3,a(**); 3,b(**) and 3,c(**) analyses. These significant associations are commonly with the sandy gravel and sandy rocky substrates.

***Raja clavata*, Thornback ray, THR.** FishBase (Brito, 1991): “Found on sand and sand-rock bottoms.” Wheeler, (1978): “...it is found on muddy, sandy, or gravelly bottoms, rarely even on rough grounds.” **Conclusion:** The literature suggests this species is found over a variety of substrates. Present in 16 % of samples (therefore valid) and no significant associations with any presence/absence data. Lowest Chi-squared *P* value with Class 3,b.

***Raja microocellata*, Small-eyed ray, SER.** FishBase (Stehmann & Bürkel, 1984): “Found on sandy bottoms.” Wheeler, (1978): “It seems to be particularly common on sandy grounds, and in the English Channel at least it is found mainly in certain sandy bays and outer estuaries.” **Conclusion:** Although rarely observed (present in 3 % of samples, therefore not valid) significantly associated with most classes of presence/absence data, (not 2,c; 2,e; or 3,b). Observed samples were qualified sand in nature.

***Raja montagui*, Spotted ray, SPO.** FishBase (Stehmann & Bürkel, 1984): No specific information. “Found in shelf waters...” Wheeler, (1978): “It is most common on sandy bottoms but is occasionally caught on rough grounds.” **Conclusion:** Very rarely observed

(present in ~ 1 % of samples, therefore not valid). Highly variable association with presence/absence data. The significant associations were 1(**); 3,a(**); 3,b(**). Expected substrate pattern was not observed.

***Raja naevus*, Cuckoo Ray, CUR.** FishBase (Stehmann & Bürkel, 1984): No specific information. Wheeler, (1978): No specific information. "...bottom-living...found in shallow water..." Also, "...feed[s] on amphipods and shrimps, and nereid worms...eats increasing numbers of fishes (chiefly herring, gadoids, sandeels and dragonets) as it grows." **Conclusion:** Feeding preferences included as these suggest a highly varied substrate coverage without particular preferences. No significant associations observed with any presence/absence data as expected. Valid as found in a quarter (26 %) of the samples.

***Raja radiata*, Starry ray, STR.** FishBase (Stehmann & Bürkel, 1984): "Found on all kinds of bottoms." Wheeler, (1978): "It prefers sandy or muddy bottoms, but is occasionally found on shell or gravel." **Conclusion:** Though only found in 6 % of the samples (therefore not valid) no pattern expected and no significant associations between presence/absence data of species with substrate.

***Raja undulata*, Undulate ray, UDR.** FishBase (Stehmann & Bürkel, 1984): "Found on sandy bottoms..." Wheeler, (1978): "...found on sandy bottoms..." **Conclusion:** Expected over sand but highly variable association observed with presence/absence substrate data according to class due to being rarely observed, (present in only 2 % of samples, therefore not valid). The significant associations were 1(**); 2,a(**); 3,c(*). Expected substrate pattern was not observed.

Class Osteichthyes, order Clupeiformes, family Clupeidae

***Alosa* sp, e.g. *A. fallax*, Shad, SHD.** FishBase (Whitehead, 1985, p199): No spec. info. "Enters tidal part of rivers...to spawn there or a little above. Eggs are demersal, scattered over gravel or sand." Wheeler, (1978): No specific information. "...migrates[s] into the tidal reaches of rivers." **Conclusion:** No association expected between substrate and

species presence/absence data. None observed however, species very rarely observed also.

***Clupea harengus*, Herring, HER.** FishBase (Whitehead, 1985, p115): Probably various as primarily pelagic. Wheeler, (1978): Lack of specific information except spawns over gravel. **Conclusion:** No association expected between species and substrate presence/absence. Significant associations observed for classes 1(**); 2,d(*); 3,b(*) and 3,c(*), though coincident with a range of sand, sand gravel and sand gravel rock sites. Present in 8 % of the samples, therefore not valid.

***Sardina pilchardus*, Sardine, SAR.** FishBase (Whitehead, 1985, p55): No specific information. Wheeler, (1978): No specific information. **Conclusion:** No association expected between species and substrate presence/absence data. Only significant associations observed for class 2,e(*) (non-rock section) though species rarely observed, (present in ~ 1 % of samples, therefore not valid).

***Sprattus sprattus*, Sprats, SPR.** FishBase (Whitehead, 1985, p49): No specific information. "...sometimes entering estuaries..." Wheeler, (1978): No specific information. "...found in estuaries and arms of the sea." **Conclusion:** Association unlikely between species and substrate presence/absence data. Variable association (Classes 2,c(*); 2,d(*) and 2,e(*)) and species infrequently observed (in 6 % of samples) as might be expected. Lack of association not valid.

Family Engraulidae

***Engraulis encrasicolus*, Anchovy, ANC.** FishBase (Whitehead *et al.*, 1988, p316): "Can enter estuaries. Substrate probably relatively unimportant." Wheeler, (1978): "[lives] in surface waters...and estuaries." Substrate is likely to be relatively unimportant. **Conclusion:** Only significant associations with substrate presence/absence data with class 1(**). Species rarely observed as expected (in only 2 % of samples) but lack of association not valid.

Order Gadiformes, family Gadidae

***Gadus morhua*, Cod, COD.** FishBase (Cohen *et al.*, 1990): "...widely distributed in a

variety of habitats...” Wheeler, (1978): “...widely distributed in a variety of habitats...”

Conclusion: Observed in 64 % of samples (therefore valid) and significantly associated with substrate presence/absence data in all classes 1(*); 2,a(**); 2,b(**); 2,c(**); 2,d(**); 2,e(**); 3,a(**); 3,b(**) and 3,c(**). Significant associations due to data, which suggests this species occurs less commonly over plain sand and much more commonly over areas of mixed substrates where sand is also present than is expected by chance alone.

***Melanogrammus aeglefinus*, Haddock, HAD.** FishBase (Cohen *et al.*, 1990): “...over rock, sand, gravel or shells...” Wheeler, (1978): No specific information. **Conclusion:** Apparently, no association with substrate expected. Significant associations with presence/absence substrate data observed with classes 3,a(**) and 3,b(*). Observed in 6 % of samples but lack of association not valid.

***Merlangius merlangus*, Whiting, WHG.** FishBase (Cohen *et al.*, 1990): “...mainly on mud and gravel bottoms, but also on sand and rock.” Wheeler, (1978): “...both in mid-water...and inhabits sandy as well as muddy bottoms.” **Conclusion:** Seemingly widely distributed therefore no association with substrate presence/absence data expected. Observed in 66 % of samples (therefore valid) and highly significantly associated with substrate presence/absence data in all classes. Significant associations due to data, which suggest this species occurs much more commonly over plain sand and much less commonly over sand with gravel than expected by chance alone.

***Micromesistius poutassou*, Blue whiting, WHB.** FishBase (Cohen *et al.*, 1990): No specific information. “Found over the continental slope.... Makes vertical migrations: surface waters at night and near the bottom during the day.” Wheeler, (1978): No specific information. “...oceanic...living mainly in mid-water over the edge of the continental shelf.” **Conclusion:** No association with substrate presence/absence data expected. Highly significant associations observed with class 1; 3,a and 3,b however too rarely observed (in only 2 % of samples) as might be expected given distribution. Lack of

association not valid.

***Molva molva*, Ling, LIN.** FishBase (Frimodt, 1995): "Occurs mainly on rocky bottoms..." Wheeler, (1978): "...most common on rocky grounds, but also colonizes the numerous wrecks found in inshore waters."

Conclusion: Association with substrate presence/absence data expected, though significant associations observed only with class 2,d(*). Data suggests however, species observed more commonly than expected when substrates contain rock (class 2,a; 2,b and 2,e) though rocky substrates generally poorly covered by trawl gear. Present in 11 % of samples (therefore valid) suggesting this species makes forays away from hard substrates or structures and results are valid. Expected association not observed.

***Pollachius pollachius*, Pollack, POL.** FishBase (Cohen *et al.*, 1990): "Pelagic to benthopelagic, mostly close to shore over hard bottoms." Wheeler, (1978): "Large fish are most abundant near rocks or on rough ground...smaller specimens tend to be less restricted and occur over sandy shores and even in estuaries." **Conclusion:** Association with substrate presence/absence data not expected. No significant associations observed with any class. Result valid as species present in 17 % of samples.

***Trisopterus luscus*, Pout whiting (pouting), BIB.** FishBase (Cohen *et al.*, 1990): No specific information. "Lives mostly on the outer shelf, but moves inshore...for spawning." Wheeler, (1978): "...particularly in rocky areas where large schools form about reefs or wrecks. Small bib are very abundant in shallow water over sand." **Conclusion:** Association with substrate presence/absence data not expected. Significant associations observed with class 3,a(*) and 3,b(**). However, species commonly observed (in 78 % of samples). It is thought important that species is even distributed across all encountered substrate types.

***Trisopterus minutus*, Poor cod, PCO.** FishBase (Cohen *et al.*, 1990): "...on muddy or sandy bottoms..." Wheeler, (1978): No specific information. "It occurs close to the bottom and in mid-water." **Conclusion:** Favouring soft sediment therefore association

with substrate presence/absence data expected despite venturing into the water column (outside sampling here). Significantly associated with substrate presence/absence data in class 1(*); 2,c(**); 2,d(**); 2,e(**); 3,a(**); 3,b(**) and 3,c(**). Present in 60 % of samples though less commonly found in samples containing rock therefore expected association observed.

Family Merlucciidae

Merluccius merluccius, **Hake, HKE**. FishBase (Cohen *et al.*, 1990): No specific information. “Lives close to the bottom during the day-time, but moves off-bottom at night.” Wheeler, (1978): No specific information. “...lives near the bottom rather than on it and makes feeding forays into mid-water at night.” **Conclusion:** Literature suggests no association with substrate presence/absence data expected. Association observed with class 1(*); 2,c(**); 2,d(**); 2,e(**); 3,a(**); 3,b(**) and 3,c(**) and present in 60 % of samples. Less commonly observed than expected with complex substrates. No association expected but one observed and valid.

Order Lophiiformes, family Lophiidae

Lophius budegassa, **Black-bellied angler, MOB**. FishBase (Caruso, 1986): No specific information. Wheeler, (1978): “...usually on sandy bottoms...”

Conclusion: Association expected though none observed with any class however, species was found in only 1 % of samples therefore not valid.

Lophius piscatorius, **Monkfish-Anglerfish, MON**. FishBase (Göthel, 1992): “Occurs on sandy and muddy bottoms.... May also be found on rocky bottoms.” Wheeler, (1978): “It lives on sandy, shell, or gravel bottoms and is found less abundantly on muddy or rough grounds.” **Conclusion:** Mainly expected on a wide range of mid-type substrates and not on particularly soft or hard sediments and since these were the substrates commonly sampled therefore no association expected. Observed in 24 % of samples though no association observed with substrate presence/absence data for any class. Despite this not co-occurring with rock; also more commonly observed than expected with gravel and less

so on plain sand. Lack of expected association observed and valid.

Order Perciformes, family Ammodytidae

Ammodytes tobianus, Lesser sand eel, **SDL**. FishBase (Bauchot, 1987): “especially sandy bays and beaches, including the intertidal zone and estuaries; rarely offshore. Alternates between lying buried in the sandy substrates and swimming in schools in the water mass.” Wheeler, (1978): “It is always found close to clean, rather fine sand in which it burrows with great rapidity.” **Conclusion:** Expected over sand despite also inhabiting water column. Species rarely observed (only 1 % of samples) and only significantly associated with substrate presence/absence data for class 1(*). Expected association not valid and lack of observation may be due to pelagic behaviour and small size.

Family Callionymidae

Callionymus sp, Dragonet, **DET**. FishBase, (Wheeler, 1979): “Occurs on sand and muddy bottoms...” Wheeler, (1978): “...particularly over sandy or muddy bottoms...” **Conclusion:** Association expected and significantly associated with substrate presence/absence data in class 2,a(*); 2,b(**); 2,c(**); 2,d(**); 2,e(*); 3,a(**); 3,b(**) and 3,c(**). More commonly observed than expected on plain sand and less so in combination with gravel. Expected association observed. Valid as observed in 42 % of samples.

Family Carangidae

Trachurus trachurus, Scad horse mackerel, **HOM**. FishBase (Smith-Vaniz, 1986): “Forms large schools in coastal areas with sandy substrates.” Wheeler, (1978): No specific information. **Conclusion:** Area of study was generally sandy in nature and species location dominated by feeding therefore no significant associations expected. Present in 74 % of samples and only significant associations with substrate presence/absence data in class 3,b(*), however, species was under-represented in samples where rock co-occurred. Lack of expected association observed and valid.

Family Labridae

***Labrus* sp e.g. *L. bergylta*, Wrasses, WRA.** FishBase (Quignard & Pras, 1986): "...around rocks, offshore reefs and seaweed." Wheeler, (1978): "...may be common locally especially close to rocks..." **Conclusion:** Literature suggests expected association though with substrate not generally encountered. Significant associations only observed with class 1(*) however species only observed in 2 % of samples, therefore association not valid.

Family Mugilidae

***Mugil* sp, Grey mullets, MUG.** FishBase (Billard, 1997): No specific information. Wheeler, (1978): "...particularly common close inshore in harbour mouths, estuaries, in sandy bays and in the channel of saltings." **Conclusion:** No association expected. Only present in 1 % of samples and no significant associations with substrate presence/absence data in any class. Lack of expected association not valid.

Family Mullidae

***Mullus surmuletus*, Red mullet, MUR.** FishBase (Hureau, 1986a): "Occurs on broken and rough grounds but also found over sand and soft bottoms..." Wheeler, (1978): "...lives in small schools on sandy or muddy bottoms...although it also occurs on rocky grounds." **Conclusion:** Literature suggests this species is expected over a wide variety of substrates therefore no association expected. No association observed with substrate presence/absence data in any class. Observation of lack of expected association valid as species present in 16 % of samples.

Family Percichthyidae

***Dicentrarchus labrax*, Bass, BSE.** FishBase (Smith, 1990): "Inhabits the littoral zone on various kinds of bottoms on estuaries, lagoons and occasionally rivers." Wheeler, (1978): "...commonly entering estuaries...upstream into almost freshwater [also]...usually found in close proximity to reefs." **Conclusion:** Association not expected since while this species occurs close to reefs sampling did not take place close to this habitat type. No

significant associations with substrate presence/absence data in any class. Present in only 7 % of samples. Therefore, lack of association not valid.

Family Scombridae

***Scomber scombrus*, Atlantic mackerel, MAC.** FishBase (Collette & Nauen, 1983): No specific information. Wheeler, (1978): No specific information. "...seasonally close inshore, as well as over offshore banks, but is highly migratory..." **Conclusion:** Literature suggests no association expected. Significant associations with substrate presence/absence data in class 1(*); 2,c(*); 2,d(*); 3,a(*); and 3,b(*). Observed in 27 % of samples (therefore valid) and significance of association due to data, which suggest this species was observed more commonly than expected over plain sand. Therefore, lack of association not borne out by data.

Order Pleuronectiformes, Family Bothidae

***Arnoglossus imperialis*, Imperial scaldfish, SCI.** FishBase (Bianchi *et al.*, 1993): "Found on sand, mud, shell and corals." Wheeler, (1978): "It lives mainly on sandy or muddy grounds." **Conclusion:** No association expected and no significant associations with presence/absence data in any class. Present in 8 % of samples therefore lack of association not considered valid though lowest P value ≈ 0.4 .

***Arnoglossus laterna*, Scaldfish, SCA.** FishBase (Nielsen, 1986a): "Lives on mixed or muddy bottoms." Wheeler, (1978): "It lives most abundantly on sandy bottoms..." **Conclusion:** No association expected and no significant associations with presence/absence data in any class. Present in only 5 % of samples therefore lack of association difficult to prove (considered not valid) though lowest P value ≈ 0.6 .

Family Pleuronectidae

***Limanda limanda*, Dab, DAB.** FishBase (Cooper & Chapleau, 1998): "Lives mainly on sandy bottoms..." Wheeler, (1978): "...shallow, sandy grounds..." **Conclusion:** Association expected and significant associations observed with substrate presence/absence data in class 1(**); 2,b(*); 2,c(**); 2,d(**); 2,e(*); 3,a(**); 3,b(**)

and 3,c(**). Data show species much more commonly observed than expected on plain sand and less so in combination with gravel. Expected association observation and valid as species present in 43 % of samples.

***Microstomus kitt*, Lemon sole, LEM.** FishBase (Cooper & Chapleau, 1998): “Lives mostly on stony bottoms.” Wheeler, (1978): “...lives on a wide range of bottoms from mud (exceptionally), and sand, gravel, even rocky grounds...” **Conclusion:** Literature suggests that no association should be expected between this species and the substrate presence/absence data. Much of the substrate in the area is suitable though this species prefers generally more gravely sediments than other flatfishes. Significant associations observed for class 1(*) and 3,b(**). These are due to this species being more commonly observed than expected over gravely and sand and gravel and rock categories in class 1 and 3,b. This species was commonly observed (present in 89 % of samples). Lack of expected association not upheld though data is more precise than literature.

***Platichthys flesus*, Flounder, FLE.** FishBase (Cooper & Chapleau, 1998): No special information. “Juveniles live in shallow coastal water and estuaries which are also the summer feeding grounds of the adults. Nocturnal and burrowing.” Wheeler, (1978): “...Also penetrating into freshwater. It lives on sandy and muddy bottoms.” **Conclusion:** Association expected and significant associations with substrate presence/absence data in class 1(**); 2,d(**); 2,e(*); 3,a(**); 3,b(**) and 3,c(**). Generally less observed than expected in complex substrates (combining sand with gravel and rock) than over plain sand. Expected association observed and valid as present in 16 % of samples.

***Pleuronectes platessa*, Plaice, PLE.** FishBase (Cooper & Chapleau, 1998): “Lives on mixed bottoms.” Wheeler, (1978): “...most abundant on sandy bottoms, but also found on muddy bottoms and gravel...” **Conclusion:** Literature suggests no association expected though data show highly significant associations with substrate presence/absence data in all classes. Significant associations are due to species being much more commonly observed over plain sand than might be expected. Lack of expected association not evident

from data. Outcome valid as observed in 51 % of samples.

Family Scophthalmidae

***Lepidorhombus whiffiagonis*, Megrim, MEG.** FishBase (Nielsen, 1986b): “Occurs on soft bottoms.” Wheeler, (1978): “most abundant on muddy bottoms, although not confined to that type...” **Conclusion:** Association expected and significant associations with substrate presence/absence data in class 1(*); 2,a(*); 2,b(*); 2,c(**); 2,d(*); 2,e(**); 3,a(**); 3,b(*) and 3,c(**). Generally more commonly observed over complex qualified sand (with gravel or mud) and less so over plain sand sediments though the pattern between expected and observed occurrences is complex. Present in 41 % of samples. Expected association observed and valid.

***Scophthalmus rhombus*, Brill, BLL.** FishBase (Bauchot, 1987): “Lives on sandy or mixed bottoms...” Wheeler, (1978): “It is most common on sandy bottoms, but is occasionally caught on gravel and mud.” **Conclusion:** Literature suggests an association expected. Significant associations observed with substrate/presence data in class 3,a(**) and 3,b(**). This species was rarely observed (present in only 5 % of the samples) though most of these were plain sandy gravel. Expected association observed though not valid.

Family Soleidae

***Solea solea*, Dover Sole, SOL.** FishBase (Desoutter, 1992): “Burrows into sandy and muddy bottoms.” Wheeler, (1978): “It is common on sandy and muddy grounds.” **Conclusion:** Association expected and significant associations observed with substrate presence/absence data in class 2,e(*); 3,b(*) and 3,c(**). These significant associations due to greater than expected number of observations of this species over sand and fewer than expected observations over complex sediments (containing rock in class 2,e). Expected association observed and valid as found in 11 % of samples.

Order Salmoniformes, family Argentinidae

***Argentina sphyraena*, Argentine, ARG.** FishBase (Cohen, 1990): No special information. Wheeler, (1978): “A relatively common, even locally abundant fish on

muddy depths of 55 - 200 m.” **Conclusion:** No association expected and no significant associations observed with substrate presence/absence data in any class. As expected however, this species was rarely observed (only present in 1 % of samples). Lack of association not valid.

Family Osmeridae

Osmerus eperlanus, Smelt, SME. FishBase (Kottelat, 1997): No specific information. “...spawns on sandy or gravelly bottoms.” Wheeler, (1978): No specific information. “...most common close to river mouths and in estuaries themselves.” **Conclusion:** No association expected and no significant associations observed with substrate presence/absence data in any class. As expected however, this species was rarely observed (only present in 1 % of samples). Lack of association not valid.

Order Scorpaeniformes, family Agonidae

Agonus cataphractus, Pogge, POG. FishBase (Gall-Le, 1969): “...preferring sandy bottoms, rarely with stones.” Wheeler, (1978): “A common fish in inshore waters especially on sandy or muddy shores.” **Conclusion:** Association expected however, no significant associations observed with substrate presence/absence data in any class. Expected association not evident (or valid) as infrequently observed (present in 7 % of samples).

Family Triglidae

Aspitrigla cuculus, Gurnard (Red), GUX. FishBase (Blanc & Hureau, 1979): “Found over sand and gravel, crag and rocks in the continental shelf.” Wheeler, (1978): “It is found on a variety of different sea-beds, usually on sand, or sand and gravel, but also on mud and even rocks.” **Conclusion:** The literature suggests that no association expected and also that this species should be common since it favours substrate types commonly found in the region. A significant associations was observed with substrate presence/absence data in class 3,a(*) and 3,b(**). This species was present in almost all samples (98 %) and the significant associations appear to be due to the ubiquity of this

species producing large X^2 values in turn producing significant P values with this number of degrees of freedom. This is likely to be responsible since there are few differences between observed and expected frequencies in any occasion. Lack of association found and valid.

***Aspitrigla obscura*, Gurnard (Long-finned), GUL.** FishBase (Hureau, 1986b): "...inhabits soft bottoms and fallen rocks." Wheeler, (1978): "...mainly on rough rocky grounds." **Conclusion:** The literature suggests that an association should be expected though none was found in any class. This species was not commonly observed (present in only 2 % of samples) and its preferred habitat may be outside that generally trawled here. Association not found though also not valid.

***Eutrigla gurnardus*, Gurnard (Grey), GUG.** FishBase (Bauchot, 1987): "Common on sandy grounds, sometimes on rocky bottoms, and also on mud..." Wheeler, (1978): "...most common on sandy bottoms but also occurs, with decreasing frequency, on mud, shell, and rocky bottoms." **Conclusion:** This species occurs on a wide variety of substrates therefore no association expected and no association was observed with substrate presence/absence data in any class. Lack of association evident and valid as observed in half of the samples.

***Trigla lucerna*, Tub gurnard, GUT.** FishBase (Richards & Saksena, 1990): "Inhabits sand, muddy sandy or gravel bottoms." Wheeler, (1978): "...on mud and muddy-sand bottoms." **Conclusion:** Association unlikely as species inhabits a variety of sediment types, though significant associations observed with substrate presence/absence data in class 2,d(*). This significant associations was due to greater number of observed than expected occurrences of this species over sand and gravel substrates in class 2,d. Lack of association generally evident and valid as this species was present in 13 % of samples.

***Trigloporus lastoviza*, Gurnard (Streaked), GUS.** FishBase (Fischer *et al.*, 1990): "Found over rocks and sand..." Wheeler, (1978): "It seems to inhabit sand and muddy grounds, especially where they are interspersed with rocky patches." **Conclusion:** This

species occupies quite complex habitats, which are similar to those preferred by *Aspitrigla obscura*. Again, an association should be expected though no significant associations observed with substrate presence/absence data in any class. It is possible that this species' preferred habitats were not generally sampled here and this species was rarely observed (present in only 3 % of samples). Despite this expected association not observed though situation not valid.

Order Zeiformes, family Caproidae

Capros aper, Zulu (Boarfish), ZUL. FishBase (Quéro, 1986): "Found over rock or coral but also trawled over sandy grounds." Wheeler, (1978): "It is thought to live among the yellow and pink coral growing on the rock faces in these depths. However, it is occasionally captured in large numbers on sandy grounds..." **Conclusion:** Association expected though no significant associations observed with substrate presence/absence data in any class however, only observed from 6 % of the samples. Expected association not evident though not valid.

Family Zeidae

Zeus faber, John Dory, JOD. FishBase (Kailola *et al.*, 1993): No specific information. "Found in areas close to the sea bed." Wheeler, (1978): No specific information. "...inshore...though exceptionally...reported close to the surface." **Conclusion:** The literature suggests that no association should be expected for this species. However, various significant associations observed with substrate presence/absence data in all classes 1(*); 2,a(*); 2,b(*); 2,c(*); 2,d(*); 2,e(*); 3,a(*); 3,b(**) and 3,c(**). The significance of these association are generally due to this species being less commonly observed than expected over plain sand. Conversely, this species was observed much more commonly than expected over all types of qualified sand particularly those containing rock. Strong association evident when none expected and this is valid as this species was observed in 69 % of samples.

8.3.2.1 Summary of species by species analysis

Table 8.5 shows the species (and totals) for which positive (1) and negative (-1) associations were produced between the species and substrate presence/absence data. Table 8.5 also shows which of these can be classed as valid (with confidence) or not valid (lacking confidence) and for which the associations were either expected (E) or not expected (\bar{E}), and subsequently observed (O) or not observed (\bar{O}).

Table 8.5. Numbers of valid and non valid associations, whether expected (E) or not expected (\bar{E}), and subsequently observed (O) or not observed (\bar{O}) between species and presence/absence substrate data according to taxonomy (class, order, family, and genus and species) and species code. Open and filled circles are described on page 262.

| Class | Order | Family | Genus and species | code | category and score | | | | | | | |
|----------------------|---------------------------------|------------------------------|--|---------------------------|---------------------------------------|-----|--------|-----|-----------|-----|-----|-----|
| | | | | | valid | | | | non-valid | | | |
| | | | | | E&O | E&O | E&O | E&O | E&O | E&O | E&O | E&O |
| | | | | | 1 | 1 | -1 | -1 | 1 | 1 | -1 | -1 |
| Chondrichthyes | Carcharhiniformes | Scyliorhinidae | <i>Scyliorhinus canicula</i> | LSD | | • | | | | | | |
| | | | <i>Scyliorhinus stellaris</i> | GSD | | | | | | | | • |
| | | Triakidae | <i>Mustelus asterias</i> | SSH | | | | | | • | | |
| | | | <i>Mustelus mustelus</i> | SMH | | | | | • | | | |
| | Rajiformes | Rajidae | <i>Raja brachyura</i> | BLR | • | | | | | | | |
| | | | <i>Raja clavata</i> | THR | | • | | | | | | |
| | | | <i>Raja microocellata</i> | SER | | | | | • | | | |
| | | | <i>Raja montagui</i> | SPO | | | | | | | • | |
| | | | <i>Raja naevus</i> | CUR | | • | | | | | | |
| | | | <i>Raja radiata</i> | STR | | | | | | • | | |
| <i>Raja undulata</i> | | | UDR | | | | | | | | • | |
| Osteichthyes | | | Clupeiformes | Clupeidae | <i>Alosa</i> sp e.g. <i>A. fallax</i> | SHD | | | | | | • |
| | <i>Clupea harengus</i> | HER | | | | | | | | | | • |
| | <i>Sardina pilchardus</i> | SAR | | | | | | | | | • | |
| | <i>Sprattus sprattus</i> | SPR | | | | | | | | | • | |
| | | Engraulididae | <i>Engraulis encrasicolus</i> | ANC | | | | | | • | | |
| | | | Gadiformes | Gadidae | <i>Gadus morhua</i> | COD | | | | ○ | | |
| | <i>Melanogrammus aeglefinus</i> | HAD | | | | | | | | • | | |
| | <i>Merlangius merlangus</i> | WHG | | | | | | ○ | | | | |
| | <i>Micromesistius poutassou</i> | WHB | | | | | | | | | | • |
| | <i>Molva molva</i> | LIN | | | | | • | | | | | |
| | <i>Pollachius pollachius</i> | POL | | | | • | | | | | | |
| | <i>Trisopterus luscus</i> | BIB | | | | • | | | | | | |
| | <i>Trisopterus minutus</i> | PCO | | | • | | | | | | | |
| | | Merlucciidae | <i>Merluccius merluccius</i> | HKE | | | | ○ | | | | |
| | | | Lophiiformes | Lophiidae | <i>Lophius budegassa</i> | MOB | | | | | | |
| | <i>Lophius piscatorius</i> | MON | | | | • | | | | | | |
| | Perciformes | Ammodytidae | <i>Ammodytes tobianus</i> | SDL | | | | | | | | • |
| | | | <i>Callionymus</i> sp | DET | • | | | | | | | |
| | | | <i>Trachurus trachurus</i> | HOM | | • | | | | | | |
| | | | <i>Labrus</i> sp e.g. <i>L. bergylta</i> | WRA | | | | | | | | • |
| | | | <i>Mugil</i> sp | MUG | | | | | | | • | |
| | | | <i>Mullus surmuletus</i> | MUR | | • | | | | | | |
| | | | <i>Dicentrarchus labrax</i> | BSE | | | | | | | • | |
| | | | <i>Scomber scombrus</i> | MAC | | | | ○ | | | | |
| | Pleuronectiformes | Bothidae | <i>Arnoglossus imperialis</i> | SCI | | | | | | | • | |
| | | | <i>Arnoglossus laterna</i> | SCA | | | | | | | • | |
| | | Pleuronectidae | <i>Limanda limanda</i> | DAB | • | | | | | | | |
| | | | <i>Microstomus kitt</i> | LEM | | | | ○ | | | | |
| | | | <i>Platichthys flesus</i> | FLE | • | | | | | | | |
| | | | <i>Pleuronectes platessa</i> | PLE | | | | ○ | | | | |
| | | Scophthalmidae | <i>Lepidorhombus whiffiagonis</i> | MEG | • | | | | | | | |
| | | | <i>Scophthalmus rhombus</i> | BLL | | | | | • | | | |
| | | Soleidae | <i>Solea solea</i> | SOL | • | | | | | | | |
| | | | Salmoniformes | Argentinidae | <i>Argentina sphyraena</i> | ARG | | | | | | • |
| | <i>Osmerus eperlanus</i> | SME | | | | | | | | • | | |
| | Scorpaeniformes | Agonidae | <i>Agonus cataphractus</i> | POG | | | | | | | | • |
| | | | Triglidae | <i>Aspitrigla cuculus</i> | GUX | | • | | | | | |
| | | <i>Aspitrigla obscura</i> | | GUL | | | | | | | | • |
| | | <i>Eutrigla gurnardus</i> | | GUG | | • | | | | | | |
| | | <i>Trigla lucerna</i> | | GUT | | • | | | | | | |
| | | <i>Trigloporus lastoviza</i> | GUS | | | | | | | | • | |
| | Zeiformes | Caproidae | <i>Capros aper</i> | ZUL | | | | | | | | • |
| | | Zeidae | <i>Zeus faber</i> | JOD | | | | ○ | | | | |
| Total by category | | | | | 7 | 11 | 1 | 7 | 3 | 13 | 9 | 3 |
| Total by score | | | | | 18 | | 8, (1) | | 16 | | 12 | |

The totals by score on Table 8.5 show that of the 54 species analysed there were 18 which have a positive and valid (see Figure 8.2, above) agreement between substrate affiliation expected from the literature and observed in this study. These were comprised of 7 species where the association was expected and observed (E&O) and 11 where the opposite was the case ($\bar{E}\&\bar{O}$). The fact that amongst the positive associations, there were more which were not expected and not observed ($\bar{E}\&\bar{O}$) than expected and observed (E&O) was interesting however this pattern was related to features of the individual species and suggests that amongst the species that were present in >10 % of samples more can be classed as habitat generalists than specialists.

According to the model presented in Table 8.2 species whether E&O, or $\bar{E}\&\bar{O}$ scored 1. Conversely there were 8 species with a valid and negative association (either E& \bar{O} , or $\bar{E}\&O$) and these species in contrast scored -1, (Figure 8.2) meaning they did not match the expected association with the substrate. According to the total by score shown in Figure 8.2 the examination of species can be considered a success though not in statistically significant terms, since if taken that the null hypothesis was that there was no particular reason to suggest that positive (1) scores should be more common than negative (-1) ones (despite attempting to best examine the association between the presence/absence of species and substrates). A Chi-squared test of independence between the positive and negative scores did not show these to be significantly different ($\chi^2 = 3.115$, d.f. = 1, $P = 0.078$, with the Yates' correction applied).

Only 1 negative score was produced where an expected association was not observed (E& \bar{O}) and this species (ling) was found more commonly than expected when substrates contain rock (as expected for this species), though these substrates were poorly covered by the trawl gear.

There were 7 species (cod, whiting, hake, mackerel, lemon sole, plaice, and John Dory) for which a negative association between substrate and species presence/absence data was produced (observed) though where one was not expected ($\bar{E}\&O$) from the

literature. These species are shown as open circles on Table 8.5. In all of these occasions (with the possible exception for lemon sole) no association between the species and the substrate presence/absence data was expected based on interpreting both FishBase (Froese & Pauly, 2003) and Wheeler, (1978) though one was observed and generally many of these associations were highly significant across many classes of analysis (see their descriptions which start on page 248, cod; page 248, whiting; page 249, hake; page 251, plaice page 255 and, John Dory page 259 in section 8.3.2). Lemon sole was included in this group because Wheeler, (1978) asserts it "...lives on a wide range of bottoms from mud (exceptionally), and sand, gravel, even rocky grounds..." Significant associations were observed for class 1(*) and 3,b(**) therefore the lack of expected association not upheld however, the significance of these associations were due to this species being more commonly observed than expected over gravelly and sand and gravel and rock categories in keeping with the comments from FishBase (Collette & Nauen, 1983) on this species.

Mackerel (description on page 252, above) was included in this group since while no association was expected, associations were observed in 5 of the 9 Classes and this species was observed more commonly than expected over plain sand, despite this species being highly migratory and residing in the water column. There are however, two reasons to suggest that mackerel does not fully deserve inclusion in the E&O category. Firstly, it was by far the most uncommon amongst these species (present in only 27 %) of samples, and secondly all of its associations were significant at the 5 % level. Had mackerel been classed in the E&O category then there would have been significantly more positive than negative associations according to the Chi-squared test of independence ($\chi^2 = 4.652$, d.f. = 1, $P = 0.031$, with the Yates' correction applied).

The importance of these 7 species stems from their representation in the samples. The data for mackerel is given above. The remainder, as ordered on Table 8.5 (and above) were present in 64, 66, 60, 89, 51 and 69 % of samples and were all amongst the most abundant 11 species by presence in the samples (and by biomass (Table 3.4, page 54,

above) ranked in the top 23). As such the observed associations with particular substrates when the literature suggested that no such association should exist should be taken as creditable, especially as these species often had many statistically highly significant results from the Chi-squared tests of independence across the three Classes of analyses, (again see their descriptions in the Results: lemon sole is shown on page 255). Thus, the 7 species, of $\bar{E}\&O$ associations, just described can be regarded as special cases. Treating them as such reveals 18 species where the association between species and substrate presence/absence was considered as valid and where the expected pattern was observed ($E\&O$, or $\bar{E}\&\bar{O}$) against only 1 species where the similar association was not as expected ($E\&\bar{O}$).

While there were more positive than negative non-valid associations between the species and substrate presence/absence data the nature of their analysis means that it is unwise to analyse these numbers in greater detail, nevertheless this result might suggest that the method is robust even on infrequently observed species. All that can be drawn from the association between the species and substrates which were considered as non-valid is that like the valid associations, there appears to be more habitat generalists ($\bar{E}\&\bar{O}$, $n = 13$) than specialists ($E\&O$, $n = 3$). Also that using the valid, positive totals by category as contingency expected frequencies and the non-valid positive totals by category as observed frequencies a Chi-squared test of independence between the observed values and expected contingency frequencies suggests that the ratios are not significantly different ($\chi^2 = 1.516$, d.f. = 1, $P = 0.218$, with the Yates' correction applied).

8.4 Discussion

This Chapter has presented a novel technique to compare the distributions of fish species from commercial trawling with that of substrate data from relatively small-scale sediment maps. It was also possible to significantly compare whether a particular association of a

fish species with specific or general substrates should be expected from consulting literature sources and identifying whether this was observed.

In undertaking this analysis, several decisions were taken that influenced outcomes. The first was to decide upon basing the analysis on the presence/absence of species within samples. Inevitably, this down weighted the common and up weighted the rare species though this was offset by establishing the requirement that a species had to be present in 10 % of samples before its association was considered as valid. The only alternative would have been to use the counts of individuals (as weight was inappropriate here) though presence/absence analysis matched the pooling of substrate data. In choosing the score for expected and observed patterns the same value was given to an observed pattern which was expected and the lack of expected pattern which was not observed (as was the case for expected pattern which was not observed and *vice versa*). In theory, it is unlikely that all these outcomes were wholly, equally likely though this scoring means that the expected values in the Chi-squared test of association are easier to calculate since the null hypothesis was that there was no significant difference between the numbers of positive and negative valid associations. Additionally, in practise, mitigation is built into the Chi-squared test as it is both distribution free and because of the application of Yates' correction which makes it more conservative.

Creating the classes of analysis proved to be useful. Having the Class 1 method with which to compare against the others allowed subtleties in the data to be identified which could not be picked up using the others. The *a priori*, Class 2 groups enabled comparisons with the classification of sediment types employed by the British Geological Survey to be made in explaining the distribution of some species. Useful though Class 2 was in general it would have been more beneficial to have surveyed a much broader range of substrate types though this could not be accomplished with trawl gear and would introduce inevitable gear related factors. Class 2 was also useful in that it offered a biologically relevant group (Class 2,d) and a separate group (Class 2,e) that separated out

those samples which contained rock which was shown (Figure 4.7, page 93, above) not to be well described by the particulate substrates. Class 3 employed PRIMER-E in a novel method by using the SIMPER routine coupled with MDS and clustering produced groups with the greatest inherent chance of showing significant associations between species and substrate presence/absence data. This was shown to be the case as described by the red highlighted areas on Table 8.4.

Finally, having all nine Classes enabled occasions where highly variable associations between species and substrate presence/absence data to reinforce the not-valid status of un-commonly sampled species. Examples of these species are the spotted and the undulate ray and their descriptions start on pages 246 and 247 in section 8.3.2.

Substrate association for non-fish species were not tested in this analysis. While it has identified groups of unique substrate categories best suited to this task (Class 3,c) this procedure is waiting for detailed knowledge to be more widely available. Databases of invertebrate distributions (e.g. the Marine Life Identification Network; and the National Biodiversity Network) are being developed to the point where they are suitable for this task and, being expanded in terms of their detail and scope. Increasing emphasis is being placed on species level analysis with environmental information (e.g. Hiscock *et al.*, 2004) as a means of understanding the wider importance of species assemblages. This analysis is in preparation and will have the advantage however, that most of the non-fish species sampled are more truly benthic in nature.

Other areas where this analysis can be advanced will be the inclusion of abundance to replace presence/absence in the species data and to generate a better understanding of the substrate data such that these can be generated as relative amounts.

Chapter 9

9 Relationship between the sample and the haul based on their species composition

9.1 Introduction

All the previous Chapters have dealt with the description of the sample data (Aim 1) or its relationship with abiotic data (Aim 2) through the Sample and Environment Themes (Figure 1.4, page 17, above). In order to scale the sample into a larger and wider context, it is necessary to relate the sample data to the haul. The description around Table D.1, page 351 and Table 3.6, page 64 (above) account for the artefacts in the data responsible for the variation in total sample weight and the composition of samples in terms of the fishes; landings “l”, discards “d” and non-fish material “n”, Chapter 5 and Chapter 6 also explored the relationship within the samples. The next step is to describe how well the sample landings data “l” describes the landed haul composition “L” and this is the aim of this Chapter. Figure 1.3, page 16 (above) shows the conceptual model for this. The rationale was to establish how well the landed sample taken describes the landed haul based on the species composition of both. The output from this analysis allows the comparison of the haul to the throughput of the market to be made, (which is the subject of Chapter 10) to assess how representative were the sampled boats to their respective markets. Therefore, this Chapter provides the link between the analysis at the sample scale and the commercial market data scale.

The reason for this sample to haul and haul to market data analysis is that it is only at the sample scale where both discarded fishes and non-fish material were assessed. It is a future expectation that the discarded fishes and non-fish material are quantified at a much larger scale and this will only be possible if the sample is a good representation of the haul and the limits of this relationship can be described and evaluated.

Section 9.2 introduces the haul data and proposes a model (section 9.2.2) to investigate how well the haul data was explained by the sample data. As part of the model a raising factor (see Appendix J, starting on page 392, below) is applied to the sample data. Two were proposed; these are compared and a choice made, as neither is perfect. Circumstances where the chosen raising factor might be flawed are also described. Potential artefacts in the sample data were explored elsewhere (around Table D.1, page 351 and Table 3.6, page 64, above). The haul composition data is similarly explored for artefacts and the performance of the pair trawling is compared to the single boat trawling in the results, (section 9.3). In addition, the outcome of the model analysis is presented and it, and the compromises that were required are discussed. In applying the sample and haul data to the model a decision regarding transforming the data is required. This is important as transforming the data compromise the full data set, meaning that some of it could not be used. The choice of whether to transform the data and criteria it had to meet are also appended to this chapter (Appendix K, starting on page 400, below). The implications of the compromised data set are also discussed.

In proposing the model, it is recognised that some species may be under- or over-represented. The extent to which this occurred according to individual species is explored in section 9.2.2.5.

The analysis in this Chapter is parametric in nature, however for comparison an equivalent and much simpler non-parametric analysis (described in section 9.2.3) is presented so that the suitability of the parametric analysis can be quantified and its performance assessed.

The relationship between the sample and haul in terms of their species composition has also been examined in a separate study (Peach & Cotterell, in prep).

9.2 Methods

The sample data to be compared to the haul data was introduced in Chapter 5 and comprise the species by species weight by haul. As introduced in the Haul meta-data (see section 2.2.1, page 25, above) species level information on the haul composition was recorded with the compliance and active help of the skipper and crew. These data were recorded once the haul had been sorted into species or groups; gutted, washed and placed in baskets on deck prior to these baskets being lowered down into the fish hold and stored in square boxes on ice. The fishermen commonly recorded the amounts (weights) of various species in stones, and since the fish baskets when full hold six stones this could be checked visually, by tipping the contents into the marked fish basket, (Figure 2.6, page 30, above) or using the spring balance. The validity of the weights and volumes in the fish basket is presented Appendix A however the histogram (Figure K.16, page 419, below) does show there were features of the haul composition data due to the way they were collected. All the weights for the sample components were calculated in grams and the haul composition “L” weights in stones were first converted to grams, taking 6,364 g per stone.

Table 3.3, (page 51, above) illustrates the fish species described by the skipper and crew, and which species were grouped by them for simplicity, (e.g. the gurnards and the rays). This produced thirty-one species or groups shown in column six (‘species code, haul’) of Table 3.3 and since the weight of these fish by species were recorded once the fish had been gutted, it was first necessary to raise the weights from gutted to ungutted, so that both groups of fish were ‘round’. This factor was also shown on Table 3.3.

9.2.1 Haul data

Table 2.1, (page 23, above) described the trawl gear. While there was some variability in the gear and amongst the vessels, it was important to determine whether these resulted in significant differences in the haul size. Section 3.5 (and associated Appendix D) explored variation in sample weight. Here the first analysis (section 9.3.1) was a similar GLM based analysis, which examined variation in the landed part of the haul.

9.2.2 Description of the model and testing the data

This section covers four areas.

- 1 This description firstly portrays the individual sample and haul data (section 9.2.2.1).
- 2 Next is described the raising factor that was required to standardize one set of data, and in order to assess the performance of the model between individual sample and haul data (section 9.2.2.2).
- 3 This is followed by a brief description of the transformations required to enable the model to be valid (section 9.2.2.3).
- 4 Finally, the mechanics of the testing of the model between individual sample and haul data is presented (section 9.2.2.4).

9.2.2.1 Basis of model

The model centred on a haul by haul regression of the weight by species found in the sample “I” against the weight by same species found in the haul composition “L” (Figure 1.3, page 16, above). Figure 9.1 shows a graphical representation of the regression model populated by ‘illustrative’ species.

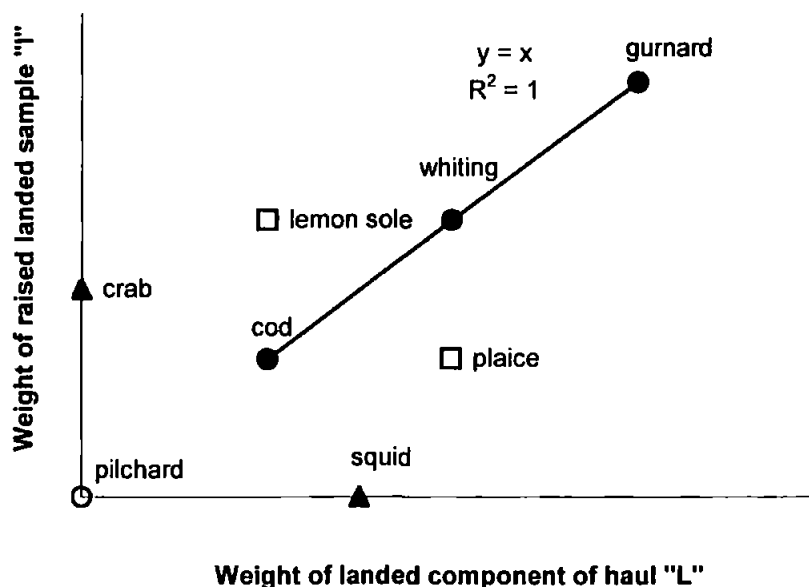


Figure 9.1. Graphical representation of the regression model showing weight of raised landed sample "I" against weight of landed component of haul "L" for eight 'illustrative' species, grouped according to type.

The species as shown in Figure 9.1 were classed into four types and these are described by their legend and type of fish.

The three demersal round fish species (●, cod, whiting and gurnard) were well represented by the model. The raising (see section 9.2.2.2) of the sample weight to the haul weight produced a trend line (where $y = x$) and the fit of the line was very good. The flat fish species (□; lemon sole and plaice) were not well described by the model, with plaice over represented in the haul compared to the sample and the lemon sole being under represented in the sample compared to the haul. Nevertheless, it was expected that these should, to some extent, balance each other out as the model was fitted by a least squares regression (section 9.2.2.5 describes this more fully).

The 'shellfish, ▲' represent species not present in either the sample or the haul. In the model, squid were found in the haul but not the sample. It is not unexpected that this occurred; as if it had not then the sampling would have been exhaustive, although the unpaired nature of these data skews the model. In contrast, crab occurred in the sample but not in the haul. This generated an unacceptable situation, though could occur if items were

overlooked in the haul composition. The case for including or excluding these data is examined in more detail below (see Appendix K, Table K.1 and Table K.2, and associated text).

The model relies on a particular species being present in both the sample and the haul. Section 9.3.2.2 details the occasions where species removals, due to their unpaired nature in the sample and the haul, were required and also tests the hypothesis that on average examples of larger species were more likely to require removal from the haul as they were under represented (and unpaired) in the sample.

Lastly, the pelagic round fish (○; pilchard) did not occur in this haul or sample. The trend only represents species present therefore the line is not forced through the origin.

9.2.2.2 Raising factors

A model as described in Figure 9.1 was generated for each pair of sample and haul datasets. However in order to pool different sample and haul models together or compare one haul with another, or any number of others, it was necessary to scale (or raise) one set of data so that the slope (β) of the regression (described in Figure 9.1) approximated 1. This was achieved by raising the sample data. Details and evaluation of two different raising factors are included in Appendix J, starting on page 392, below) and all regressions of raised landed sample weight “I” against landed component of the haul “L” according to all species occurring in both are presented in Appendix L (Figure L.1 to Figure L.6).

9.2.2.3 Transformations

After raising the sample data, transformations were applied to both the sample and haul data sets. Applying any common transformation compromised further analysis being based on the full data set due to the skew imposed by species present in the haul but not the sample therefore transformations that did not require the exclusion of some of the data were explored first. Also, common transformations were assessed for homogeneity of

variance and fit of model against the untransformed data by testing their performance against an idealised situations of double Box-Cox transformations (Sokal & Rohlf, 1981, p423-426 & 544) which resulted in the $\log_{(10)}(+1)$ being most suitable. The procedure for choosing and applying the transformation and the detailed criteria that the transformed data had to satisfy are described in Appendix K.

9.2.2.4 Testing the data

Once raised and transformed, the sample and haul data were each pooled and individual hauls were compared to the pool of all the others. This was achieved by generating a regression of the raised landed sample weight “I” against the landed component of the haul “L” for one haul (e.g. haul 1). This regression was then compared to assess whether it was significantly difference in both slope and intercept to a regression of the raised landed sample weight “I” against the landed component of the haul “L” for all the other hauls (e.g. hauls 2 – 88). In other words, each haul was compared to the average of all the others. Although this process meant each haul was compared to a slightly different pool of the other hauls it meant that the haul under scrutiny did not occur in the population of hauls to which it was compared.

The regression slopes and intercepts were compared using ANCOVA in Statgraphics (Manguistics, 2000) and the validity of these regressions was examined by testing the residuals for approximating a normal distribution according to the A-D test.

9.2.2.5 Species over/under representation in the model

In proposing the model as described in Figure 9.1 (above) it was recognised that certain species would be over- or under-represented and on Figure 9.1, the flat fishes demonstrated this. The hypothesis tested was whether, by species, the shape of the fish, its average size, its habit or its classification were responsible for it being over- or under-represented.

Whether particular species were systematically over- or under-represented, when comparing the sample and the haul data for the full data set of hauls, was investigated by examining the residual values of the model regressions pooled according to each species. The formal testing of the regression residuals (the over- or under-representation) was carried out through GLM analysis with the residual values being the dependent variable. The factors and covariates that were examined were:

- The shape of the fish (according to both the “*a*” and “*b*” values in the equation $W = aL^b$). “*a*” and “*b*” values were taken from Table 3.3, (page 51, above). Where several species formed one group on Table 3.3 (e.g. the gurnards) averages were taken of both “*a*” and “*b*” values as required.
- The average length of the species. This was calculated from average length per species (or group of species e.g. gurnards and rays) of the landed component of the sample “I”.
- Whether the species were demersal, pelagic or shellfish. Table 10.1, (page 303, below) was used for this data.
- The classification of the species, family, order, and class. Picton & Howson, (1999) and Appendix C (Table C.1, page 348 and Table C.2, page 349, below) were used for this data.

Given that each of these factors or covariates are independent each group were analysed separately.

9.2.2.6 Number of species removed as unpaired in the haul and sample

Heales *et al.*, (2003) investigated the effect of different sizes of sub samples on the probability that species in the haul would be missed in the sample. Here, the number of species in the haul that were unpaired in the sample was investigated as a function of the total haul size to determine whether the sampling strategy (to collect a fixed sample

volume from a variable haul size was robust. This was undertaken as a regression analysis of hauls size against number of species removed, and as a factor analysis of the number of removals according to port and type of trawling.

9.2.3 Non-parametric analysis

This model described in Figure 9.1 (page 271, above) being based on regression analysis was parametric in nature. The parallel non-parametric analysis was undertaken to assess its performance. Two analyses were used.

PRIMER-E (Clarke & Warwick, (2001a) offers a matrix comparison test, based around the Mantel test (Mantel, 1967; Rohlf, 1988). This conceptually simple test using the *RELATE* feature produces a Mantel statistic (M) which is a correlation (or matching) coefficient, although PRIMER-E generates a non-parametric Spearman's rank-order correlation (r_s).

The starting point for this analysis was the two site species matrices, which require at least one example of commonality between the two of the landings component of the fish basket sample "I" and the landed part of the haul "L". To be consistent the sample data was raised (see section 9.2.2.2, (above) and Appendix J, starting on page 392, below) to the haul data (though this process would not have adjusted the rank-order within the matrix). *RELATE* in PRIMER-E (Clarke & Warwick, 2001a) is based on comparing the similarity matrices rather than the initial site species matrices. The similarity matrices were created using the Bray-Curtis similarity measures and based on double square root transformed data (in keeping with Appendix G).

The second non-parametric analysis was a corollary to the ANCOVA comparison of the regression lines. This was a rank-order analysis of the species present in both the sample and the haul and employed the Wilcoxon signed ranks test (Zar, 1999, p165).

Dytham, (1999, p75) further suggests, "...a minimum of six pairs of data [are] required before the test can be carried out."

The performance of the parametric model was compared to the non-parametric analysis (for those hauls which the assessment was possible) through examination the significance values (as correlations) of the parametric and non-parametric models, since it was expected that hauls well described by their sample in the parametric model should also similarly be well described in terms of the non-parametric analysis.

9.3 Results

9.3.1 Haul data

Table 9.1 shows the possible reasons (from a full factor GLM) for variation in the size of the landed component "L" according to a variety of factors and covariates.

Table 9.1. Full factor GLM testing the size of the landed component "L" for: wind = wind speed (knots) encountered, dur = duration of tow (mins), dep = depth of haul (m), speed = speed of tow (ms^{-1}), d/n/t = time of haul (day/night/twilight), trip # = sequential trip aboard that particular boat, port & type = port and type of trawling (pair or single boat) and interaction factors. Note that covariances are not dealt with as interactions, and no interactions generated zero d.f. Significant interactions are highlighted.

| source | d.f. | F value | P value |
|------------------------------|------|---------|---------|
| corrected model | 40 | 4.359 | < 0.001 |
| intercept | 1 | 0.429 | 0.516 |
| wind | 1 | 2.376 | 0.130 |
| dur | 1 | 0.159 | 0.692 |
| dep | 1 | 0.461 | 0.500 |
| speed | 1 | 0.043 | 0.836 |
| trip # | 3 | 1.548 | 0.215 |
| d/n/t | 2 | 1.696 | 0.194 |
| port & type | 5 | 6.447 | < 0.001 |
| trip # * d/n/t | 6 | 0.810 | 0.567 |
| trip # * port & type | 14 | 3.181 | 0.001 |
| d/n/t * port & type | 3 | 0.488 | 0.692 |
| trip # * d/n/t * port & type | 2 | 0.105 | 0.901 |
| error | 47 | | |
| total | 88 | | |
| corrected total | 87 | | |

Only port and type of trawling, (and relationships involving this factor) generated significant interactions for the total size of the landed component. The Levene's test of equality of error variance returned $P < 0.001$ and suggests that the variance was not evenly distributed for the chosen factors; therefore, Table 9.1 should be interpreted with a degree of caution. Nevertheless, none of the other results in Table 9.1 were close to the $P = 0.05$ level of significance. $R^2 = 0.788$ for the GLM in Table 9.1, though the adjusted $R^2 = 0.607$ suggesting the model is well described by the data. Figure 9.2 shows the total landed component of the haul for the four ports and two types of fishing.

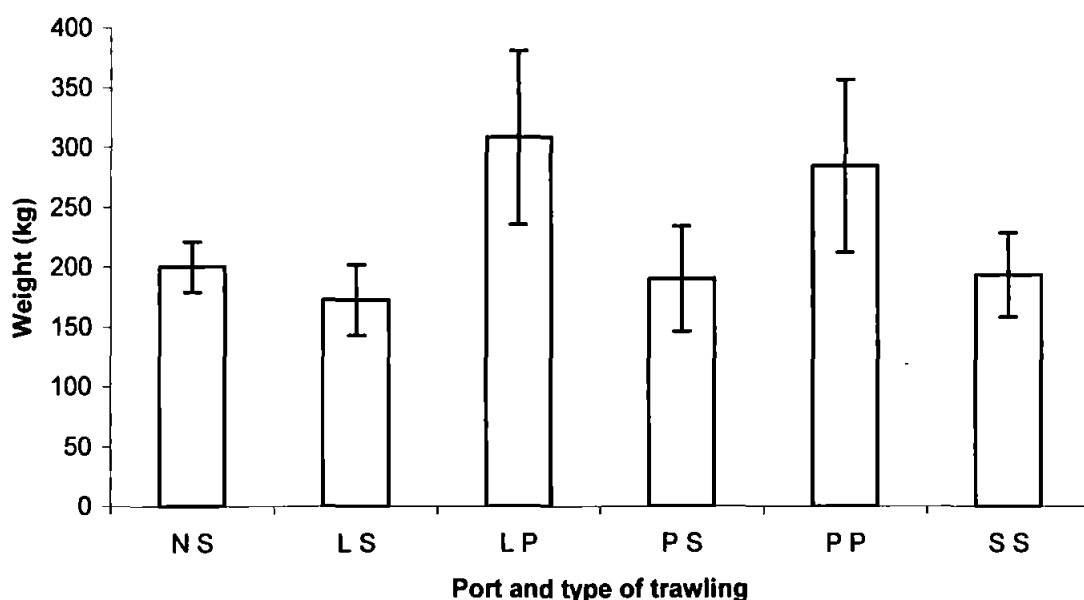


Figure 9.2. Average and 95 % confidence intervals of total landed component (kg) of the haul according to port and type of trawling, N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling.

As expected the pair boat trawling yielded the greatest landed component with a degree of similarity amongst the average weight by haul of the single boat operations, though if the average total weight was calculated by boat, (i.e. the values for pair boat trawling are halved) then the result are as depicted by Figure 9.3.

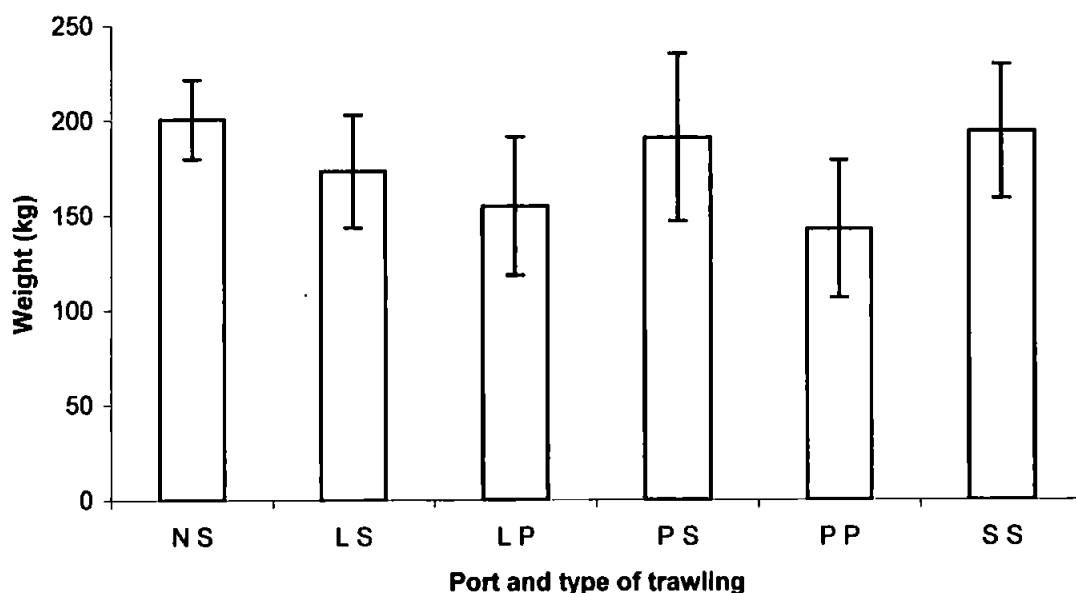


Figure 9.3. Average and 95% confidence intervals of total landed component (kg) according to the number of boats involved according to port and type of trawling, N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling.

Figure 9.3 shows that the largest average landed component (Newlyn) came from the largest boat (with by far the greatest engine power, see section 2.1), although this did not result in significant differences. Also, that pair boat trawling was less productive (as measured by the landed component) than single boat trawling.

Table 9.2 shows the results of the GLM where the landed component was halved for the pair boats operations.

Table 9.2. Full factor GLM testing the size of the landed component “L” per number of boats involved for: wind = wind speed (knots) encountered, dur = duration of tow (mins), dep = depth of haul (m), speed = speed of tow (ms^{-1}), trip # = sequential trip aboard that particular boat, d/n/t = time of haul (day/night/twilight), port = port of sailing, type = type of trawling (pair or single boat) and interaction factors. Note that covariances are not dealt with as interactions and the interactions of d/n/t * type, trip # * d/n/t * type, d/n/t * port * type, and trip # * d/n/t * port * type generated zero d.f.

| source | d.f. | F value | P value |
|-----------------------|------|---------|---------|
| corrected model | 40 | 1.234 | 0.243 |
| intercept | 1 | 1.990 | 0.165 |
| wind | 1 | 1.510 | 0.225 |
| dur | 1 | 0.304 | 0.584 |
| dep | 1 | 0.193 | 0.662 |
| speed | 1 | 0.002 | 0.963 |
| trip # | 3 | 1.463 | 0.237 |
| d/n/t | 2 | 0.567 | 0.571 |
| port | 3 | 1.074 | 0.369 |
| type | 1 | 0.009 | 0.924 |
| trip # * d/n/t | 6 | 0.821 | 0.559 |
| trip # * port | 9 | 1.615 | 0.138 |
| d/n/t * port | 3 | 0.575 | 0.634 |
| trip # * d/n/t * port | 2 | 1.297 | 0.283 |
| trip # * ty | 3 | 0.824 | 0.487 |
| port * ty | 1 | 0.828 | 0.367 |
| trip # * port * type | 2 | 0.191 | 0.827 |
| error | 47 | | |
| total | 88 | | |
| corrected total | 87 | | |

Table 9.2 shows that after dividing the landed part of the hauls by the number of boats involved in the operation there were no significance difference in the size of the landed component. This GLM was valid as $P = 0.652$ according to the Levene’s test of equality of error variance and the $R^2 = 0.512$. The great difference in the Levene’s test between this GLM and Table 9.1 suggested that much of the variance in the above GLM was due to the very different size of the landed part of the haul according to whether the operation was from single or pair boats:

The GLM in Table 9.2 adequately showed there were no artefacts in terms of the factors and covariates that bias the relative size of the landed component of the haul “L” according to the number of boats in the operation. This is important as it confirmed the lack of difference in landed part of the haul. Interactions involving type of trawling returned zero d.f. due to the inability to nest type of trawling within port of sailing (as explained on page 351 below).

9.3.2 Model output

Figure K.14 (page 417, below, in Appendix K) shows the full set of raised and log transformed landed sample weight data (employing the more simple raising factor 2, validated in Appendix J) against the adjusted (gutted to ungutted) weight of landed species within the haul for species present in both the sample and the haul; ($y = 0.8517x + 0.609$, $R^2 = 0.5349$).

Figure 9.4 shows the same data though arranged to present the model output for haul 1, (the first of two hauls taken onboard a single trawl boat from Looe on 24/04/98) and the regression for the data in haul 1 compared to hauls 2 to 88 inclusive. Thus, it shows the full data set split into the haul under scrutiny (haul 1) and all the others (hauls 2 to 88).

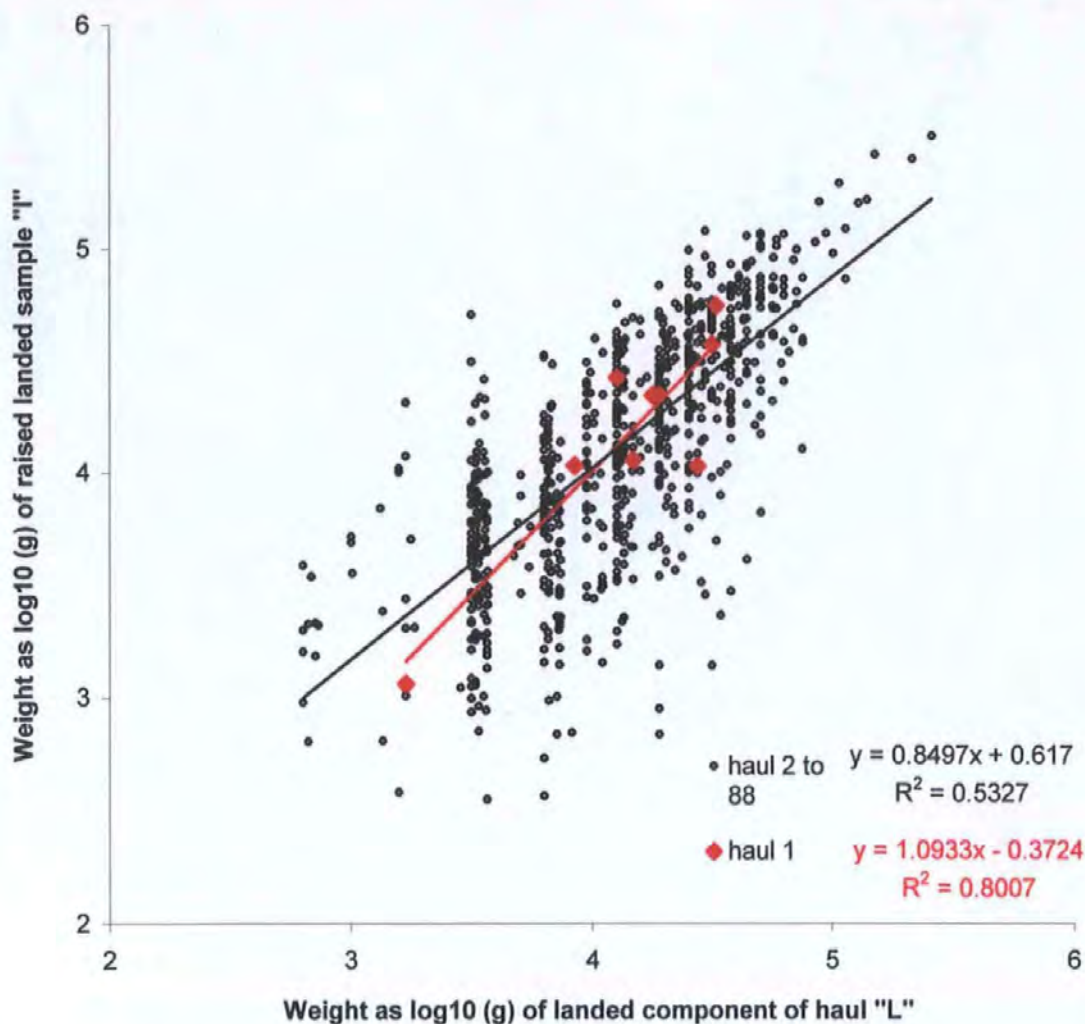


Figure 9.4. Weight as \log_{10} (g) of raised landed sample "I" against weight as \log (g) of landed component of haul "L" showing the data and slope for haul 1, ($n = 9$) compared to the data and slope for all other (2 – 88) hauls, ($n = 768$).

The comparison of the two regression lines described in Figure 9.4, carried out in Statgraphics, (Manguistics, 2000) suggested that the regressions were not significantly different for intercept, or slope, (ANCOVA intercept $P = 0.840$; slope $P = 0.442$, d.f. = 1).

Figure 9.4 illustrated the model for one haul. Rather than show all individual comparisons in this way Figure 9.5 shows a scatter plot of the intercept and slope ANCOVA P values for all hauls, ($n = 88$) generated when comparing the regression of landed sample species "I" against landed haul species "L" for each haul (haul 1, haul 2 ...haul 88) compared to the pool of all the others (haul 2 to 88, haul 1 and 3 to 88...haul 1 to 87).

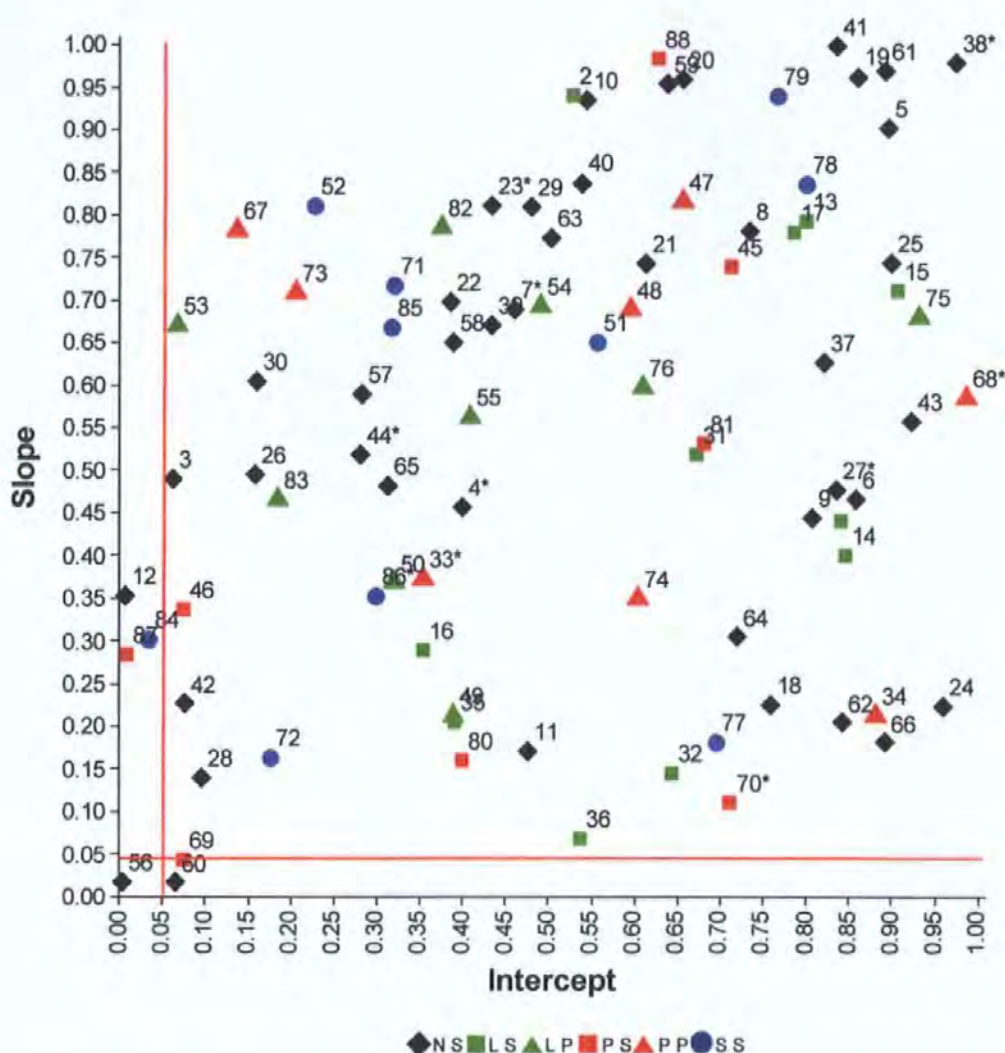


Figure 9.5. Scatter plot showing slope and intercept P values, results of ANCOVA (comparison of slopes) between weight as \log_{10} (g) of raised landed sample "I" against weight as \log (g) of landed component of haul "L" for each individual haul ($n = 1$) and the sum of all the others ($n = 87$). The data are numbered by sequential hauls (Table 3.2, page 49, above and labelled according to port and type of trawling, N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling.

The two red lines on Figure 9.5 denote values of $P = 0.05$ for slope and intercept. Only on two occasions were the slopes of the regression lines between particular hauls and the pool of all the others significantly different (hauls 60 and 69) and on three occasions were intercepts similarly significantly different (hauls 12, 84 and 87). There was also one haul (# 56) that was significantly different to the rest for both slope and intercept and there did not appear to be a trend evident in the scatter of Figure 9.5 in terms of port and type of trawling. Figure 9.5 does show that for the majority of hauls (96 % of them) the species

composition of the samples was not significantly different to the species composition of the haul itself; therefore, these hauls were well described (statistically significant) by their sample. Section 9.3.3 further describes the hauls that were not significantly well described by their samples.

Figure 9.5 represented a compact way of illustrating this rather than showing all 88 graphs similar to that shown in Figure 9.4, above. Appendix L (Figure L.1 to Figure L.6) presents the untransformed weight of raised landings against weight of haul composition for the 88 hauls. These graphs display only those species present in both the sample and the haul, and are complete with regression statistics and r^2 values. These figures also show the range of the fit between the two plotted data sets, though as the size of the haul varied the axes scales also differ.

There were 10 hauls (numbers 4, 7, 23, 27, 33, 38, 44, 68, 70 and 86, denoted with an asterisk on Figure 9.5) where the regression model was not strictly valid in that the regression residuals did not approximate a normal distribution (according to the A-D test at the 5 % level), though for all of these hauls mentioned there was not a significant difference between either the intercept or slope ANCOVAs for the model outcome.

9.3.2.1 Species over/under representation in the model

Figure 9.6 shows (according to species) the average and (generally) 95 % C.I. of the residuals from the regression of co-occurring raised (and transformed) landed sample data "I" against gutted to ungutted transformed landed haul data "L" (derived from the regression shown in Figure K.14).

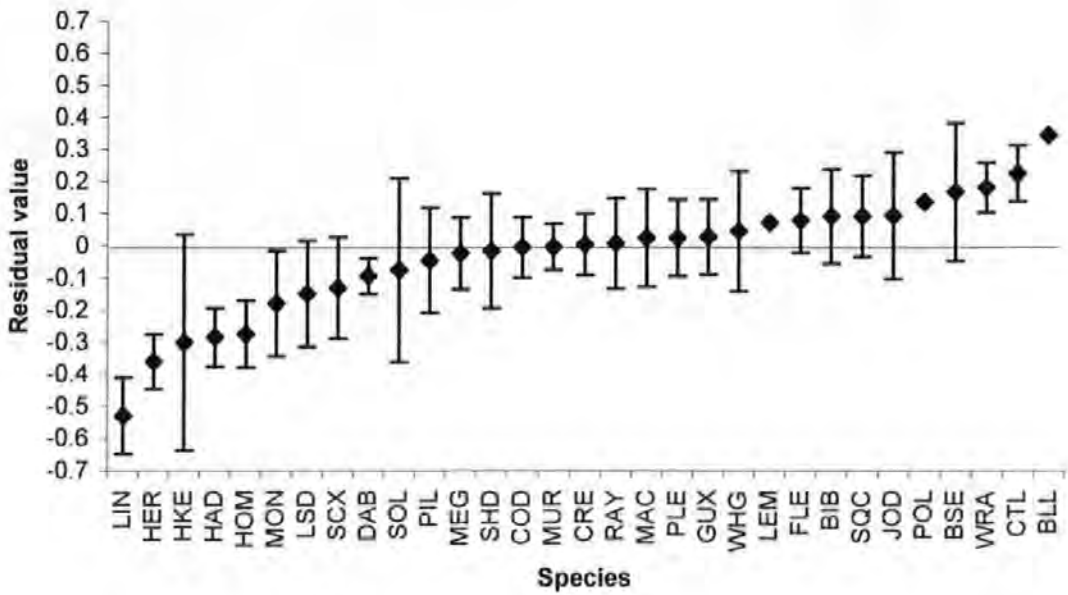


Figure 9.6. Average and 95* % C.I. of residuals according to species (in order of average residual values) present in both the sample and the haul. See Table 3.3 (page 51, above) for a list of species and codes, (*66 % C.I. are shown for herring, scallops, crabs and brill, and averages only for pilchards, shad, and wrasse).

Ling was the most under-represented species in the sample “l” when compared to the haul “L” and brill was the most over-represented species, though the over-representation was generally smaller (by species) than the under-representation according to species. The formal testing of over and under representation of species are summarised in the GLM outputs in Table 9.3.

Table 9.3. Significance and validity (only for factors and not covariates) of the residuals against the shape of the fish (“a” and “b” values), the average length according to species, whether the species were demersal, pelagic or shellfish and the species’ classification.

| factor* or covariate [†] | significance, (P value) | validity, (P value from Levene’s test of equality of variance) |
|-----------------------------------|-------------------------|--|
| “a” value [†] | 0.237 | * |
| “b” value [†] | 0.517 | * |
| length of fish [†] | 0.783 | * |
| demersal, pelagic or shellfish* | 0.219 | 0.913 |
| family* | 0.841 | 0.229 |
| order* | 0.801 | 0.180 |
| class* | 0.673 | 0.466 |

None of the factors or covariates described in section 9.2.2.5 produced significant interactions as shown in Table 9.3 suggesting the under-and over-representation of species present in both the sample and the haul was not due to shape or size of fish, functional type of the fishes or according to taxonomic classification.

9.3.2.2 Number of species removed as unpaired in the haul and sample

Figure 9.1 (above) graphically displayed the rationale (maintaining a good line of best fit) for excluding species present in the haul but not present in the sample and Figure K.6 (page 408, below) showed that this was indeed necessary and Table K.1 (page 402, below) showed how many data were excluded for this analysis. The exclusion however removed a proportion of the sample data which while justified in the analysis and expected because the sample was a sub-set of the haul it was nevertheless large (35 %). Figure 9.7 shows a frequency histogram of the number of species removed for all 88 hauls.

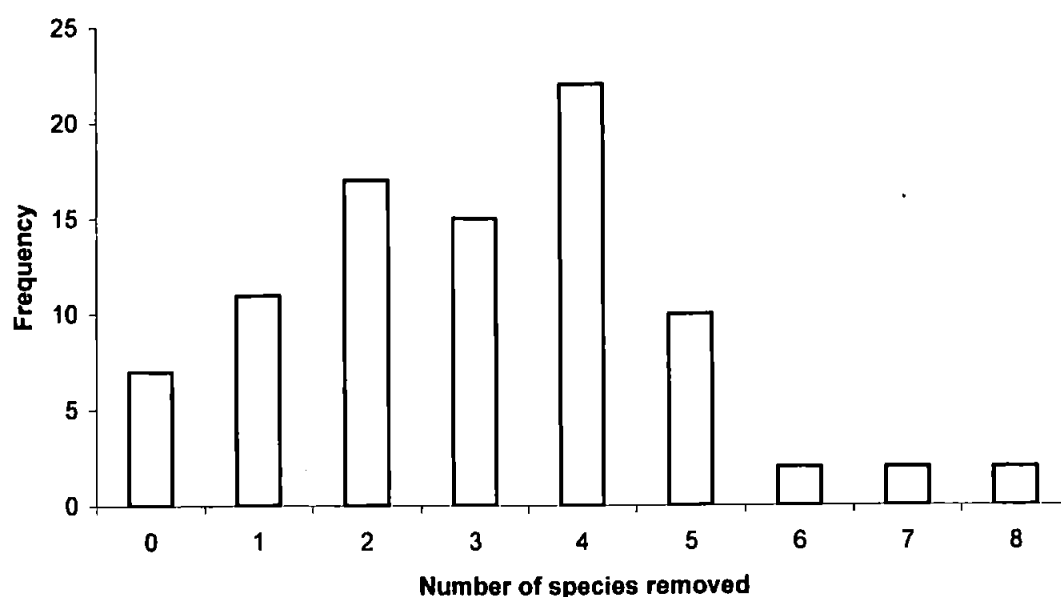


Figure 9.7. Frequency of the species removed from each haul due to being present in the haul "L" but not in the sample "I", $n = 270$.

It is apparent from Figure 9.7 that for 7 hauls no species needed to be removed and the most common number of removals was 4. As evident the distribution in Figure 9.7 is right skewed ($g_1 = 0.621$), and large numbers of removals of species (≥ 5) were very uncommon. How these removals break down according to species present in the landed part of the haul but not present in the landed part of the sample is shown in Table 9.4.

Table 9.4. Number of times species (or groups) were removed for analysis because they occurred only in the haul and not in the sample. See Table 3.3, on page 51 (above) for a list of species and species codes.

| sp | # removed | # in both | % | sp | # removed | # in both | % |
|-----|-----------|-----------|-----|--------------|------------|------------|-----|
| RAY | 31 | 38 | 82 | MUR | 6 | 12 | 50 |
| LIN | 22 | 6 | 367 | PLE | 6 | 44 | 14 |
| MON | 22 | 22 | 100 | BIB | 4 | 49 | 8 |
| SOL | 20 | 5 | 400 | BSE | 4 | 6 | 67 |
| HOM | 17 | 26 | 65 | DAB | 4 | 23 | 17 |
| LSD | 16 | 25 | 64 | HAD | 4 | 5 | 80 |
| COD | 15 | 51 | 29 | SQC | 4 | 77 | 5 |
| MEG | 15 | 30 | 50 | CTL | 2 | 6 | 33 |
| POL | 13 | 14 | 93 | FLE | 2 | 13 | 15 |
| CRE | 11 | 3 | 367 | PIL | 2 | 1 | 200 |
| WHG | 11 | 56 | 20 | GUX | 1 | 82 | 1 |
| BLL | 9 | 3 | 300 | HER | 1 | 3 | 33 |
| SCX | 9 | 3 | 300 | MAC | 0 | 15 | 0 |
| LEM | 7 | 75 | 9 | SHD | 0 | 1 | 0 |
| HKE | 6 | 32 | 19 | WRA | 0 | 1 | 0 |
| JOD | 6 | 50 | 12 | TOTAL | 270 | 777 | |

The order of the species (or groups) in Table 9.4 was according to the numbers removed, and it is clear that rays, then ling and monkfish occurred most commonly in the haul but not in the sample. Conversely, there was only one occasion on which gurnards were found in the haul but not in the sample. While much rarer in the haul herring were only once missed in the sample when present in the haul. Shad and wrasses were rare too but never missed when sampling.

Examining the list of groups in Table 9.4 it appear that physically larger species or groups more often occurred in the haul but were not present in the sample. This was shown to be the case by a (two-tailed) Spearman's rank-order correlations between the average fish length by species and the number of times that species was unpaired, ($r_s =$

0.448, $n = 31$, $P = 0.008$). The (two-tailed) Spearman's rank-order correlations was chosen since while the average length of fishes in Table 9.4 approximated a normal distribution according to the A-D test ($A^2 = 0.435$, $n = 31$, $P = 0.281$) the number of removals do not ($A^2 = 1.059$, $n = 31$, $P = 0.008$).

A further degree of bias was evident in the sample to haul analysis. The number of unpaired species in the sample and the haul increased as the haul size increased according to the relationship $\log_{10} y = 0.036x + 5.184$, $R^2 = 0.144$, where y = the total haul weight and x = the number of species removed so that only paired species remained. While the equation explains only 14 % of the variation in the total haul size, the result was nevertheless significant ($P < 0.001$). Total haul size was log transformed as with this transformation the residuals approximated a normal distribution according to the A-D test ($A^2 = 0.593$, $n = 88$, $P = 0.118$). According to the K-W test, there were no significant differences between in the number of species removed according to port and type of trawling ($H = 9.13$, d.f. = 5, $P = 0.104$, adjusted for ties). The K-W test was chosen as the number of removals did not approximate a normal distribution according to the A-D test ($A^2 = 1.453$, $n = 88$, $P < 0.005$). Indeed the average number of species removed for all the pair trawl samples (mean \pm s.d. = 3.65 ± 1.22 , $n = 17$) was less than the number for the equivalent (Looe and Plymouth) single boat hauls (mean \pm s.d. = 2.42 ± 1.57 $n = 19$).

9.3.3 Non-parametric analysis and comparison with parametric analysis

RELATE in PRIMER-E (based on comparing the Bray-Curtis derived and double square root transformed data (in keeping with Appendix G) of the similarity measures (the landed sample and landed haul data rather than the initial site species matrices) produced $r_s = 0.715$, $P = 0.001$, showing that the two matrices were significantly similar. The comparable (Sokal & Rohlf, 1995, p817-818; Dytham, 1999, p169) parametric, multiple R,

of the model in Figure K.14 417 (below) was slightly higher at $R = 0.731$, though both procedures produced superficially similar significance levels $P = 0.001$ and $P < 0.001$ respectively.

Limiting the Wilcoxon signed ranks test to occasions where there were 6 or more species in both the landed sample and landed haul meant that only 82 hauls could be examined with numbers 13, 18, 37, 50, 77, 87 being excluded. There were however often more species present in both the landed part of the sample and haul (mean \pm s.d. = 8.8 ± 2.4). Figure 9.8 shows the outcome of the Wilcoxon signed ranks tests comparing the order of species co-occurring in both the landed part of the sample and haul.

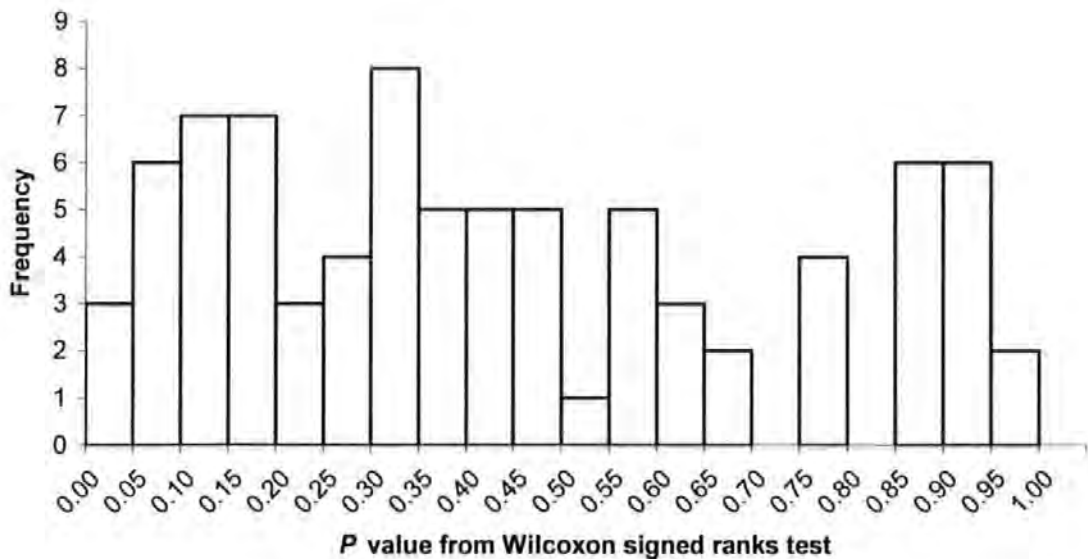


Figure 9.8. Frequency histogram of P values from Wilcoxon signed ranks tests between the landed species in the sample and haul where n (number of species in both) ≥ 6 ($n = 82$).

Figure 9.8 shows that in only 3 out of the tested 82 hauls ($\sim 4\%$) were the rank-order of the species common to both the landed part of the sample and landed part of the haul significantly different according to the Wilcoxon signed ranks tests. Figure 9.8 can be thought of as a 1-dimensional representation of the 2-dimensional plot in Figure 9.5.

While there were no sample to hauls analyses which were not analysable by the parametric method 6 hauls failed to satisfy the criteria (Dytham, 1999, p75) for comparing

the co-occurring landed sample and haul data according to species so it appears that the non-parametric methods were robust and reliable, however the correlation between the P values for either slope or intercept when compared to the P values as generated by the non-parametric Wilcoxon signed ranks test were low; (slope and non-parametric $r_s = -0.131$, $n = 82$, $P = 0.239$; intercept and non-parametric $r_s = 0.120$, $n = 82$, $P = 0.339$). Thus, while the non-parametric method seemed superficially better in some respects it has failed to accurately describe the data. This is borne out by examining the hauls that the parametric model suggested were significantly different to the pool of all the others. Figure 9.9 shows the six hauls which were not significantly well described by their sample.

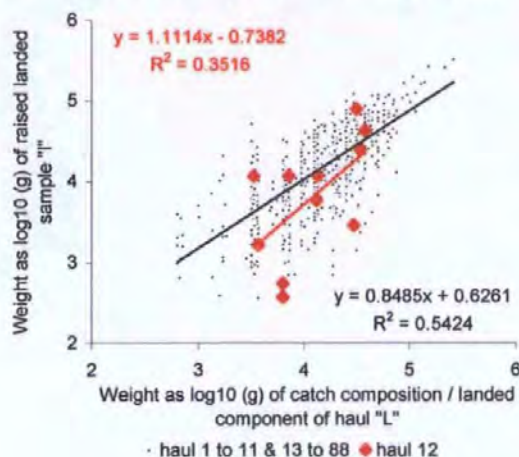
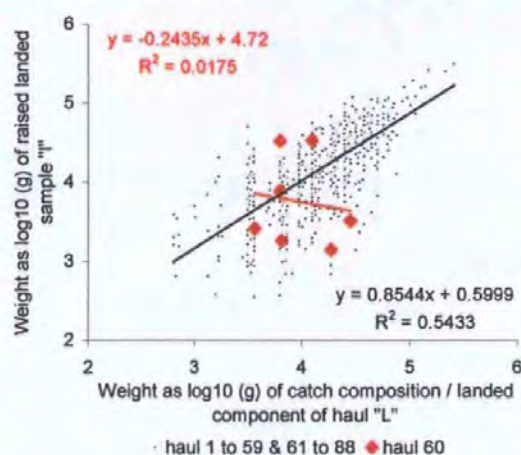
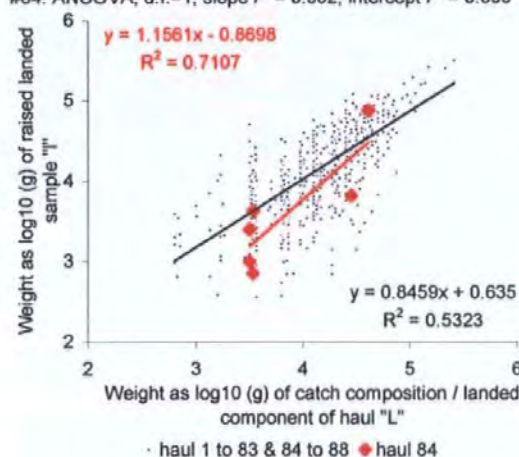
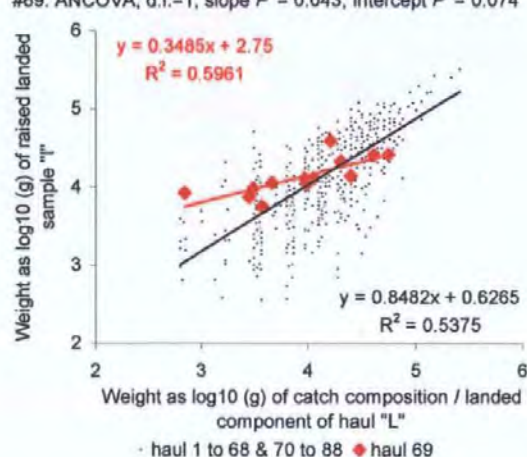
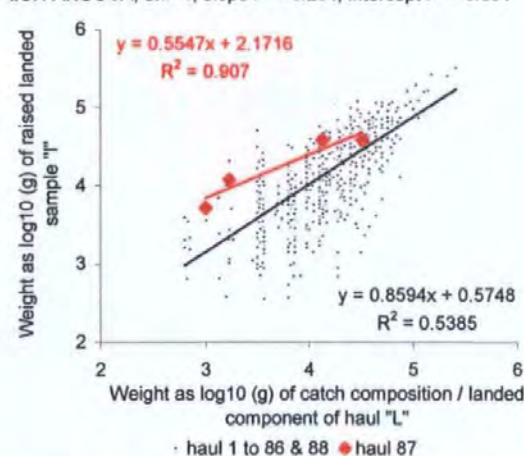
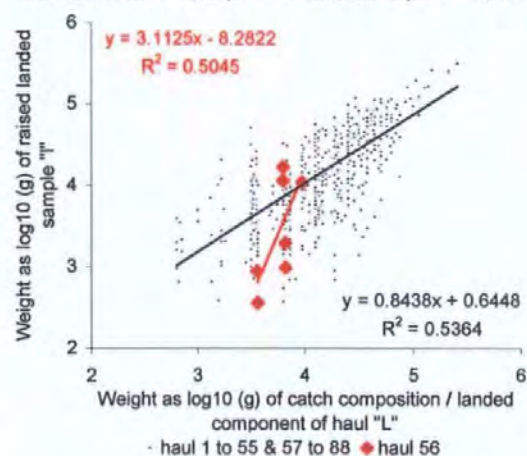
#12. ANCOVA, d.f.=1, slope $P = 0.354$; intercept $P = 0.007$ #60. ANCOVA, d.f.=1, slope $P = 0.017$; intercept $P = 0.086$ #84. ANCOVA, d.f.=1, slope $P = 0.302$; intercept $P = 0.035$ #69. ANCOVA, d.f.=1, slope $P = 0.043$; intercept $P = 0.074$ #87. ANCOVA, d.f.=1, slope $P = 0.284$; intercept $P = 0.001$ #56. ANCOVA, d.f.=1, slope $P = 0.018$; intercept $P = 0.004$ 

Figure 9.9. Weight as log₁₀ (g) of raised landed sample "I" against weight as log (g) of haul composition/landed component of haul "L" showing the data and slope for [left, top to bottom] hauls 12, 84 and 87 and [right, top to bottom] hauls 60, 69 and 56. Each haul is compared to the pool of all the other. Regression equations for the haul are top left and for the pool are bottom right on each figure.

The left side of Figure 9.9 shows three hauls (numbers 12, 84 and 87). The parametric model suggested these hauls were significantly different to the pool for intercept. The right side of Figure 9.9 shows two hauls (numbers 60 and 69) and the parametric model suggested these hauls were significantly different to the pool for slope. Also on the right is the single haul (number 56) which the parametric model suggested was significantly different to the pool for both intercept and slope. In examining the plots on Figure 9.9, it was generally obvious that the hauls differed to the pool as described. Table 9.5 shows the outcome of the nonparametric Wilcoxon signed ranks tests for these hauls.

Table 9.5. Wilcoxon signed ranks test statistic (Z), number of observations and significance (P) value for the same hauls as shown in Figure 9.9. The data are also arranged in the same order as was shown in Figure 9.9.

| # | Z | n | P | # | Z | n | P |
|----|--------|-----|-------|----|--------|-----|-------|
| 12 | -1.067 | 11 | 0.286 | 60 | -0.845 | 7 | 0.398 |
| 84 | -0.524 | 6 | 0.600 | 69 | -0.943 | 13 | 0.345 |
| 87 | * | 4 | * | 56 | -0.169 | 7 | 0.866 |

According to Table 9.5 the Wilcoxon signed ranks test was not able to detect a significant difference between the rank-order of co-occurring species in the sample and haul data. Haul 87 did not have sufficient co-occurring species for the test to be conducted.

It appears therefore that while the derived non-parametric matrix comparison of the sample and haul may be valid it is not acceptable to compare the rank-order of species present in each when a parametric method can be applied.

9.4 Discussion

9.4.1 Haul data

The haul data showed that pair trawling did generate about twice the landed haul of single boat trawling. Importantly though, according to the number of vessels there was no

significant difference in the landed part of the haul by port and type of trawling. However many other factors may influence skippers' decisions as whether to pair trawl, or operate independently. In my experience, (and supported by Gray, 1995; Pawson *et al.*, 2002) the skippers in this study preferred to operate independently and only tended to pair trawl for two reasons. Firstly, if they expected the fishing yield to be relatively poor and by pairing they split the risk (and return). This was most commonly found during the period early in the New Year when whiting were the target species. Also during the late summer when there were few aggregations of fish and squid may become more plentiful. The second reason was if the boats are short of crew. Here rather than requiring one crewmember per boat, they only really need one crewmember between the boats, though this means that everyone in the pair team is required to work very hard. In addition, there is the added complication and potential hazard of possibly transferring the crewmember between boats to work on the haul, or lifting and processing the haul onto only one boat. One-man operation of a fishing boat (however it is engaged) is very hazardous. Fishermen in this study told me of several accidents which were due to the one-man operation of fishing boats though when operating as a pair some of these risks are reduced.

9.4.2 Model output

The minimum number of species present in both the landed part of the sample and haul was 4. This was relevant since this is the minimum number of points required to accurately describe a regression or apply a confidence interval, thus Figure 9.4, on page 281 and Figure 9.5, page 282 (above) derived from it and Appendix L (Figure L.1 to Figure L.6) display regression plots which are valid in this feature.

The variability of the raised landed sample values against the landed haul composition data was expressed (according to each haul) in $r^2 < 1$. The lack of goodness of fit of the model was due to the over or under representation of sampled species when

compared to the haul, though this was not related to features of the fishes' shape, size, life-style or taxonomy.

That physically larger species or groups more often occurred in the haul but were not present in the sample suggested a not unexpected bias in the fish basket sampling method. Also, that the number of species removed was positively (though poorly) related to the size of the landed part of the haul showed another bias in the method, although trends in the number of species removed did not suggest that the basket method of sampling was unrepresentative for the size of samples and hauls in this study.

9.5 Conclusions

This section has described how effective the sub-sampling of the haul has been and that, generally, a sub-sample of one basket of fish from the cod end was a statistically significantly similar representation of the haul for 97 % of the samples when the ANCOVA model described above is examined for slope only. This dropped to 95 % where the sample was a statistically significantly similar representative of the haul for intercept only. 94 % of the samples were statistically significantly similar to the haul for both intercept and slope of the model as described above.

This analysis has required several components of the data to be removed, though this has been justified, and analysis was made on the removed data. Additionally, two raising factors were compared for their ability to describe the data. In addition, several transformations were compared though the best transformation of the data turned out to be the $\log_{10}(x+1)$ and this was rigorously tested.

The analysis carried out in this Chapter was important because, in scale, it was positioned between the small scale of the sample (Chapter 5 and Chapter 6) and the throughput of the market (see Chapter 10). It was necessary to describe the relationship

between the composition of species in the sample and the haul to join these two disparate scales in a meaningful way.

Chapter 10

10 The relationship between the haul species composition and commercial market data

10.1 Introduction

Chapter 5 and Chapter 6 examined the sample and Chapter 9 showed that in most cases the sample was a good descriptor of the haul. This chapter explores the larger scale of the relationship between the landed part of the haul and the market data, asking the question: how representative were sampled boats to the throughput of their respective ports? The outcome of this analysis will allow a future examination of discarding at the level of the Market though here it completes the scaling of the sampling Aims in describing the region (ICES VIIe).

Market sampling does not feature strongly in the published literature though its obvious time and cost benefits (Agger *et al.*, 1974) suggest that it would be useful to link the operation of a vessel with the activity of the market. Using market statistics to derive information about the features of the stock are rare (Bromley, 2000; 2003) and there are no published sources where individual hauls are compared to the market throughput, although being able to make this link may allow predictions on the market data to be made from sampling relatively few representative vessels or conversely, knowledge of the impact of trawling to be determined from market throughput. The aim of this Chapter was to

determine how representative were the studied vessels to their respective markets to determine whether these scaling-up or scaling-down assessments can be made. The four ports studied here also differed qualitatively in their use and quantitatively in their size; therefore, it was also possible to assess the scale of the relationship.

10.2 Methods

This aim of this Chapter was achieved through a pair-wise analysis of species (or aggregated groups of species) between commercial landings from market data and a list from boats sampled in this study.

The first part of the Methods (section 10.2.1) describes the data sources and compares and contrasts the character of each port and describes their demersal, pelagic and shellfish components. In order to generate a paired relationship between the species in the sample and market data a two-stage examination of the species composition was required (section 10.2.2 and 10.2.3). Section 10.2.4 presents the resulting species list and section 10.2.4.1 analyses whether it was best to compare the haul data with quarterly or monthly derived market data. The final part (section 10.2.5) describes a process whereby the bias in the market data due to the presence of types of fishing boat not sampled in this study was considered.

10.2.1 Data sources

The landed part of the haul was introduced in Figure 1.3 and described in detail in Chapter 9. In order to relate these data to the throughput of the fish markets data at two scales of resolution were employed.

- Annual landings data for Newlyn, Looe, Plymouth and Salcombe from 1990 to 2001 inclusive. This was to provide a broad historical overview of the performance and inter-annual variability of the four ports.
- Monthly data from the same four ports during 1998, 1999 and 2000 (the period of this study). This was the finest scale data available.

The main source for annual data by port was MAFF/DEFRA, (1990-2001) which were whole numbers of tonnes (quantity) or pounds (value).

The ports included in MAFF/DEFRA, (1990-2001) varied over time. Only Plymouth and Newlyn were included for the entire period. Looe first appeared in the data in 1993 though Salcombe, (not being in the top fifty ports by quantity of landings) was combined into “Other South Coast Ports.” The reasons for the exclusion of both Salcombe and Looe, (until 1993) is contained in explanatory notes seven and eight (MAFF/DEFRA, 1990-2001, p1) which detail some of the shortfalls of using these data. These explanatory notes are included and rationalised below:

Explanatory note seven

“There is no statutory requirement for owners of vessels 10 metres and under overall length to declare their catches. Information for this Sector is collected with the co-operation of the industry: it comprises log sheets and landings declarations voluntarily supplied by fishermen and assessments of landings derived from market sources and by correspondents located in these ports. Also full documentation is not required for most fishing for non-TAC species, including shellfish, and summary records are compiled using information supplied voluntarily by the industry, from a variety of local sources and surveys run by Sea Fisheries Committees. Where assessments are made, the information may not be fully disaggregated by port. At the most detailed level, the figures shown may not therefore be complete.”

Vessels 10 metres and under in overall length vary in the significance to which they contribute in the ports of Newlyn, Plymouth, Looe, and Salcombe, (their contribution increasing in order as listed (Gray, 1995;Pawson *et al.*, 2002).

Explanatory note eight

“Certain ports have been combined geographically to safeguard commercial confidentiality.”

This statement is of particular relevance to the port of Salcombe of the four studied here, where on average approximately 600 tonnes of crabs are landed annually (see Figure 10.2, page 300, below), by the potting fleet, which are by far the majority of the boats using the port. In comparison, a few tonnes of demersal fish are landed by a handful of trawlers operating as day boats, (Devon Sea Fisheries *pers com.*).

Annual data for 1990 to 2001 for Salcombe and 1990 to 1992 for Looe was obtained directly from the Fish Statistical Unit of DEFRA, (London, *pers com.*). The list of species described in MAFF/DEFRA, (1990-2001) were slightly different to those as supplied by DEFRA with the species list supplied by DEFRA being more comprehensive. Also, the species list in MAFF/DEFRA, (1990-2001) changed over time, from 1990 to 1993 inclusive having a few less common species added to them, but from 1994 to 2001 they remained unchanged. In order to allow comparability between ports the lists were adapted so that they all featured the same species list of the later years, with the additional data being again supplied by the Fish Statistical Unit of DEFRA, (London, *pers com.*).

The next section describes the market throughput of the ports and their demersal, pelagic and shellfish composition.

10.2.1.1 Port throughput

Figure 10.1 shows that of the four ports sampled two can be described as large and the other two as small.

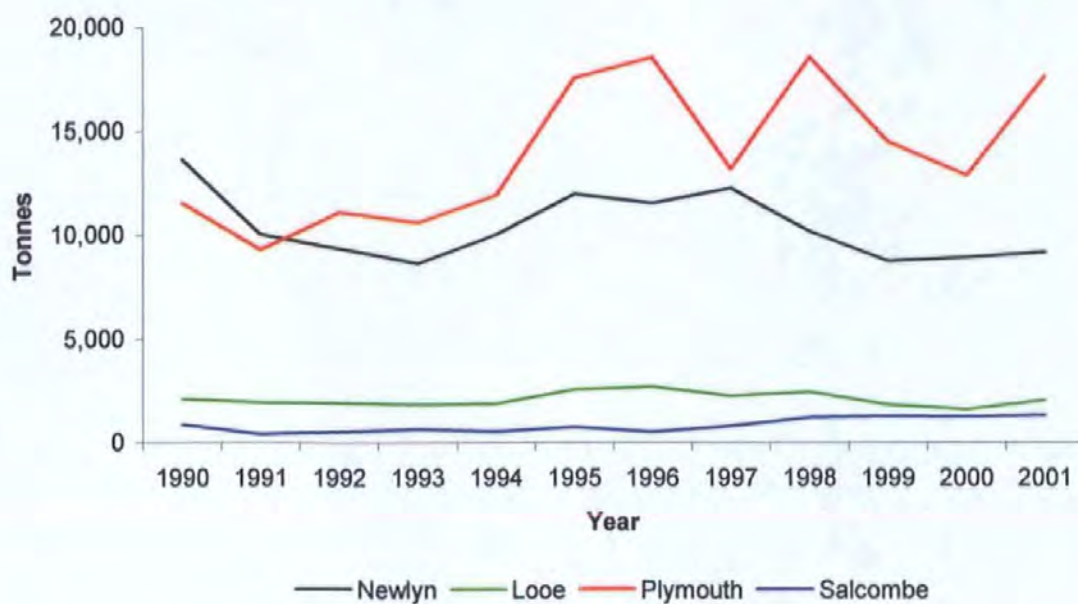


Figure 10.1. Annual total throughput of four ports (Newlyn, Looe, Plymouth and Salcombe) from 1990 to 2001. Source, MAFF/DEFRA, (1990-2001) and London (*pers com*).

There was also considerable variation in the landings through Plymouth (evident on Figure 10.1 and explained below) though there is a greater degree of stability in the data reported for the other ports.

10.2.1.2 Individual ports

The landings composition according to totals of demersal, pelagic and shellfish groups (Figure 10.2) for the same years as described in Figure 10.1 shows how these ports differ in their constituent components.

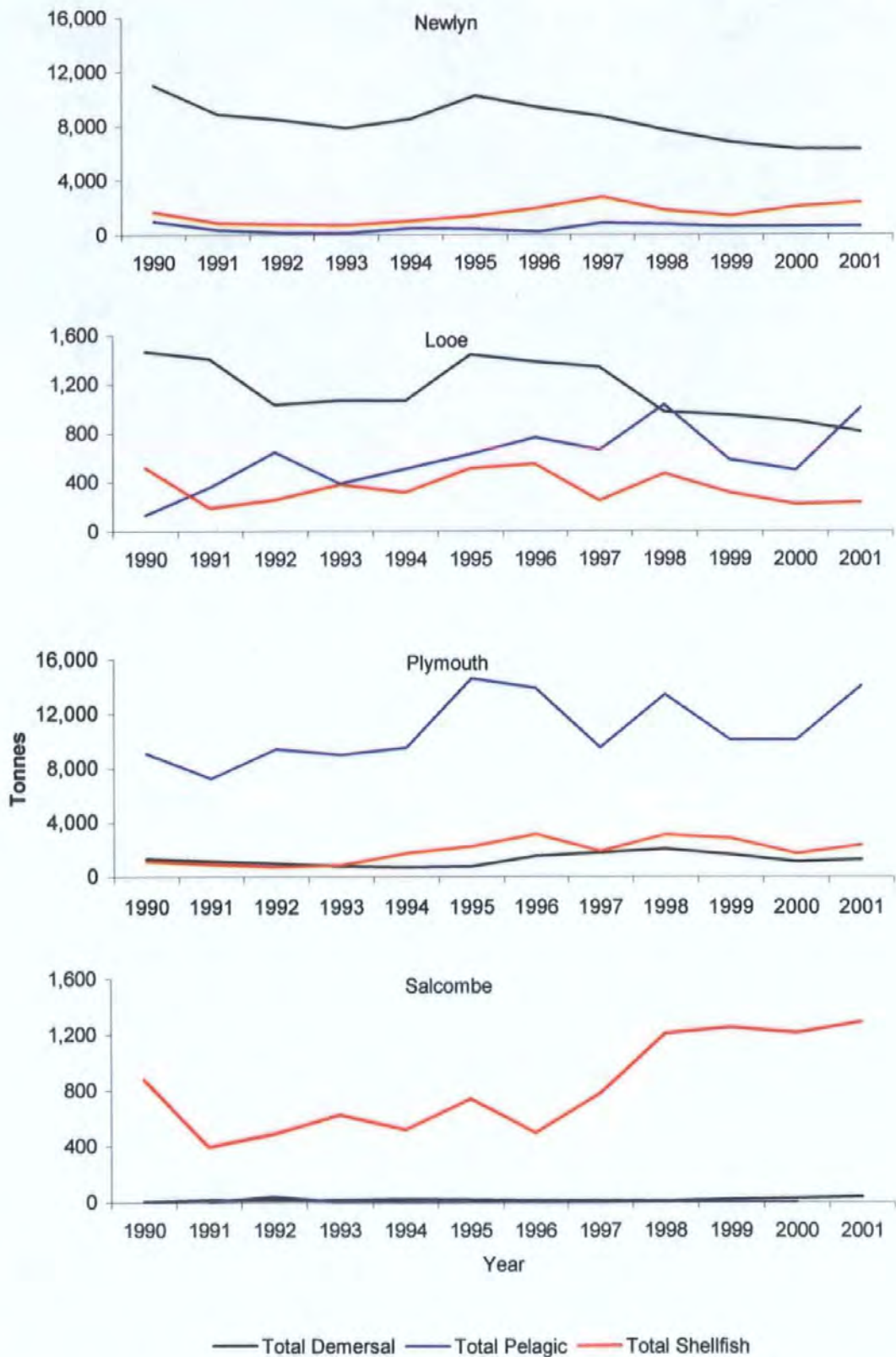


Figure 10.2. Annual landings data (tonnes) for (top to bottom) Newlyn, Looe, Plymouth and Salcombe as total demersal, total pelagic and total shellfish. Note the different scales for Newlyn and Plymouth, and Looe and Salcombe. Source, MAFF/DEFRA, (1990-2001) and London (*pers com*).

The display of ports in Figure 10.2 are in the order they are generally shown; geographically from west to east. However, given the general similarity between Newlyn and Plymouth, and Looe and Salcombe here are discussed in this order.

Figure 10.2 shows that landings into Newlyn was dominated by demersal species, though this group has generally been declining between 1990 and 2001. Numerically and consistently there have been larger landings of shellfish than pelagic species and the amount of these latter two groups has increased so that the overall landing (by weight) through the market has remained relatively static (average across the 12 years from 1990 to 2001 = 10,375 t; 95 % C.I. = 911 t). The port of Newlyn is dominated by a beam-trawl fleet (Gray, 1995; Pawson *et al.*, 2002), though the change in numbers of these vessels over time has influenced the species composition through the market (Hawke, *pers com.*).

Landings into Plymouth conversely were dominated by fluctuating levels (around 10,000 t to 14,000 t) of pelagic fish, with much less throughput of shellfish. Demersal fish landings are consistently smaller in magnitude. The fluctuation in the weight of pelagic fishes through Plymouth also dominated the total annual landings (Figure 10.1), and was due to varying numbers of non-resident vessels landing into the port. Overall, vessels landed more fishes into Plymouth than Newlyn, (average across the 12 years from 1990 to 2001 = 13,934 t; 95 % C.I. = 1,880 t).

Looe has seen quite regular three-yearly cycles of better and worse landings of demersal fishes, though there has been a general decline in the period shown in Figure 10.2. The landing of pelagic fishes was the next largest component and these have been increasing, occasionally eclipsing the landings of demersal fishes. This was most likely due to the increasing popularity of handlining for mackerel, which can yield 1,200 kg per man per day, (Pawson *et al.*, 2002). Generally, fewer shellfish were landed than pelagic fishes. The decline in demersal fishes coupled to the increase in pelagic and trend in landings of shellfish has kept the total landings (Figure 10.1) relatively constant (average across the 12 years from 1990 to 2001 = 2,097 t; 95 % C.I. = 188 t).

Landings into Salcombe were dominated by shellfish. Up to 1996, these landings were quite stable around 600 t, though after 1997 levels have doubled. In comparison the landings of pelagic and demersal fishes were very small, with approximately, three times the landings of demersal (18 t) to pelagic (6 t).

10.2.2 Species composition across all ports: Initial species aggregations

Table 10.1 shows the full demersal, pelagic and shellfish species list (as common names) reported by MAFF/DEFRA, (1990-2001).

Table 10.1. Species list (to be read in newspaper style columns) as common names for landings from MAFF/DEFRA, (1990-2001). Species in blue (e.g. Bass) are those reported. Species in black (e.g. Dabs) are subdivided further into those species coloured in red (e.g. Long Rough Dabs and Dabs).

| | | | | |
|----------------------------|--------------------------------|--------------------------------|------------------------------------|--------------------|
| Bass | Megrim | Roes | WRASSES | Spider Crabs |
| Blue Ling | Monks or Anglers | Other Demersal | WRECKFISH | Stone Crab |
| Sea Breams | Mullet | ALFONSINO (BERYX) | Total Demersal | Velvet Crabs |
| Brill | Grey Mullet | BLACK SEABREAM | Herring | King Crab |
| Catfish | Red Mullet | BALLAN WRASSE | Horse Mackerel | Lobster |
| Cod | Plaice | BLACK SCABBARD FISH | Mackerel | Lobsters |
| Conger Eels | Pollack | EELS | Pilchards | Lobster – Squat |
| Dabs | Redfishes | DEEP-WATER CARDINAL FISH | Sprats | Mussels |
| Long Rough Dabs | Saithe | TOPE | Other Pelagic | Nephrops |
| Dabs | Sandeels | FORKED BEARD | ALBACORE | Oysters |
| Dogfish | Sharks | JOHN DORY | ANCHOVY | Native Oysters |
| Birdbeak Dogfish | Angel Shark | LUMPFISH | GARFISH | Pacific Oysters |
| Black Dogfish | Blue Shark | LIVERS – OIL | SHAD | Portuguese Oysters |
| Blackmouth Dogfish | Friiled Shark | LIVERS – RAW | SILVER SMELT | Winkles |
| Greater Spotted Dogfish | Great Lanternshark | LOPHIUS PISCATORIUS (BSDB) | SUNFISH | Queen Scallops |
| Knifetooth Dogfish | Greenland Shark | MIXED DEMERSAL | SWORDFISH | Scallops |
| Lesser Spotted Dogfish | Kitefin Shark (Darkie Charlie) | NORWAY POUT | Total Pelagic | Shrimps/Prawns |
| Longnose Velvet Dogfish | Leafscale Gulper Shark | RABBIT FISH(RATTAIL) | Clams | Brown Shrimps |
| Portuguese Dogfish (Shark) | Sailfin Roughshark (Sharpback) | BLUEMOUTH (BLUE MOUTH REDFISH) | Clams (<i>M. arenaria</i>) CLS | Deep Sea Shrimps |
| Spurdog | Sharks | ROUGHEAD GRENADIER | Clams (<i>M. mercenaria</i>) CLH | Mixed Shrimps |
| Dogfish (Scyliorhinidae) | Six-Gilled Shark | GRENADIER | Clams (<i>V. decussata</i>) CTG | Pink Shrimps |
| Unidentified Dogfish | Mako Shark | SALMON | Manilla Clam CLM | European Squid |
| Flounder or Flukes | Porbeagle | GILT HEAD SEABREAM | Mixed Clams CLX | Squid |
| Gurnard | Skates and Rays | RED (BLACKSPOT) SEABREAM | Cockles | Mixed Squid |
| Gurnards – Grey | Sole | RED SCORPION FISH | Crabs | Squid |
| Gurnards – Red | Sand Sole | SMOOTHOUN | Crabs - Other | Whelks |
| Gurnard And Latchet | Sole | SAND SMELT | Crabs (C. p. Female) | Other Shellfish |
| Haddock | Torsk | STURGEON | Mixed Crabs | ENGLISH PRAWNS |
| Hake | Turbot | ROCKLING | Crabs (C. p. Male) | CRAWFISH |
| Halibut | Whiting | PANTAGONIAN TOOTHFISH | Crabs (C. p. Mixed Sexes) | CUTTLEFISH |
| Halibut-Mock | Blue Whiting | TRIGGER FISH | Deepwater Red Crab | OCTOPUS |
| Lemon Sole | Pout Whiting | SEA TROUT | Green Crab | RAZOR CLAM |
| Ling | Witch | GREATER WEEVER | Hermit Crab | Total Shellfish |

The importance of Table 10.1 is that it shows the many species for which direct comparisons with the landed species (see Table 3.3, page 51, above) from boats in this study can be made. There are however, difficulties in making direct comparisons for species that were not recorded separately (whether part of the market or haul data) but form a part of combined groups.

It was therefore necessary to aggregate some species in the sample data set to allow comparisons with the market data. It is likely that for some groups this was not very important, for example whilst there were several species of gurnards grouped together in the landings data similar species were found onboard the boats studied. However, the multi-species groupings of “Other...” particularly “Other demersal” (in Table 10.1) is such that the prominence of John Dory for example cannot easily be established, therefore including this species (which was significant in the sample and the haul data) was a greater challenge.

Thus for the species described in blue in Table 10.1 it was simply necessary to compare their proportion of the hauls. The species highlighted in red (on Table 10.1) required analysis on a case by case basis which is described below. Most of the commercial data (MAFF/DEFRA, 1990-2001) did not include the subdivided (more detailed) species, therefore the analysis can only be conducted on a relatively small number of cases for data acquired from London (*pers com*). These groups are explained in the order they occurred in Table 10.1.

10.2.2.1 Demersal fishes

Table 10.1 showed that commercial landings for dabs were a combined group of the common dab *Limanda limanda* and the long rough dab *Hippoglossoides platessoides*, though the latter was not recorded in this study. Therefore the question is how much of the recorded landings of dab were attributed to *H. platessoides* and how much to *L. limanda*?

Between 1990 and 2001 inclusive no commercial landings were recorded for *H. platessoides* therefore, dabs were taken to represent *L. limanda* entirely.

Commercial landings of dogfish consisted of 11 species or groups on Table 10.1, of which spurdog (*Squalus acanthias*) accounted for 81 %, lesser spotted dogfish (*Scyliorhinus canicula*) for 12 % and unidentified dog fish 6 %. No spurdog were landed in this study therefore to retain this category, dogfish landings were classed as dogfish (code LSD) and adjusted accordingly to retain 12 % of the initial value.

Commercial market data for Gurnards comprised the common red gurnard *Aspitrigla cuculus*, and the grey gurnard *Eutrigla gurnardus*. Latchet (*Pterygotrigla* sp) were nominally included but can safely be ignored as while these fish look similar they are geographically distinct (Richards & Jones, 2002). The landings data was not separated into these sub groups so this group can be included as a whole.

Mullet consisted of the grey mullet (*Mugilidae* sp) which was not landed from boats studied here (it was a discarded species) and the red mullet (*Mullus surmuletus*) which was generally quite rare. Commercially these species divided up as 4 % grey mullet and 96 % red mullet. To retain this group it was classed as red mullet (code MUR) and adjusted to retain 96 % of the initial value.

No landings which fit into the category of sharks were sampled from boats in this study therefore this category can remain in the data in its entirety, though it was not required in the analysis. It is worth pointing out that all skates and rays (Order Rajiformes) were treated by the market as a single group. This was the same for the haul composition of the sampled boats.

The market data for sole comprised two species, the sand sole (*Solea lascaris*) and the common or Dover sole (*Solea solea*). The commercial landing for these species divided into 0.01 % sand sole and 99.9 % common sole, therefore this species were presumed to be common sole.

The most complex group of market data was that of the “Other Demersal” species which (according to Table 10.1) was made up from thirty-six species or groups. While this group was large across all ports and years, it only comprised ~ 2.5 % of the total demersal landings. In order of composition, the largest group by weight within “Other Demersal” was mixed demersal (69 %). This group is occasional landings of mixed species which are lumped together to comprise a box of fishes that on their own are not marketable, though are when grouped together, (Hawke, *pers com.*). While it might be thought that this category could be used to hide fishes from inclusion in quotas it is not in the fishermen’s interest to do this, as this category generally fetches a much lower price than these fishes would if landed as single species. After mixed demersal the next most significant component of “Other demersal” was John Dory (*Zeus faber*) at 27 %. The ballan wrasse (*Labrus bergylta*) made up 4 %; the next largest category. Two other species made up measurable levels though these are below 1 %; tope (*Galeorhinus galeus*) 0.4 % and salmon (*Salmo salar*) 0.02 %. Many of the group classed as “Other demersal” were zero values. While the proportion of the largest single fish species (John Dory) was only around a quarter of the total, and there may be other species which contributed a larger (though undefined) proportion for analysis here the category of “Other demersal” was renamed John Dory (code JOD) and its magnitude adjusted accordingly to represent 27 % of its initial value. While this process might be problematical for the reason given above, it is the only way that the landings of John Dory can be introduced into the analysis. This species was important as it was, overall, the fifth most dominant species in the samples contributing 6.1 %, (see Table 3.4, page 54, above) and was always in the top 15 species of the sample by port and type of trawling, (Table 3.5, on page 56, above).

10.2.2.2 Pelagic fishes

There were only five pelagic species landed and all of these except shad (*Alosa* spp.) were accounted for individually. Shad was included in the “Other pelagic” group though this

does not comprise nearly as many species as “Other demersal” (only 7). Shad only made up < 0.05 % of “Other pelagic” therefore this group remained unaffected.

10.2.2.3 Shellfishes

Amongst the shellfish there were five types of clams, though no clams were sampled in this study therefore this groups can remain unaffected.

There were twelve species or groups together called crabs. Amongst these the most abundant (at 61 %) was female *Cancer pagurus*, followed by mixed sexes *C. pagurus* (32 %) then male *C. pagurus* (6 %). Spider crabs (*Maja* spp.) only comprised 1 %. No regard to the sex of edible crabs was recorded in this study. Therefore, since the *Cancer* spp. made up such an overwhelming dominance of this group, it is taken to be crabs, (code CRE).

Lobsters, oysters, and shrimps were not encountered in this study therefore there are no problems with these categories. Squid were taken to refer to *Loligo* spp, (code SQC) and amongst the “Other shellfish” the dominant group (98 %) was cuttlefish, (*Sepia* sp). This group was taken to represent cuttlefish in its entirety, (code CUT) and was not adjusted.

10.2.3 Further species removals, additions and aggregations

Conger (*Conger conger*) and saithe (*Pollachius virens*) were removed from the species lists in the Sample theme (Chapter 3, Chapter 5 and Chapter 6). Also in the analysis of the sample and the haul (Chapter 9) because conger eels were too large to be included in the sample (see Figure 2.5, page 29, above) and saithe were not sampled in the fish basket therefore these species did not exist in a paired relationship and had to be excluded. These two species were included in the landed part of the haul and do occur in the market data

(see Table 10.1, above) and were reintroduced in this analysis.

As described above shad were included in the “Other pelagic” group and therefore have to be removed from the boats’ landings data as they do not have an equivalent ‘pair’ in the market data. The removal of shad was minor since they only contributed 0.6 kg to the entire sum of landed hauls (18,824 kg). The situation was similar for wrasse which was an unknown component of “Other demersal” category although it was recorded (3.1 kg) as landed from the studied boats. Wrasse were a tiny fraction (~ 0.01 %) of the sum of landed hauls.

Sprats were not recorded as market landings in sufficiently large numbers to appear as a value from any of the four ports. Also, they were only categorised as discards in the sample of the haul and were not landed as a distinct species.

Finally, combining whiting (*Merlangius merlangus*, WHG) and blue whiting (*Micromesistius poutassou*, WHB) was a simple process since WHB was only landed in a sufficiently large amount in year 2000, quarter 1 into Plymouth where 19 t (0.43 %) were landed in comparison to 23 t (0.52 %) of WHG.

10.2.4 Choice of test statistic, and threshold of analysis

The above described species aggregations left 31 species for which the comparison of landed fish from boats in this study to the commercial throughput of the port can be made. These are presented in Table 10.2 by rank-order of market data across three timescales. These three timescales are:

- According to all quarters and ports; the annual period of 1998 – 2000 inclusive.
- According to the quarter and year of sampling (Table 3.1, page 48, above) for which each trip was undertaken according to port, and

- According to the month and year of sampling (Table 3.1, page 48, above) for which each trip was undertaken according to port.

The last column in Table 10.2 presents the sum of all landed hauls by weight ($n = 88$).

Table 10.2. Rank-order of species by weight from market data and all the sampled boats. Full market data are the totals by quarter of the year for 1998 to 2000 inclusive across all four ports sampled. Valid quarter market data include only those quarters of the year (according to port) from which samples were taken. Valid month market data includes only those actual months of the year (again according to port) from which samples were taken. Sampled boats are the sum of all landed hauls by weight, ($n = 88$). See Table 3.3, page 51 (above) for an explanation of the species codes.

| rank | full market data | | valid quarter market data | | valid month market data | | sampled boat landings | |
|------|------------------|-------|---------------------------|-------|-------------------------|-------|-----------------------|-------|
| | species code | % | species code | % | species code | % | species code | % |
| 1 | MAC | 28.3 | MAC | 17.7 | MAC | 18.7 | GUX | 15.9 |
| 2 | PIL | 13.1 | SCX | 16.7 | SCX | 16.9 | WHG | 14.0 |
| 3 | SCX | 10.6 | MEG | 9.4 | MEG | 9.5 | SQC | 8.4 |
| 4 | CRE | 7.4 | MON | 9.2 | MON | 9.3 | RAY | 7.9 |
| 5 | MON | 4.9 | PIL | 8.0 | PIL | 6.6 | COD | 7.3 |
| 6 | MEG | 4.9 | CRE | 5.1 | RAY | 5.0 | MON | 6.2 |
| 7 | HOM | 4.0 | RAY | 4.5 | LIN | 4.2 | BIB | 6.1 |
| 8 | LIN | 2.9 | LIN | 4.4 | CRE | 4.1 | JOD | 5.1 |
| 9 | POL | 2.7 | HKE | 3.3 | HKE | 3.3 | LSD | 4.6 |
| 10 | CTL | 2.6 | COD | 2.6 | COD | 2.7 | LEM | 4.6 |
| 11 | WHG | 2.4 | LEM | 2.5 | LEM | 2.6 | HOM | 3.1 |
| 12 | RAY | 2.4 | POL | 2.0 | WHG | 2.1 | PLE | 3.1 |
| 13 | LEM | 2.1 | WHG | 1.9 | PLE | 1.9 | HKE | 1.8 |
| 14 | COD | 1.8 | CTL | 1.8 | POL | 1.9 | MAC | 1.5 |
| 15 | HKE | 1.7 | PLE | 1.8 | HOM | 1.9 | MEG | 1.4 |
| 16 | PLE | 1.6 | HOM | 1.8 | CTL | 1.9 | DAB | 1.4 |
| 17 | SOL | 1.3 | SOL | 1.5 | SOL | 1.5 | LIN | 1.4 |
| 18 | HAD | 0.7 | CON | 0.9 | CON | 1.1 | POL | 1.0 |
| 19 | CON | 0.6 | SQC | 0.8 | SQC | 0.7 | CTL | 0.8 |
| 20 | SQC | 0.6 | HAD | 0.7 | GUX | 0.7 | CON | 0.8 |
| 21 | BIB | 0.6 | GUX | 0.6 | HAD | 0.6 | CRE | 0.8 |
| 22 | HER | 0.5 | BIB | 0.5 | POK | 0.6 | SOL | 0.6 |
| 23 | BSE | 0.4 | POK | 0.5 | BIB | 0.5 | FLE | 0.6 |
| 24 | GUX | 0.4 | BLL | 0.4 | HER | 0.4 | BSE | 0.4 |
| 25 | POK | 0.4 | JOD | 0.4 | JOD | 0.4 | MUR | 0.4 |
| 26 | BLL | 0.3 | BSE | 0.3 | BLL | 0.4 | SCX | 0.3 |
| 27 | JOD | 0.2 | HER | 0.3 | BSE | 0.2 | BLL | 0.3 |
| 28 | MUR | 0.2 | MUR | 0.2 | MUR | 0.2 | HAD | 0.2 |
| 29 | DAB | 0.1 | LSD | 0.1 | LSD | 0.1 | HER | 0.1 |
| 30 | LSD | 0.1 | DAB | 0.1 | DAB | 0.1 | PIL | 0.1 |
| 31 | FLE | < 0.1 | FLE | < 0.1 | FLE | < 0.1 | POK | < 0.1 |

It is apparent from Table 10.2 that some of the same species (e.g. whiting and rays, shown in yellow) rank highly across both the market data and sampled boats while others are

commonly low down in the ranking, (e.g. brill and red mullet, shown in blue). This suggests some similarity within the market data regardless of its temporal scale, although there are some (e.g. mackerel and John Dory, in green) whose ranking was not similar at all.

The data in Table 10.2 were strongly right skewed and do not approximate normal distributions according to A-D tests (full market data, $A^2 = 4.401$, $n = 31$, $P < 0.001$; valid quarter market data, $A^2 = 3.488$, $n = 31$, $P < 0.001$; valid month market data, $A^2 = 3.566$, $n = 31$, $P < 0.001$; sampled boats. $A^2 = 2.557$, $n = 31$, $P < 0.001$). Therefore, although the species were paired between the boat landing data and the market data parametric statistics cannot be used in this analysis.

The weights in both the boat (landings) and market (throughput) were very different in scale. The market data was available (MAFF/DEFRA, 1990-2001) and London, *pers com.*) as tonnes while the landings data was recorded in kg. This is borne out in Table 10.3 which shows the sampled boat's landed data for haul 1 (21/04/98) compared to the valid quarter of the year (April 98 – June 98) and the valid month of the year (April 98).

Table 10.3. Market data as valid quarter of the year and valid month of the year. Also total landed data. All data are kg.

| species code | market data, valid quarter of the year (Apr 98 - Jun 98) | market data, valid month of the year (Apr 98) | boat data, haul 1, 21/04/98 |
|--------------|--|---|-----------------------------|
| BIB | 6,000 | 2,000 | 12.7 |
| BLL | 0 | 0 | 0 |
| BSE | 0 | 0 | 0 |
| COD | 5,000 | 1,000 | 14.9 |
| CON | 1,000 | 0 | 0 |
| CRE | 0 | 0 | 0 |
| CTL | 14,000 | 5,000 | 0 |
| DAB | 0 | 0 | 1.7 |
| FLE | 0 | 0 | 0 |
| GUX | 3,000 | 1,000 | 19.1 |
| HAD | 2,000 | 1,000 | 0 |
| HER | 0 | 0 | 0 |
| HKE | 1,000 | 0 | 0 |
| HOM | 2,000 | 2,000 | 0 |
| JOD | 3,240 | 1,080 | 0 |
| LEM | 81,000 | 35,000 | 33.1 |
| LIN | 4,000 | 3,000 | 11.0 |
| LSD | 0 | 0 | 0 |
| MAC | 1,000 | 0 | 0 |
| MEG | 1,000 | 0 | 0 |
| MON | 9,000 | 2,000 | 0 |
| MUR | 960 | 0 | 0 |
| PIL | 0 | 0 | 0 |
| PLE | 14,000 | 5,000 | 8.5 |
| POK | 0 | 0 | 0 |
| POL | 1,000 | 1,000 | 14.5 |
| RAY | 4,000 | 1,000 | 27.6 |
| SCX | 18,000 | 1,000 | 3.2 |
| SOL | 0 | 0 | 0 |
| SQC | 3,000 | 1,000 | 31.8 |
| WHG | 52,000 | 22,000 | 18.0 |

Combining the non-normal distribution of the weight data and large difference in absolute size between the haul and market meant the obvious analysis was to examine only the rank-order of species from most to least abundant in the market and boat data, thus removing the large data range in the data as shown in Table 10.3. Two-tailed Spearman's rank-order correlations (r_s), (Dytham, 1999, p158) was the test of choice to which pairwise exclusions (where values of zero in one or both data sets meant the pair was excluded) were applied. It was decided satisfactory if 50 % or more of the hauls according to port and type of trawling were significantly correlated (r_s).

10.2.4.1 Most appropriate temporal scale of the market data

The first species list in Table 10.2 (full market data) describes the rank-order of those species across the four ports and between 1998 – 2001. The second species list in Table 10.2 (valid quarter) comprised only those quarters of the 1998 – 2001 period for particular ports sampled and the valid month market data narrows the quarter periods to the particular months (and particular ports) sampled. Thus, the valid quarter and month does take into consideration that the samples were taken during specific quarters or months of the year whereas the full market data was the sum by quarter of the year throughout the sampling period.

It might be expected that the correlation between the quarterly market data and landed haul would not be as high as between the monthly market data and landed hauls given the seasonality of landings that might be expected to occur over a three month period. However, a degree of smoothing is created when combining three month's data into the quarterly type that might ameliorate fluctuations caused by atypical landings of the sampled boats. For example (from Table 10.3) the monthly market data for both bib (2,000 t) and gurnard (1,000 t) equalled a third of the quarterly market data for these species (6,000 and 3,000 t respectively). In Table 10.3 there were a total of four (non-zero) examples where the quarterly market data equalled three times the monthly market data, though there are seventeen (non-zero) occasions where the quarterly data did not equal three times the monthly data for this haul alone. This suggests that while the quarterly data broadly described the market data the monthly data better resolved the situation.

This was tested by examining the average Spearman's rank-order correlation and also the number of significant and non-significant association between landed haul data and the monthly and quarterly market data.

Figure 10.3 shows the frequency of Spearman's rank-order correlations (r_s) comparing the market data as quarter of the year and market data as monthly data with the

sampled boat landings for all hauls, comparing each one to the equivalent monthly or quarterly market data.

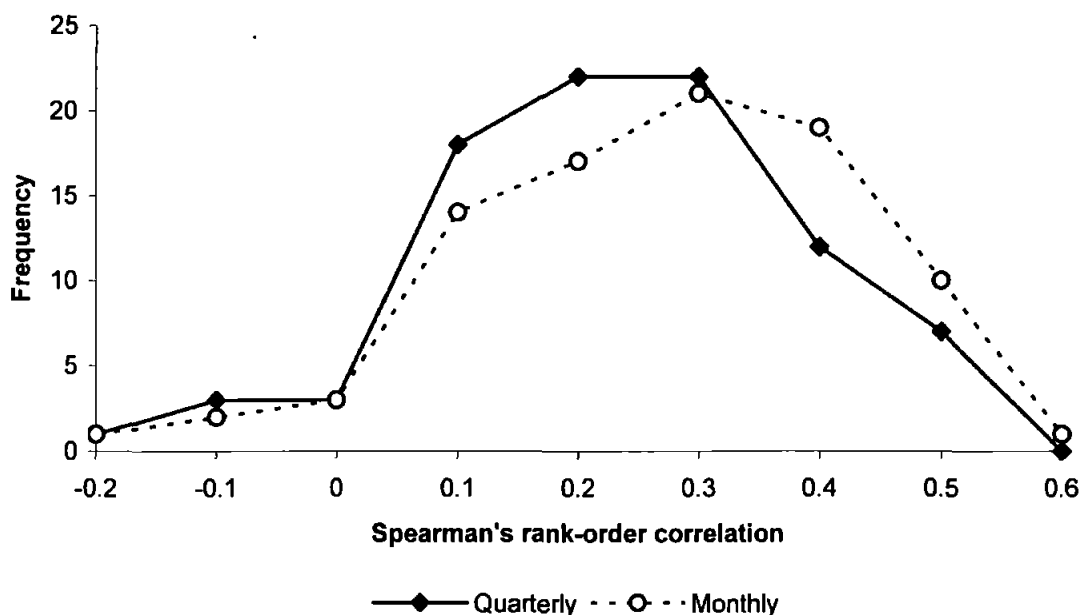


Figure 10.3. Frequency histogram of Spearman's rank correlation (r_s) comparing market data as quarter of the year and market data as monthly data with the sampled boat landings, ($n = 88$). Note the bin size in 0.1.

It is apparent from Figure 10.3 that the correlation between the monthly market data to the sampled boat data was generally better than the correlation between the quarterly market data and the sampled boat data. Figure 10.3 shows this visually while Table 10.4 shows this based on the number of significant correlations.

Table 10.4. Numbers (and %) of variously significant Spearman's rank-order correlations (r_s) (based on P values) comparing quarterly and monthly market data with sampled boats, $n = 88$.

| levels of significance | quarterly | | monthly | |
|---|-----------|----|----------|----|
| | <i>n</i> | % | <i>n</i> | % |
| not significant ($P \geq 0.05$) | 60 | 68 | 52 | 59 |
| significant ($P < 0.05$ to ≥ 0.01) | 15 | 17 | 17 | 19 |
| highly significant ($P > 0.01$) | 13 | 15 | 19 | 22 |
| Total significant | 28 | 32 | 36 | 41 |

While it is apparent from Table 10.4 the number of non-significant correlations outweighed the significant ones there were more significant and also more highly significant correlations between the monthly market data and the sampled boat data than between the quarterly market data and the sampled boat data. Thus the degree of seasonality embedded within the quarterly data was greater than the fluctuation potentially caused by unusual landings or other short-term factors. Also, the degree of smoothing offered by the correlation of the sampled boat data with the quarterly rather than the monthly data was unhelpful. This was tested by comparing the differences between the paired (according to haul) quarterly market and monthly market Spearman's rank correlations (r_s) to the sampled boat data. Firstly, both sets of r_s values do approximate normal distributions according to the A-D test. $A^2 = 0.252$, $n = 88$, $P = 0.731$ for the quarterly and $A^2 = 0.267$, $n = 88$, $P = 0.680$ for the monthly derived r_s values therefore in comparing the paired data the parametric paired t -test can be employed. The results of the (two-tailed) paired t -test ($P < 0.001$, 87 d.f.) suggests that the monthly derived market data described the sampled boat data to a very highly significantly better degree.

10.2.5 Further analysis for Newlyn and Plymouth: 'intelligent' species removal

In an effort to account for the known bias in the market data due to the dominance of non-resident pelagic trawlers and scallop dredges featuring in the Plymouth market data, and resident though clearly different beam trawlers landing into Newlyn (Gray, 1995; Pawson *et al.*, 2002) a breakdown of the landings into these ports was sought that would divide the fleet into the local trawler fleet (studied here) and the others. Plymouth Fish Market initially released a sample of this data however, they subsequently requested that it should not be used. Newlyn Market said it could not make this data available. Therefore, an alternative approach had to be undertaken.

Instead, species were removed that were particularly dominant in the market data but only due to the presence of the other fishing methods in the market data. In total four sets of species deletions were undertaken. These are described in section 10.3.2

10.3 Results

10.3.1 Major compositional analysis of the landed part of the haul and market data

Figure 10.4 shows the relationship across the ports and types of trawling of the Spearman's rank-order correlation between the rank-order of species in the sampled boats' landed hauls and their equivalent monthly market data.

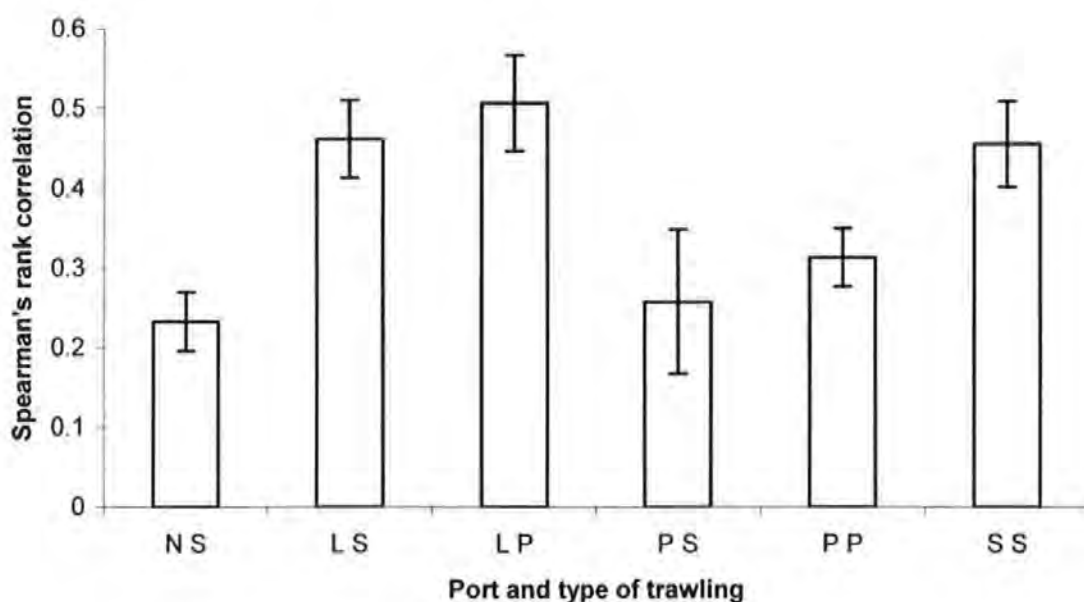


Figure 10.4. Average (and 95 % C.I.) Spearman's rank-order correlation (r_s) between monthly market data and sampled boats according to port and type of trawling, N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling.

It is apparent from Figure 10.4 that the correlation (r_s) between the monthly derived market data and the sampled boats according to port and type of trawling was higher for the smaller ports of Looe and Salcombe. That the described correlation was best for Looe was not surprising since this port is both quite small and dominated by trawling boats (though other, smaller fishing vessels do use the port, they are unlikely to be represented in the commercial market data as explained by explanatory note 7, (page 297, above).

That the described correlation was good for Salcombe was also not surprising since while this port was dominated by the landings of crabs, ~ 97 % of the annual market data from 1990 to 2001 was *C. pagurus* (MAFF/DEFRA, 1990-2001) in rank-order correlation the dominance of any one species, is unlikely to greatly influence the final outcome. Figure 10.4 also shows that the previously defined correlations were not so good for the ports of Plymouth and Newlyn, though interestingly for Plymouth and Looe the pair trawling boats were more closely correlated to the monthly market data than the single trawling operations. That the correlations were not so strong for the ports of Newlyn and Plymouth was because these ports were dominated by beam trawling for Newlyn and non-resident pelagic trawling and scallop dredging boats for Plymouth.

The proportion (as %) of significant, highly significant and non-significant correlations (r_s) between the monthly derived market data and the sampled boat is shown in Table 10.5.

Table 10.5. Proportion (as %) of significant, highly significant and non-significant Spearman's rank-order correlations (r_s) between the monthly derived market data and the sampled boats according to port and type of trawling, N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling. Highlighted ports and type of trawling satisfied the 50 % significant level.

| levels of significance | port and type of trawling | | | | | | | | | | | |
|---|---------------------------|----|-----|----|-----|-----|-----|----|-----|----|-----|----|
| | N S | | L S | | L P | | P S | | P P | | S S | |
| | n | % | n | % | n | % | n | % | n | % | n | % |
| not significant ($P \geq 0.05$) | 36 | 86 | 1 | 9 | 0 | 0 | 7 | 87 | 6 | 75 | 2 | 20 |
| significant ($P < 0.05$ to ≥ 0.01) | 6 | 14 | 4 | 36 | 2 | 22 | 1 | 13 | 2 | 25 | 2 | 20 |
| highly significant ($P > 0.01$) | 0 | 0 | 6 | 55 | 7 | 78 | 0 | 0 | 0 | 0 | 6 | 60 |
| Total significant | 14 | 14 | 10 | 91 | 9 | 100 | 1 | 13 | 2 | 25 | 8 | 80 |

Table 10.5 shows that from Looe only 9 % of the hauls, actually only one haul, number 2 (in which none of the top five species were similar) did not significantly correlate with the monthly derived market data, though all the Looe pair boat hauls correlated significantly. 80 % of the hauls from Salcombe did correlate significantly, with only 2 hauls failing. One of these was haul 77 of which only 3 groups of the monthly market data for October 1999 were landed by the sampled boat. The other, haul 79, was similarly different to its corresponding monthly derived market data. Therefore, without any further analysis the sampled hauls from Looe and Salcombe meet the validity threshold as set out on in Section 10.2.4.

10.3.2 Further analysis for Newlyn and Plymouth: 'intelligent' species removal

While Table 10.4, above (and the results of the paired *t*-test) showed that the monthly derived market data better described the sampled boat data than the quarterly data there were still many ($n = 52$ out of 88, or 59 %) hauls (Table 10.4) for which the monthly market data did not correlate significantly with the landed haul data. However as Table 10.5 showed 49 (or 94) % of these were Newlyn or Plymouth hauls.

Table 10.6 shows the Spearman's rank-order correlations for Newlyn, and, Plymouth single and pair boat trawls between the sampled boat data (as averages for all hauls) and monthly derived market data (as averages from equivalent months).

Table 10.6. Spearman's rank-order correlations (r_s) and associated significance (P) value for the Newlyn and, single and pair boat trawling from Plymouth showing the rank-order of species and abundance (as %) based on the average for all hauls (from the sampled boat species) and the average from monthly derived market data. In calculating r_s pair-wise deletions are used. Mackerel, pilchards and scallops are flagged with ¹ across the three groups. Megrim, monkfish and scallops are flagged with ² and horse mackerel, scallops, John Dory and gurnard are flagged with ³ for Newlyn and pilchards, scallops and dogfish are flagged with ⁴ for the Plymouth pair boat. The relevance of these highlights is discussed in section 10.3.2.1, (page 321, below).

| r_s | 0.294 | | | | 0.111 | | | | 0.285 | | | |
|-------|-------------------------------|----|--|----|-------------------------------|----|--|----|-------------------------------|----|--|----|
| P | 0.108 | | | | 0.552 | | | | 0.12 | | | |
| p&t | Newlyn | | | | Plymouth single boats | | | | Plymouth pair boats | | | |
| data | average for all sampled hauls | | average from monthly derived market data | | average for all sampled hauls | | average from monthly derived market data | | average for all sampled hauls | | average from monthly derived market data | |
| | sp code | % | sp code | % | sp code | % | sp code | % | sp code | % | sp code | % |
| rank | | | | | | | | | | | | |
| 1 | GUX ¹ | 24 | SCX ^{1,2} | 20 | WHG | 12 | MAC ¹ | 55 | WHG | 24 | MAC ¹ | 34 |
| 2 | COD | 12 | MEG ² | 16 | RAY | 9 | SCX ¹ | 13 | GUX | 8 | PIL ^{1,4} | 27 |
| 3 | JOD ¹ | 10 | MON ² | 15 | BIB | 9 | PIL ¹ | 11 | MON | 7 | SCX ¹ | 14 |
| 4 | SQC | 9 | RAY | 8 | MON | 8 | CRE | 4 | SQC | 6 | HOM | 8 |
| 5 | RAY | 8 | LIN | 7 | GUX | 8 | CTL | 3 | PLE | 6 | CRE | 2 |
| 6 | MON ² | 8 | HKE | 6 | LEM | 7 | HOM | 2 | LSD ² | 5 | CTL | 2 |
| 7 | BIB | 5 | COD | 4 | COD | 6 | HER | 2 | MAC | 5 | PLE | 2 |
| 8 | HOM ² | 5 | LEM | 3 | PLE | 6 | PLE | 2 | RAY | 5 | POL | 1 |
| 9 | LEM | 4 | POL | 2 | CTL | 5 | SOL | 1 | HOM | 4 | SOL | 1 |
| 10 | LSD | 3 | CRE | 2 | SQC | 4 | POL | 1 | COD | 4 | LEM | 1 |
| 11 | MEG ² | 2 | PLE | 2 | LSD | 4 | WHG | 1 | DAB | 4 | WHG | 1 |
| 12 | HKE | 2 | MAC ¹ | 2 | MAC ¹ | 4 | MON | 1 | BIB | 3 | MON | 1 |
| 13 | WHG | 2 | SOL | 2 | POL | 4 | BIB | 1 | CTL | 3 | BIB | 1 |
| 14 | CON | 1 | CON | 2 | DAB | 2 | LEM | 1 | LEM | 3 | RAY | 1 |
| 15 | POL | 1 | HAD | 1 | CRE | 2 | RAY | 1 | JOD | 2 | COD | 1 |
| 16 | LIN | 1 | POK | 1 | BSE | 2 | LIN | 1 | HKE | 2 | BSE | 1 |
| 17 | PLE | 1 | CTL | 1 | HKE | 1 | BSE | <1 | LIN | 2 | LIN | 1 |
| 18 | BLL | <1 | WHG | 1 | HAD | 1 | SQC | <1 | FLE | 2 | SQC | 1 |
| 19 | SOL | <1 | GUX ¹ | 1 | CON | 1 | COD | <1 | SOL | 1 | GUX | <1 |
| 20 | MUR | <1 | SQC | 1 | HOM | 1 | MUR | <1 | MEG | 1 | MUR | <1 |
| 21 | HAD | <1 | JOD ¹ | 1 | SOL | 1 | BLL | <1 | MUR | 1 | MEG | <1 |
| 22 | SCX ^{1,2,3} | <1 | BLL | 1 | FLE | <1 | GUX | <1 | CRE | 1 | BLL | <1 |
| 23 | CRE | <1 | BIB | <1 | LIN | <1 | CON | <1 | PIL ¹ | <1 | CON | <1 |
| 24 | HER | <1 | MUR | <1 | MEG | <1 | DAB | <1 | POL | <1 | DAB | <1 |
| 25 | BSE | 0 | LSD | <1 | POK | <1 | MEG | <1 | SCX ¹ | <1 | HKE | <1 |
| 26 | CTL | 0 | DAB | <1 | MUR | <1 | JOD | <1 | BLL | <1 | JOD | <1 |
| 27 | DAB | 0 | HER | <1 | JOD | <1 | LSD | <1 | BSE | <1 | LSD ² | <1 |
| 28 | FLE | 0 | BSE | 0 | BLL | 0 | HKE | <1 | CON | 0 | FLE | <1 |
| 29 | MAC ¹ | 0 | FLE | 0 | HER | 0 | FLE | 0 | HAD | 0 | HAD | <1 |
| 30 | PIL ¹ | 0 | HOM ² | 0 | PIL ¹ | 0 | HAD | 0 | HER | 0 | POK | 0 |
| 31 | POK | 0 | PIL ¹ | 0 | SCX ¹ | 0 | POK | 0 | POK | 0 | HER | 0 |

While none of the correlations in Table 10.6 were significant it is relevant to note that correlations within the haul and market data were. These were: Plymouth single boat haul data to Plymouth pair boat haul $r_s = 0.731$, $P < 0.001$; Plymouth single boat market data to

Plymouth pair boat market data $r_s = 0.872$, $P < 0.001$. That both of these correlations were very highly significant suggests that the haul data were not significantly different whether fished by single and pair boat trawling. Also, that the market data for these various months were similarly not significantly different. While it was possible to demonstrate this similarity within both haul and equivalent market data between single and pair boat trawling for Plymouth it was not possible to demonstrate this for Newlyn since only one type of trawling was sampled here. However, all the hauls from Newlyn were sampled either during the second or third quarters of 1998 and 1999 and it was possible to examine (at the trip level) the correlation between the sampled boats and equivalent monthly derived market data on this basis.

Examining these correlations was undertaken as a full permutation; between market and boat data within quarters (highlighted in grey); separately between boats and between market data (highlighted in yellow), and separately across boat and market data (highlighted in blue). Table 10.7 shows the results.

Table 10.7. Full permutation of Spearman's rank-order correlations, r_s (first data value) and significance (P) value (second data value) between combinations of sampled boat (= b) and equivalent monthly derived market data (= m) according to date of haul. Thus 'b - m, 0.272, 0.138' on 24/05/98 represents a Spearman's rank-order correlation of 0.272 between the sampled boat data and the equivalent monthly derived market data; (grey highlights = boat and market data comparison). This correlation is not significant since the P value is 0.138. Also, 'b, 0.878, < 0.001, b' represent a Spearman's rank-order correlation of 0.878 between the sampled boat data of 24/05/98 and the sampled boat data of 29/08/98 and this correlation is very highly significant; (yellow highlights = separate boat to boat and market to market data comparison; blue highlights = separate boat to market and market to boat data comparisons).

| 24/05/98 ('98 Q2) | 29/08/98 ('98 Q3) | 05/05/99 ('99 Q2) | 26/07/99 ('99 Q3) |
|---------------------|----------------------|----------------------|---------------------|
| b - m, 0.272, 0.138 | b - m, 0.365, 0.043 | b - m, 0.363, 0.045 | b - m, 0.329, 0.070 |
| | b, 0.878, < 0.001, b | | |
| | m, 0.846, < 0.001, m | | |
| | b, 0.795, < 0.001, b | | |
| | m, 0.890, < 0.001, m | | |
| | b, 0.835, < 0.001, b | | |
| | m, 0.875, < 0.001, m | | |
| | b, 0.774, < 0.001, b | | |
| | m, 0.899, < 0.001, m | | |
| | b, 0.904, < 0.001, b | | |
| | m, 0.943, < 0.001, m | | |
| | | b, 0.684, < 0.001, b | |
| | | m, 0.973, < 0.001, m | |
| | b, 0.401, 0.025, m | | |
| | m, 0.176, 0.343, b | | |
| | b, 0.356, 0.049, m | | |
| | m, 0.271, 0.140, b | | |
| | b, 0.354, 0.051, m | | |
| | m, 0.149, 0.424, b | | |
| | b, 0.295, 0.107, m | | |
| | m, 0.318, 0.081, b | | |
| | b, 0.329, 0.071, m | | |
| | m, 0.383, 0.033, b | | |
| | | b, 0.380, 0.053, m | |
| | | m, 0.270, 0.142, b | |

Firstly there were significant correlations between the boat and market data for two of the four trips, 29/08/98 ('98 Q3) and 05/05/98 ('99 Q2). These are shown on the top data line of Table 10.7, (highlighted in grey). The importance of this was that summing the haul data into trips has reduced the bias between the sample and market data, as individually only 14 % (Table 10.5, on page 316, above) of the correlations were significant though by trip 50 % were.

All the correlations within sampled boat or market data (top full permutations on Table 10.7, highlighted in yellow) were highly significant. This was similar to the within

sampled boat data and within equivalent monthly derived market data for the single and pair boat sampling from Plymouth. However, the importance here was with the timing of these hauls (as trips) both between and within the years in which they were sampled. Only three (out of the possible twelve) correlations between the sampled boat and market data (shown in the lower part of Table 10.7, highlighted in blue) are significant. That fewer of these correlations are significance than the 50 % of those between date (the sampled boat and market data by trip) was not surprising since these correlations test the relationship between the permutations of boat samples and market data between trips (at different times of the year and between years). It is also relevant to note that two of the three significant correlations are between quarters 2 of years 98 and 99 and quarters 3 of 98 and 99 showing a degree of seasonality in the data and similarity between the sampled boat and market data. The seasonality of these sample data was previously explored, in terms of their biodiversity, in section 6.2.2 and section 6.3.2, (Chapter 6).

10.3.2.1 Species adjustment

The above described pattern of significant, and non-significant, correlations for Newlyn and Plymouth hauls (and trips) suggests that despite the bias in the market data due to the variety of boats operating from these ports (which were not subject to sampling) there were clear grounds for proposing a degree of relationship in the full species data set and that the pattern of bias (in terms of species, see Table 10.6, above) in that the market data can be attributed to the types of boats not sampled here. Thus, the adjustment to the species should attempt to overcome this based on known conditions about the respective fisheries.

The adjustment to species' rank-order was achieved by removing mackerel, pilchards and scallops from both the sampled boat and market data. These species are highlighted (with a ¹) in Table 10.6, above and were removed as they were not targeted by the trawlers studied here.

Figure 10.5 shows the average and 95 % confidence intervals of Spearman's rank-order correlation between sampled boat data and equivalent monthly derived market data according to port and type of trawling for Newlyn and Plymouth before and after the species adjustment ¹.

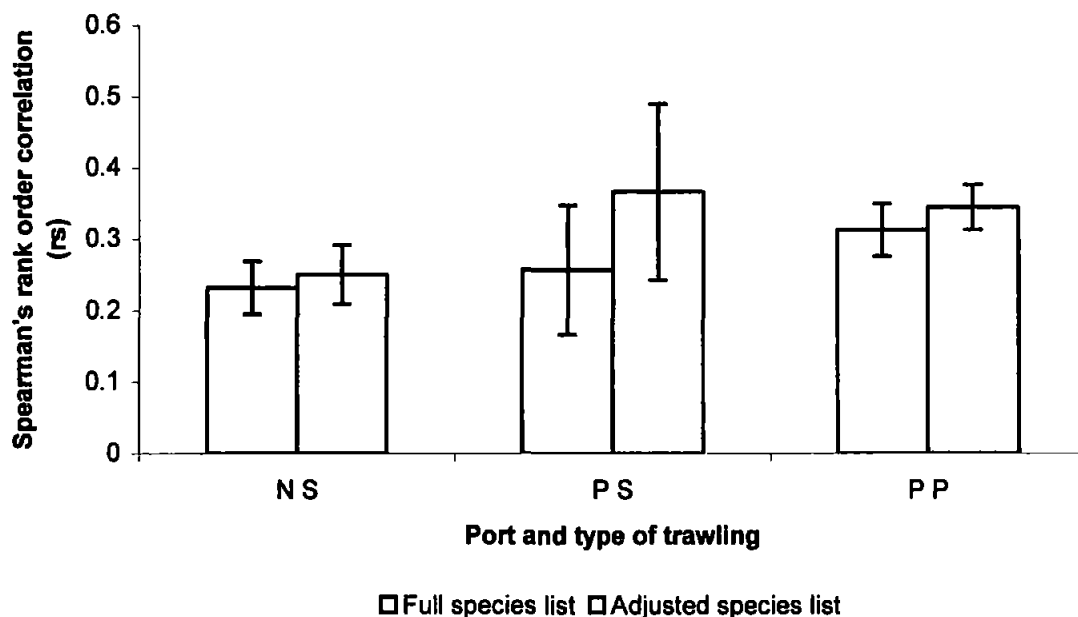


Figure 10.5. Average (and 95 % confidence intervals) of Spearman's rank-order correlation according to port and type of trawling, N- = Newlyn, P- = Plymouth; -S = single boat trawling, -P = pair boat trawling (for Newlyn and Plymouth) based on the full and adjusted (¹ removed MAC, PIL and SCX) species list.

In all cases demonstrated in Figure 10.5 the removal of mackerel, pilchards and scallops improved the correlation between the sampled boat and market data. Also, for Newlyn and Plymouth single boat trawling the 95 % confidence intervals were smaller for the full, when compared to the adjusted species list, though the opposite was the case for the Plymouth pair trawled data. Table 10.8 shows how these correlations were distributed according to their significance.

Table 10.8. Proportion (as %) of non-significant, significant, highly significant Spearman's rank-order correlations (r_s) between the sampled boat and monthly derived market data for the full and corrected species, according to port and type of trawling, N- = Newlyn, P- = Plymouth; -S = single boat trawling, -P = pair boat trawling, (for Newlyn and Plymouth). Highlighted ports and type of trawling satisfied the 50 % level.

| levels of significance | port and type of trawling | | | | | |
|---|---------------------------|--------------------|-----------|--------------------|-----------|--------------------|
| | full list | N S corrected list | full list | P S corrected list | full list | P P corrected list |
| not significant ($P \geq 0.05$) | 86 | 81 | 88 | 25 | 75 | 75 |
| significant ($P = 0.05$ to ≥ 0.01) | 14 | 12 | 13 | 50 | 25 | 25 |
| highly significant ($P > 0.01$) | 0 | 7 | 0 | 25 | 0 | 0 |
| Total significant | 14 | 19 | 13 | 75 | 0 | 0 |

Table 10.8 shows that the removal of mackerel, pilchards and scallops (adjustment 1) improved the Spearman's rank-order correlations most for Plymouth single boat trawls. After adjustment 1, 75, rather than 13 % of the correlations (r_s) were significant. Also, there were now highly significant correlations for Newlyn which there were not before adjustment 1, though the situation for Plymouth pair boat trawls has remained unchanged, overall. Overall, is important since there were instances where the rank-order correlations became less strong after the removal of mackerel, pilchards and scallops, and instances where correlations were significant before these species were removed and which are not after adjustment 1.

Taking into consideration the twin facts that after adjustment 1 some of the correlations were less strong though many were better the obvious test was to compare the means or medians of the before (full species), after (adjustment 1) list according to port and type of trawling, treating each haul as a pair of values. To see whether mean or medians should be tested the Spearman's rank-order correlation values (r_s) of full and removed species lists according to port and type were tested for normality using the A-D test. The results are show in Table 10.9.

Table 10.9. P values from Anderson-Darling test of normality for Spearman's rank-order correlations (r_s) for the full species list and after removal of mackerel, pilchards and scallops¹, according to port and type of trawling, N- = Newlyn, P- = Plymouth; -S = single boat trawling, -P = pair boat trawling.

| species list | port and type of trawling | | |
|--|---------------------------|-------|-------|
| | N S | P S | P P |
| full | 0.521 | 0.339 | 0.640 |
| after adjustment ¹ (removal of MAC, PIL, SCX) | 0.239 | 0.005 | 0.795 |

Table 10.9 shows that for comparing the Spearman's rank-order correlations for Newlyn, and Plymouth pair boat trawls the rank-order correlations approximated a normal distribution and the paired t -test can be employed. However, after adjustment¹ the (r_s) correlations from Plymouth single boat do not approximate a normal distribution so the non-parametric equivalent of the paired t -test, the Wilcoxon signed ranks test (Dytham, 1999, p75) was used, despite the full species list for Plymouth single boat approximating a normal distribution. The hypothesis being tested was that the removal of the three species had, overall, improved the correlations therefore this should be a one-tailed test however, SPSS only reports both the paired t -test and the Wilcoxon signed ranks test as 2-tailed. According to the paired t -test $P = 0.005$ for Newlyn and $P = 0.031$ for Plymouth pair trawled and according to the Wilcoxon signed ranks test $P = 0.017$ so the removal of the three species has significantly improved the (r_s) correlations though this has not been manifest in changed the proportions of significant correlations. Further analysis of the Plymouth pair boat sampled boat to market data follows the analysis for the Newlyn hauls since these hauls were used to show the additional analysis method.

10.3.2.2 Additional analysis of Newlyn based hauls

The most significant improvement from the full species to adjusted species list (¹) was evident for the hauls from Newlyn, though as Table 10.8 (above), shows there were still more than 80 %, or in excess of thirty of the hauls from this port for which a significant correlation between the sampled boat and equivalent monthly market data was not apparent. Table 10.8 (above) showed that the removal of mackerel, pilchards and scallops

(adjustment ¹) preferentially favoured the port of Plymouth, which was landed into by many pelagic trawlers and scallop dredgers that are non-resident in nature. Conversely, Newlyn is dominated by beam trawlers and its equivalent monthly derived market data reflects this. Reinstating mackerel, pilchards and scallops and examining the three most dominant species amongst the market data (which proved successful in improving the correlations for Plymouth) suggests that based on species removal scallops, megrim and monk-fish (adjustment **II**) should be applied as these species dominated the equivalent monthly derived market data. However, this approach was not very successful at improving the degree of correlation (r_s) between the sampled boat and monthly derived market data. Based on the full species list the average correlation $r_s = 0.232$, $n = 42$. This average across all the hauls from Newlyn rose to $r_s = 0.251$ after removing scallops, mackerel and pilchards (adjustment ¹), though the average across all hauls from Newlyn fell to $r_s = 0.238$ where the species' deletions were scallops, megrim and monkfishes (adjustment **II**). In fact because mackerel and pilchards were absent from the sampled boat landings (thus being removed anyway in pair-wise deletions) and scallops contributed < 1 % of the sampled boat landings their deletion may not have made much difference to the (r_s) correlations although through adjustment **III** (removal of megrim, monk-fish and scallops) these species were more significant (contributing 2, 8 and < 1 % respectively), and the average (r_s) correlation reflected this.

So far the majority of the correlations between the sampled boat and equivalent monthly derived market data have been significantly similar for the ports of Looe and Salcombe and the removal of species has been based on a rationale according to the type and nature of fishing and has been successful in ensuring 50 % or more of the Spearman's rank-order correlations at the haul level for Plymouth although gaining a similar proportion of statistically significant (r_s) correlations for the Newlyn hauls has not been possible, although it has been possible to produce 50 % statistically significant correlations at the trip level. In attempting to bolster the number of statistically significant (r_s) correlations

between the sampled boat and equivalent monthly derived market data at the haul level from Newlyn it was insufficient simply to remove the most dominant species from the market data. Instead, examining the rank-order of species in Table 10.6, it was apparent that in addition to the disparity between the dominant market to sampled boat data, the most abundant species in the sampled boats (gurnards, cod and John Dory) did not feature strongly (with the exception of cod at 4 %) in the monthly derived market data. Therefore a twin track approach was required examining both components of the data. Table 10.10 shows the rank-order of species from all the Newlyn hauls in the sampled boat and equivalent monthly derived market data according to their difference.

Table 10.10. Rank of species from all Newlyn hauls ($n = 42$) according to their proportion (as %) from the sampled boats and equivalent monthly derived market data. The species are listed in the order of the difference between the two lists of ranks.

| species | rank-order from sampled boat | rank-order of equivalent monthly derived market data | difference between the two rank-orders (without sign) |
|---------|------------------------------|--|---|
| CON | 14 | 14 | 0 |
| DAB | 27 | 26 | 1 |
| FLE | 28 | 29 | 1 |
| LEM | 9 | 8 | 1 |
| PIL | 30 | 31 | 1 |
| RAY | 5 | 4 | 1 |
| BSE | 25 | 28 | 3 |
| HER | 24 | 27 | 3 |
| MON | 6 | 3 | 3 |
| BLL | 18 | 22 | 4 |
| MUR | 20 | 24 | 4 |
| COD | 2 | 7 | 5 |
| WHG | 13 | 18 | 5 |
| HAD | 21 | 15 | 6 |
| HKE | 12 | 6 | 6 |
| PLE | 17 | 11 | 6 |
| POL | 15 | 9 | 6 |
| SOL | 19 | 13 | 6 |
| CTL | 26 | 17 | 9 |
| MEG | 11 | 2 | 9 |
| LIN | 16 | 5 | 11 |
| CRE | 23 | 10 | 13 |
| LSD | 10 | 25 | 15 |
| POK | 31 | 16 | 15 |
| BIB | 7 | 23 | 16 |
| SQC | 4 | 20 | 16 |
| MAC | 29 | 12 | 17 |
| GUX | 1 | 19 | 18 |
| JOD | 3 | 21 | 18 |
| SCX | 22 | 1 | 21 |
| HOM | 8 | 30 | 22 |

The species in Table 10.10 were in the order of the difference between the two ranks (column 4). Based on Table 10.10 the most appropriate species to be removed were horse mackerel, scallops, John Dory and gurnard. The latter two share equal rank and so in this instance the adjustment concerned four species. Table 10.11 shows how the (r_s) correlations were distributed according to their significance level for adjustment and.

Table 10.11. Proportion (as %) of significant, highly significant and non-significant Spearman's rank-order correlations (r_s) between the sampled boat and monthly derived market data for the Newlyn hauls based on two adjustments (I and II) of species removals. This table should be viewed as a continuation of Table 10.8, above. Highlighted ports and type of trawling satisfied the 50 % significant level.

| levels of significance | adjustment I (MEG, MON and SCX removed) | adjustment II (HOM, SCX, JOD and GUX removed) |
|---|---|---|
| not significant ($P \geq 0.05$) | 88 | 48 |
| significant ($P = 0.05$ to ≥ 0.01) | 12 | 19 |
| highly significant ($P > 0.01$) | 0 | 33 |
| Total significant | 12 | 52 |

Table 10.11 shows how much more successful adjustment II (the species deletions of horse mackerel, scallops, John Dory and gurnard were compared to those from adjustment I (removal of megrim, monk-fish and scallops); in that after adjustment II > 50 % of the (r_s) correlations were significant. Also that the Newlyn samples should not be treated in the same manner as the Plymouth single boat samples.

Whilst adjustment I (removal of horse mackerel, scallops, John Dory and gurnard) was not strictly based on the difference between the actual sampled boats and the difference that might be expected by removing the influence caused by the many beam trawling boats which land into Newlyn it is nevertheless the case that beam trawlers do not routinely catch horse mackerel and John Dory and the proportion of gurnards in their landed part of the haul might not be as high (at 24 %) as in the sampled boats from Newlyn. Also, scallops did not contribute a large proportion of any of the sampled boat data, therefore the removal of these four species, while, by the very nature of the way in which they were selected were bound to improve the degree of (r_s) correlation between the sampled boat and equivalent monthly derived market data, their removal can also be justified according to the pattern evident in comparing Newlyn to the other ports sampled here and with knowledge of and sensitivity to the predominant use of this port.

10.3.2.3 Additional analysis of Plymouth pair boat hauls

The same process to that carried out for the Newlyn hauls was undertaken on the Plymouth pair hauls. Table 10.12 shows the rank-order of species from all the Plymouth pair boat hauls in the sampled boat and equivalent monthly derived market data according to their difference.

Table 10.12. Rank of species from all Plymouth pair trawled hauls ($n = 8$) according to their proportion (as % from the sampled boats and equivalent monthly derived market data. The species are listed in the order of the difference between the two lists of ranks.

| species | rank-order from sampled boat | rank-order of equivalent monthly derived market data | difference between the two rank-orders (without sign) |
|---------|------------------------------|--|---|
| HAD | 29 | 29 | 0 |
| LIN | 17 | 17 | 0 |
| BIB | 12 | 13 | 1 |
| HER | 30 | 31 | 1 |
| MEG | 20 | 21 | 1 |
| MUR | 21 | 20 | 1 |
| POK | 31 | 30 | 1 |
| PLE | 5 | 7 | 2 |
| BLL | 26 | 22 | 4 |
| LEM | 14 | 10 | 4 |
| COD | 10 | 15 | 5 |
| CON | 28 | 23 | 5 |
| HOM | 9 | 4 | 5 |
| MAC | 7 | 1 | 6 |
| RAY | 8 | 14 | 6 |
| CTL | 13 | 6 | 7 |
| HKE | 16 | 25 | 9 |
| MON | 3 | 12 | 9 |
| FLE | 18 | 28 | 10 |
| SOL | 19 | 9 | 10 |
| WHG | 1 | 11 | 10 |
| BSE | 27 | 16 | 11 |
| JOD | 15 | 26 | 11 |
| DAB | 11 | 24 | 13 |
| SQC | 4 | 18 | 14 |
| POL | 24 | 8 | 16 |
| CRE | 22 | 5 | 17 |
| GUX | 2 | 19 | 17 |
| LSD | 6 | 27 | 21 |
| PIL | 23 | 2 | 21 |
| SCX | 25 | 3 | 22 |

As was the case for Table 10.10, (above) the species in Table 10.12 are in the order of the difference between the two ranks. Based on Table 10.12 the most appropriate species to be

removed were dogfishes (lesser spotted), pilchards and scallops (1). Two of these species (MAC and PIL) remain unchanged from the first (1) example of removals. The relevant rationale for removal of LSD is that on many occasions, this species was discarded, though depending on the boat and time of year (as sometimes dogfish are landed to act as bait but this is common only during the height of the crab potting season). Gurnard, too, (as was seen for Newlyn) often falls into this category and the occasional landing of a species to act as bait may produce a false representation of this species in the sampled boat to market data at a variety of scales, (and ranks) which perhaps was also evident from the Newlyn based hauls.

Examining the Spearman's rank-order correlations (r_s) between the sampled boat and equivalent monthly derived market data for the Plymouth pair boat trawled hauls based on the difference between the rank-order of species for this port and type of trawling (1) has meant that 50 % of the correlations were not significant, 25 % were significant and 25 % were highly significant. Thus altering the removed species from MAC, PIL and SCX (1) to LSD, PIL and SCX (1) improved the proportion of significant correlations (r_s) to the 50 % level.

Table 10.13 draws together the various methods employed in producing the significant correlations.

Table 10.13. Proportion (as %) of significant ($P = 0.05$ to ≥ 0.01), highly significant ($P > 0.01$), and non-significant ($P \geq 0.05$) Spearman's rank-order correlations (r_s) between the sampled boat and monthly derived market data for the full and variously adjusted species lists, according to port and type of trawling, N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling. Mackerel, pilchards and scallops are flagged with (1) across Newlyn, Plymouth single and pair boat trawls. Megrim, monk-fish and scallops are flagged with (1) and horse mackerel, scallops, John Dory and gurnard are flagged with (1) for Newlyn and pilchards, scallops and dogfish are flagged with (1) for the Plymouth pair boat. 50 % or more significant correlations (at whatever level) are also highlighted.

| port and type species list | N S | | | | L S | | L P | | P S | | P P | | S S | |
|-------------------------------|------|-----|-----|-----|------|------|------|------|------|-----|------|-----|------|------|
| | full | (1) | (1) | (1) | full | full | full | full | full | (1) | full | (1) | full | full |
| not significant | 86 | 81 | 88 | 48 | 9 | 0 | 87 | 25 | 75 | 75 | 50 | 20 | | |
| significant | 14 | 12 | 12 | 19 | 36 | 22 | 13 | 50 | 25 | 25 | 25 | 20 | | |
| highly significant | 0 | 7 | 0 | 33 | 55 | 78 | 0 | 25 | 0 | 0 | 25 | 60 | | |

Table 10.13 allows the proportion of significant correlation (r_s) to be compared for the various methods. It also shows that after the four groups of species deletions were carried out 50 % or more of the correlations were significant by port and type of trawling.

10.4 Summary

In order to compare the boats sampled here with commercially available data on landings it was necessary to group together some species and also to acquire further non-public domain data to ensure that groups not normally represented in the commercial data can be included in this type of assessment.

The sampled boat data was correlated against equivalent quarter and equivalent monthly derived market data, with the latter providing significantly higher correlations; thus the increased resolution in the monthly data outweighs the smoothing in the quarterly data. This result is interesting in that it shows the good relationship between the chosen vessels and their markets.

Without further manipulating the species lists it was possible to show that the boats sampled from the smaller ports of Looe (both single and pair trawl boats) and Salcombe did significantly correlate (r_s) with their equivalent monthly derived market data. This was despite Salcombe being predominately landed into by crab potting boats however, in using the Spearman's rank-order correlation the dominance of a particular species is reduced.

In attempting to significantly correlate the sampled boats from the larger ports of Plymouth and Newlyn some rationally based manipulation of the species lists was required after these Markets would not allow their data to be used. Instead, for the Plymouth single boats this involved the relatively straightforward task of reducing the influence of the pelagic trawling and scalloping boats through removing the mackerel, pilchards and

scallops. Landings into Newlyn were dominated by beam trawlers and the species removal based on the same species as removed for Plymouth was not successful. Instead, a method of removing those species which were the most disparate in the rank-orders between the sampled boat and monthly derived market data was adopted. While bound to improve the degree of correlation overall the removal of John Dory, horse mackerel, gurnards (and scallops, due to statistical reasons) can also be justified on biologically relevant grounds.

A similar and successful process to that described for Newlyn was undertaken on the Plymouth pair trawled hauls. This removed dogfish, pilchards and scallops and again the removal of these species (though bound to increase the degree of correlation) was justified on biological grounds.

Chapter 11

11 Conclusions and future directions

This study examined the impact of inshore single boat otter trawling from Newlyn, Looe, Plymouth and Salcombe and pair boat demersal trawling from Looe and Plymouth on the benthic environment off the SW peninsula of the UK.

Sampling of the commercial fleet occurred between 1998 and 2000 with at least one trip being undertaken per technique per quarter of the year. Onboard, prior to any disturbance by the crew, a ~ 38 kg sample of the haul was taken. All fishes and shellfish (54 and 11 species respectively) were identified and measured at sea and the non-fish material (124 species) was analysed later. In addition to individual length measurements, components of the sample were weighed at sea to test the reliability of derived weight from length both at species and component level.

Overall (by weight) 79.8 % of the sample was landed fish and shellfish, 15.8 % was discarded fishes and 4.4 % was invertebrates and other material. Although each sample was a full basket the samples from Newlyn were the lightest, though this was due to them packing less well as they contained the largest fish according to species.

In general, pair trawling samples contained more landed, less discarded and less non-fish material than their single boat equivalents. Pair trawl samples also contained fewer examples of large invertebrate species. This may be gear related or it may be due to the pair trawling taking place in less structurally complex areas than the single boat fishing.

Related information about the substrate and tide were generated from British Geological Survey data and a computer simulation of the maximum mean tidal strength.

Newlyn derived trawls were over mainly gravely sand and sandy gravel, though there were many additional substrates, including rock. The majority of the Plymouth, Looe and Salcombe hauls featured sand, though closer inshore the trawls extended into patches of gravely sand, sandy gravel as well as other mixed substrate types and again included rock. Unmodified gravel was confined to Newlyn.

The Looe and Plymouth single and pair trawls were from areas which generally have similar values of maximum tidal strength (rarely $> 0.50 \text{ ms}^{-1}$), and had relatively low variability as expressed in their range. This was largely due to the trawls being around 4h 30 min and being generally in east west directions. Higher values $\approx 0.82 \text{ ms}^{-1}$ were generated from trawls that passed close to headlands; these were typically the trawls from Salcombe.

The Newlyn samples (which were between those from Looe or Plymouth and Salcombe in magnitude, $\approx 0.65 \text{ ms}^{-1}$) were also relatively similar in terms of average maxima (given their similarity of location) except those during Q2 '98 which were more geographically distant.

A classification based on the abiotic factors showed greater similarity between ports rather than between type of trawling for Looe and Plymouth, which suggested that the sampled vessels have favoured areas in which they fish and this was supported by anecdotal information.

After undertaking a redundancy analysis the abiotic data of nine substrate types, two factors of the tide and depth were retained for subsequent analyses. Although these data were dominated by the substrate, the Principal Component Analysis (PCA) was not adjusted to take into consideration the likely influence of these groups as this varies unpredictably. Most of these factors were well described by two axes of a PCA, although the presence of rock was very important in the third axis. Substrate data for this region

has been collected over a long timescale therefore, it is possible that fishing has altered the substrate and this is not reflected in the data.

Overall, the full sample was well represented by the fish species. The top 10 species (*Aspitrigla cuculus*, *Merlangius merlangus*, *Trisopterus luscus*, *Gadus morhua*, *Zeus faber*, *Loligo vulgaris*, *Microstomus kitt*, *Scyliorhinus canicula*, *Loligo* spp., and *Pleuronectes platessa*) comprised nearly 70 % of the sample by weight.

In agreement with the different abiotic regime, the dominant fishes were different in Newlyn compared to the other ports. According only to port, the Looe and Plymouth samples were not significantly different, either as full samples or for their fish and non-fish components. The Salcombe samples were not significantly different to those from Looe or Plymouth for the non-fish part of the sample. Including the type of trawling in the groups analysed meant that the greatest similarity was for the non-fish part of the sample, although the relative amounts of the components varied (see above).

A spatial and temporal analysis of the Newlyn samples revealed that there was some similarity across successive years for the non-fishes though only after the removal of the shellfishes. The greatest similarity was spatially and suspected seasonal trends were not significant.

Abundance Biomass Comparison (ABC) analysis as a method of estimating disturbance within the fished assemblages for the non-fish part of the sample and the full sample were similar and before extending this analysis to include the fishes the size spectra of the sample was analysed. ABC analysis suggested that the whole region was relatively undisturbed though it is recognised that mobile scavengers (which are often large) may be responsible for raising the *W*-test statistic. According to just the non-fishes, this analysis suggested that Newlyn and Looe were the most disturbed area though extending the analysis into the full sample only Newlyn seemed to have suffered the greatest amount of disturbance. This was supported by findings of an assessment of average (Δ^+) and variation (Λ^+) in taxonomic distinctness.

Taxonomic distinctness analyses also showed that according to both the non-fish or the whole sample the areas pair trawled had greater variability in disturbance than the single boat samples. The pair trawl samples also had lower average taxonomic distinctness than the single boat samples.

Several within and between-species relationships were explored to assess the wider patterns apparent in the fish community data. Whilst the relative abundance of the *Raja* spp. did not match the replacement mortality order suggested by Walker & Hislop, (1998), (which may be due to the small sample size as rays made up only 1.2 % of the total) their average length was in keeping with the order of resilience hypothesized by Walker & Hislop, (1998).

An investigation of three common predators (described by Veale *et al.*, 2000) on *Pecten maximus* according to their co-occurrence in the sample showed similar trends for *A. rubens* and *Liocarcinus* spp. in that while *P. maximus* was not ubiquitous, where it was found there was a 2:1 and 3:1 chance that *A. rubens* and *Liocarcinus* spp respectively would be co occurring. The third group investigated was *Pagurus* spp. They were both not common and not commonly occurring in the sample though their small size may have been responsible.

This study showed that *M. glacialis* may be a better indicator of the impacts of trawling than *A. rubens*. In agreement with Ramsay *et al.*, (2000b), the data from this study suggest that *M. glacialis* has a lower incidence of arm loss when it was also present in the samples with known examples of its predators. It is also easier to detect arm loss in *M. glacialis* than *A. rubens* from weight which may have benefits for examples that have regenerated arms or where batch processing is undertaken, although in order to develop this idea further there is a need to understand its ecology and life history better.

Other areas of the taxonomic distinctness analysis revealed that the samples from close to the Inshore Potting Agreement area, while not the most species rich, were amongst the most undisturbed and had the most even taxonomic distinctness, suggesting

that there may be a degree of leakage from this voluntarily protected area. The practical usefulness of this is that Salcombe may be regarded as a reference area for the region. Thus while it was not an aim of this study to establish 'control' or 'impact' areas it appeared both from examining Δ^+ and Λ^+ that the Salcombe area and its management could be a model for the whole of the study area and perhaps beyond. Additionally that Δ^+ and Λ^+ appear to be both sufficiently sensitive and robust to detect the trends in diversity where methods that are more traditional may not be.

There was evidence of seasonality in the Newlyn samples shown by some increase in average taxonomic distinctness later in the year, which was consistent with theories of settlement or successional changes though this was not consistent for the other ports.

The plot of Δ^+ against number of species in this study was in general agreement with the analysis by Rogers *et al.*, (1999). Analysis of the relative contribution of selected groups to taxonomic diversity showed the derived conservation priorities for orders of fishes were Elasmobranchs (Rajiformes and Carcharhiniformes) > Pleuronectiformes > Gadiformes. In general, the fact of 'losing' orders of fishes was more important for single rather than pair trawl samples, which reinforces the view that single boat samples were collected from structurally more complex areas supporting a wider taxonomic diversity.

This analysis of groups for conservation priority was also carried into the invertebrates and showed that the echinoderms had the greatest influence on the taxonomic distinctness for Newlyn. The study of samples from this port would be a useful contribution to the understanding of disturbance monitoring. Also, it is recognised that the analysis of these data by phyla is unrefined. It is proposed to reanalyse this information by finer taxonomic classification, by its sensitivity to fishing (Macdonald *et al.*, 1996) and according to functional groups.

When examining the abiotic and biotic data sets, the arrangement of the abiotic factors according to their ordination was closely followed, and removing the species of low abundance generally improved the correlation though care was required for the removal not to be too severe. Those species contributing 5 or 10 % biomass yielded the highest correlations. Surprisingly perhaps, the fish species bore the closest similarity to the abiotic data suggesting that much of the study area was dominated by similar invertebrate species. Given that the most common invertebrates tend to be scavengers it is not surprising that, though categorised as moderately disturbed to moderately undisturbed, the occurrence in the samples of examples of long lived and slow growing invertebrates species (see page 202, above) and fish species that do not become mature until they have reached 50 cm or more (Table 5.16, page 141, above) suggests that fishing is not evenly distributed.

An assessment of the location of the fishes in relation to the substrates was compared to the literature. There was general agreement between the data and the literature, which suggests that the novel method developed here, can be more widely applied to commercial catch data if the trawl track (and therefore the substrates encountered) are known. Additionally, for eight of the most commonly occurring species it was possible to be more precise in their substrate preferences than suggested from the literature. In recent years, there has been a consolidation of knowledge on the habitat preferences of the invertebrates and it is proposed to widen this analysis to take advantage of this information. The benefit of undertaking this is that while the analysis presented here confirmed and added to the relationship between fish species and substrates, habitat complexity is a function of surface topography and sessile epifauna. The latter is important in the survival of round fishes, particularly (Gotceitas *et al.*, 1995; Borg *et al.*, 1997; Thrush *et al.*, 2002) whereas substrate properties alone may be more important for flatfishes (Gibson & Robb, 1992; Rogers, 1992).

Gutting the fishes is a major part of processing the catch. It was recognised that the collection and analysis of fish stomachs is extremely useful in describing trophic relationships and while there are several examples of this analysis for the North Sea (Daan, 1989; Hislop, 1997) the more species diverse English Channel is far less well studied. Trophic relationships are highly location specific and it is recommended that future studies of this nature should include a component of stomach contents analysis, especially since samples could be easily taken and stored onboard for later processing.

The landed fish part of the sample was shown to be a statistically good approximation of the landed part of the haul (for which the commercial data was known) in $> 95\%$ of the hauls. In part, it was the species-rich nature of the fish populations, in the study area, which enabled this analysis to be undertaken. Other features were the cooperation of the skippers who allowed the catch data to be known and the size of the sample that meant relatively few species were unpaired between the sample and the haul. In addition, data on the commercial landings for each port show that the boats sampled in this study were representative of these ports.

The use of logbook data to infer spatial and other type of data is becoming more widespread (Ragnarsson & Steingrimsen, 2003). A future goal would be to develop the ideas in this study such that a model of the impact of fishing at species or community level could be generated, based on knowledge of the spatial and temporal activity of fishing effort. Whilst the methods in Chapter 9 and Chapter 10 are simple, they describe the process of scaling up the sample data to that of the haul and that of the market respectively. Given that an economic value is placed onto the landed part of the haul and the relationship between the landed part of the sample and the landed part of the haul has been shown to be reliable the goal would be to complete the model set out in Figure 1.3, (on page 16, above). By ground-truthing market to haul to sample data more fully (Peach & Cotterell, in prep) it is hoped that an economic and ecological model of the effects of fishing can be generated. It is also hoped that this can be incorporated into the future

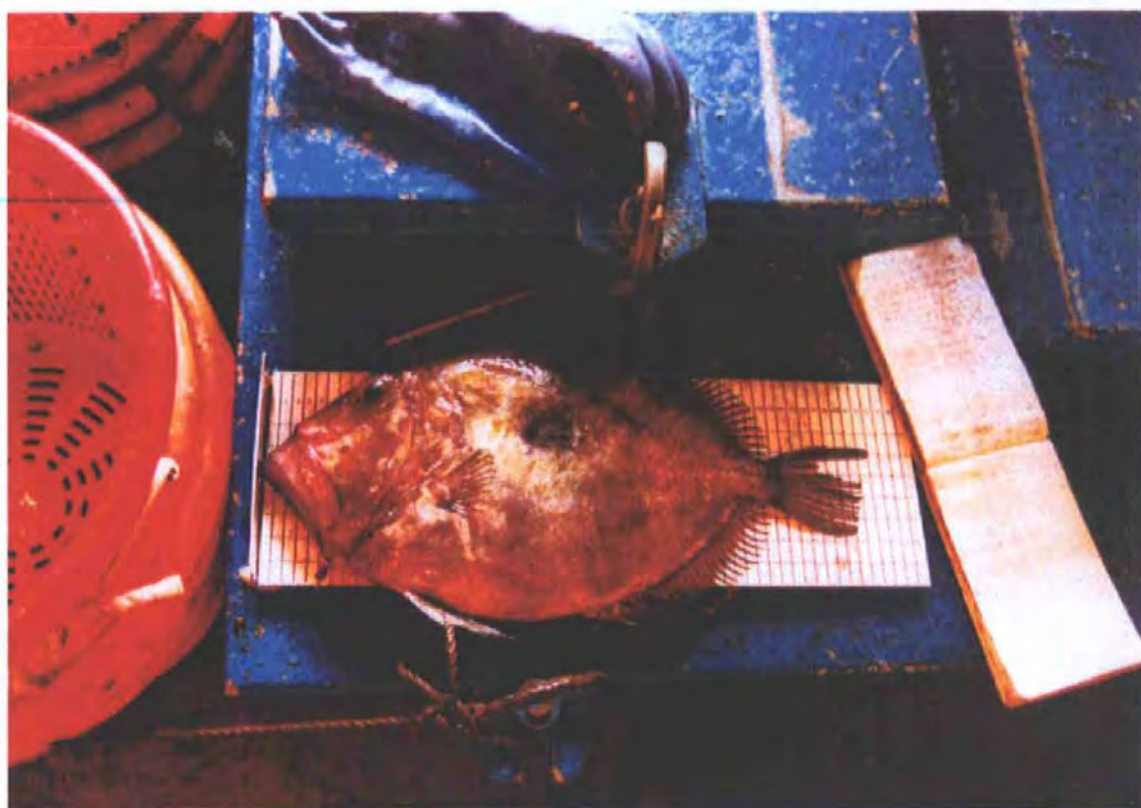
management regime of European fisheries, which are due to be updated to incorporate the Maximum Sustainable Yield (MSY) concept (COM, 2006, p21), though this is currently the only proposed mechanism to reduce over-fishing.

The proposed EU Marine Strategy Directive sets out a requirement to achieve “‘Good Environmental Status’ (GEnS) of the marine environment by 2021,” (COM, 2005, p5), though the assessment unit of this will be according to proposed ‘marine eco-regions’ (EC, 2006, p19) which are generally very large. Laffoley *et al.*, (2006) sets out to define GEnS considerations and amongst these are nineteen headline indicators, divided into function and process, and habitat and species that attempt to address ecosystem health. Some of these headline indicators (such as the fish index, the sharks, skates and rays index, and the seabed disturbance index) mirror those employed here though others are beyond the scope of this study. Comparative assessment however, with larger data sets may provide useful information to be included into the trophic index, the species index and the habitats condition index.

Missing from the indices of Laffoley *et al.*, (2006) as measures of ecosystem health are measures of taxonomic diversity (Δ^+ and Λ^+) as described in Chapter 6. These measures, proposed together as a ‘taxonomic index’ have here been shown to possess ecologically meaningful relationships in terms of taxonomic diversity (Δ^+) and resilience to disturbance (Λ^+). Importantly too, the employment of the proposed taxonomic index can be undertaken at a far higher spatial resolution than in the proposed ‘marine eco-regions’ (EC, 2006, p19) although samples from a 12 nm seabed swathe have the advantage of not being regarded as ‘point sources. Another advantage of the taxonomic index would be in its application to both ecosystem functional groups and the contribution that particular taxonomic groups have to overall diversity. In order to examine the usefulness of a taxonomic index, Δ^+ and Λ^+ should be generated for a broader range of trawl surveys than was available to Rogers *et al.*, (1999).

Overall this work has provided a comprehensive and detailed picture of the trawl fishery of the southwest English Channel particularly in terms of geographical variation in catch composition, abiotic drivers of this and relative disturbance of the fished assemblages. In doing this, it has tested a range of methodologies and extended their application into different taxonomic components, principally from the inclusion of non-fish material with typically landed and discarded fish species. It has also improved the understanding of single species of fishes, of invertebrates, their communities and their ecology. The utility of the sampling methods in providing snapshots of the hauls and approximating the typical catch of the ports was also demonstrated.

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Appendix A

A Sample accuracy

Recording the raw weight of both the landed and discarded part of the sample by spring balance allowed these data to be compared to the value subsequently calculated by converting then summing each length to weight according to individual species. The comparison is shown by the regression in Figure A.1.

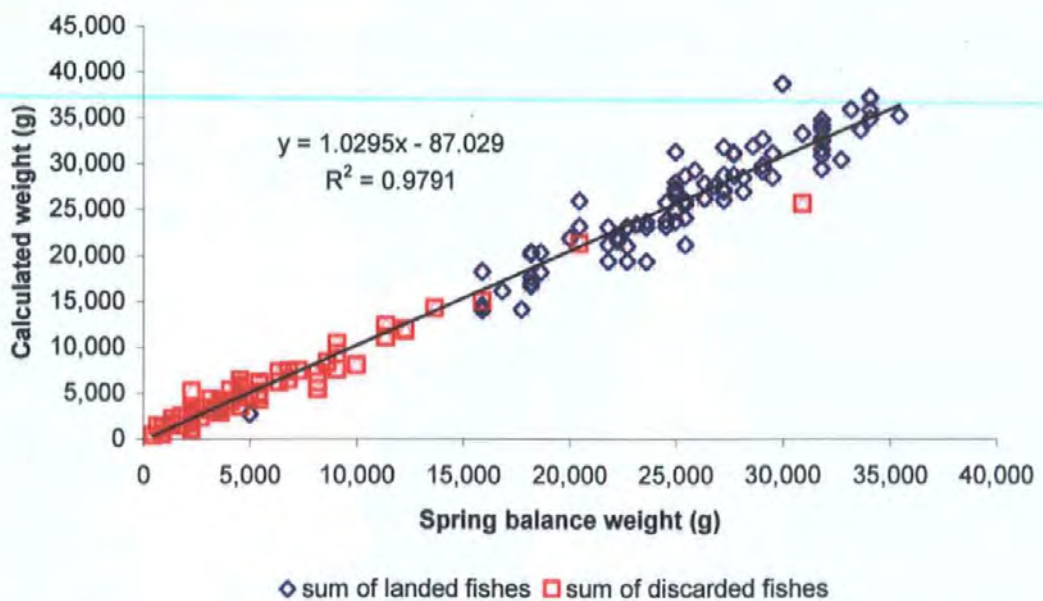


Figure A.1. Calculated weight by summing all fish per species and summing all species and spring balance weight taken on board, n (landed fishes) = 88 and n (discarded fishes) = 88.

The regression shown in Figure A.1 was very highly significant ($P < 0.001$) though the regression was not strictly valid as the residuals did not approximate a normal distribution according to the A-D test; ($A^2 = 2.047$, $n = 176$, $P < 0.001$). This was due to the bimodal nature of the data since Figure A.1 shows the values for the landed and discarded part of the sample nevertheless as is evident from Figure A.1 the two differently derived measurements are highly related. Not only does this suggest that the measurements were accurately collected but the generated weight from length calculations can be trusted.

Appendix B

B Generated length to weight conversion data

Through testing, it was discovered that the values for dragonet (*Callionymus sp*) were unreliable. A sample ($n = 31$) of male dragonet (*Callionymus lyra*) were collected at sea, brought back to the laboratory and were measured to the nearest 0.1 cm and 0.1 g. Figure B.1 shows the data.

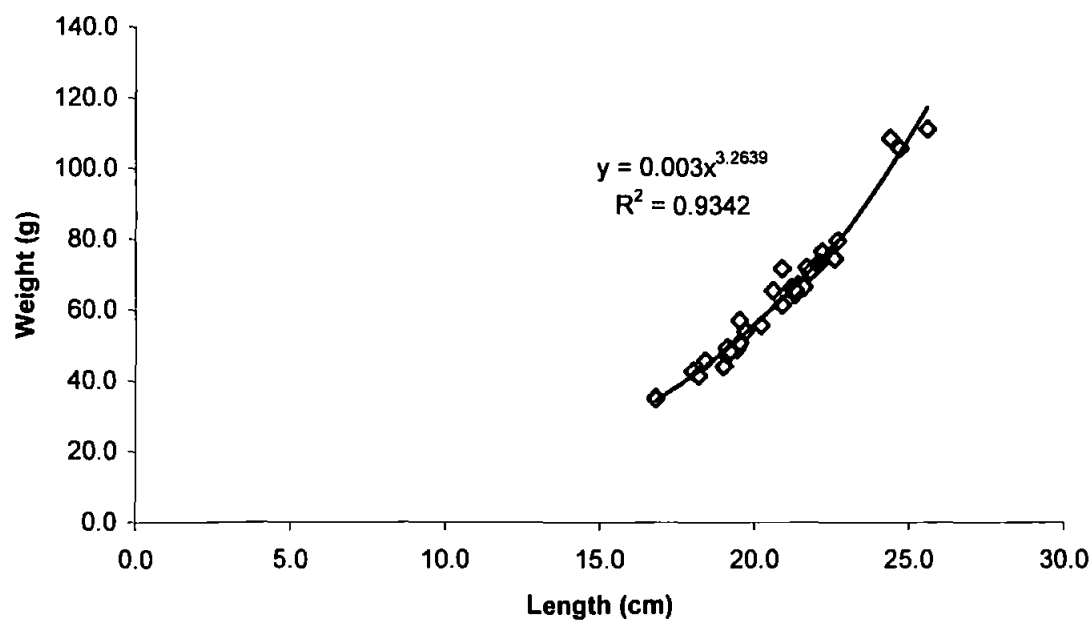


Figure B.1. Length:weight relationship for the dragonet (*Callionymus lyra*), $n = 31$. The specimens were collected out of Plymouth (06/06/1999, $n = 26$) and Looe (07/07/1999, $n = 5$). The values of a , b (and R^2 are shown on the graph).

The linear regression of log-weight on log-length was very highly significant $P < 0.001$, $\log(y) = 2.867\log(x) - 1.982$, $R^2 = 0.974$, and this regression was valid with the residuals approximating a normal distribution according to the A-D test, ($A^2 = 0.648$, $n = 31$, $P = 0.082$).

It was not possible to find length:weight relationship and exponent for the starry smooth hound (*Mustelus asterias*). Lart (*pers com*) provided the data for the smooth hound (*M. mustelus*), (see Table 3.3, above), though there are differences in shape and size, as well as colouration in these species. Wheeler, (1978) described the smooth hound as being "...slender-bodied..." attaining "...a maximum length of 1.6 m, more usually between 1 and 1.2 m." Also, he describes the starry smooth hound as being "a moderately slender-bodied shark" grow[ing] to a maximum length of 1.8m; averag[ing] near 1.2m." For balance Miller & Loates, (1997) notes the smooth hound as growing larger than the starry smooth hound. When available a sample ($n = 15$) of starry smooth hound (*M. asterias*) were collected at sea, (Newlyn 05/05/1999) brought back to the laboratory and were measured to the nearest 0.1 cm and 0.1 g. Figure B.2 shows the data.

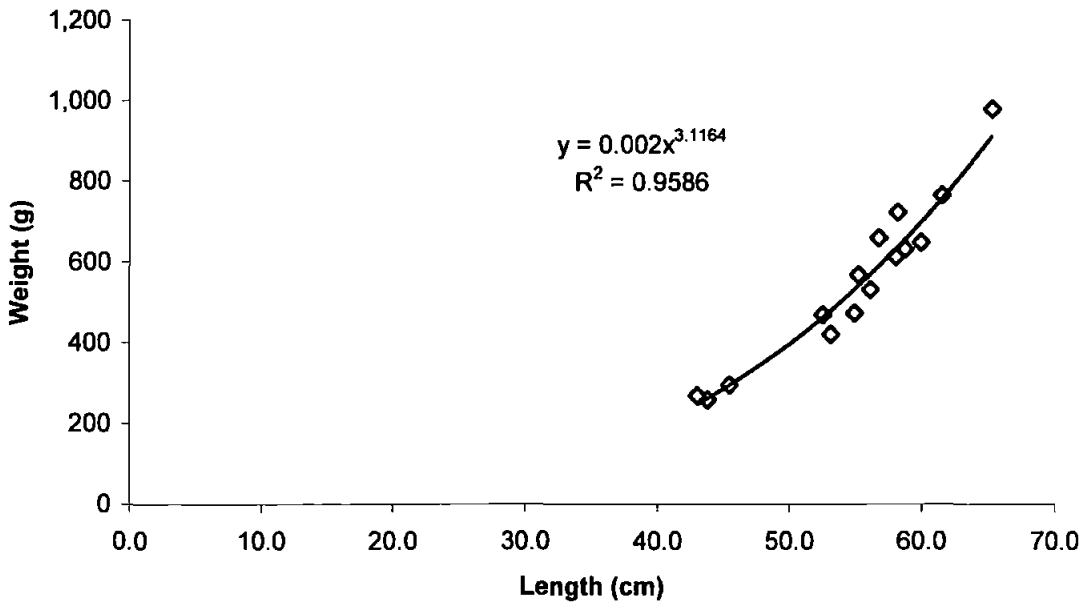


Figure B.2. Length:weight relationship for the starry smooth hound (*Mustelus asterias*), $n = 15$. The specimens were collected out of Newlyn (05/05/1999). The values of a , b (and r^2 are shown on the graph).

The linear regression of log-weight against log-length was very highly significant, $P < 0.001$, $\log(y) = 3.116\log(x) - 2.698$, $r^2 = 0.959$, and this regression was valid with the residuals strongly approximating a normal distribution according to the A-D test, ($A^2 = 0.157$, $n = 15$, $P = 0.939$).

Appendix C

C Full species list

Table C.1. Classification (across fifteen levels and including Taxon ID) of encountered species, part 1; Phylum PORIFERA to *Ophiura ophiura*.

| Taxon ID | species | Genus | Subfamily | Family | Superfamily | Section | Infraorder | Suborder | Order | Subclass | Class | Superclass | SubPhylum | Phylum | Kingdom | |
|----------|----------------------------------|-----------------------|-------------------|-------------------|------------------|------------------|------------------|------------------|---------------|-------------------|----------------|-------------|-------------|-------------|----------|----------|
| C1 | PORIFERA | PORIFERA | PORIFERA | PORIFERA | PORIFERA | PORIFERA | PORIFERA | PORIFERA | PORIFERA | PORIFERA | PORIFERA | PORIFERA | PORIFERA | PORIFERA | Animalia | |
| C4080 | <i>Stelligera stuposa</i> | <i>Stelligera</i> | Hemistrellidae | Hemistrellidae | HADROMERIDA | HADROMERIDA | HADROMERIDA | HADROMERIDA | HADROMERIDA | TETRACANTHOMORPHA | DEMOSPONGIAE | PORIFERA | PORIFERA | PORIFERA | Animalia | |
| D10240 | <i>Alcyonium digitatum</i> | <i>Alcyonium</i> | Alcyoniidae | Alcyoniidae | ALCYONACEA | ALCYONACEA | ALCYONACEA | ALCYONACEA | ALCYONACEA | OCTOCORALLIA | OCTOCORALLIA | ANTHOZOA | CNIDARIA | CNIDARIA | Animalia | |
| D10430 | <i>Eunicella verrucosa</i> | <i>Eunicella</i> | Plexauridae | Plexauridae | GORGONACEA | GORGONACEA | GORGONACEA | GORGONACEA | GORGONACEA | OCTOCORALLIA | OCTOCORALLIA | ANTHOZOA | CNIDARIA | CNIDARIA | Animalia | |
| D11510 | <i>Actinia equina</i> | <i>Actinia</i> | Actiniidae | Actiniidae | NYNANTHEAE | NYNANTHEAE | NYNANTHEAE | NYNANTHEAE | ACTINIARIA | HEXACORALLIA | HEXACORALLIA | ANTHOZOA | CNIDARIA | CNIDARIA | Animalia | |
| D13700 | <i>Caryophyllia smithii</i> | <i>Caryophyllia</i> | Caryophylliidae | Caryophylliidae | SCLERACTINIA | SCLERACTINIA | SCLERACTINIA | SCLERACTINIA | SCLERACTINIA | HEXACORALLIA | HEXACORALLIA | ANTHOZOA | CNIDARIA | CNIDARIA | Animalia | |
| D2380 | <i>Eudendrium ramosum</i> | <i>Eudendrium</i> | Eudendriidae | Eudendriidae | FILIFERA | FILIFERA | FILIFERA | FILIFERA | FILIFERA | ANTHOATHECATAE | LEPTOLIDA | HYDROZOA | CNIDARIA | CNIDARIA | Animalia | |
| D5160 | <i>Lafoea dumosa</i> | <i>Lafoea</i> | Lafoeidae | Lafoeidae | LAFOEOIDEA | LAFOEOIDEA | LAFOEOIDEA | LAFOEOIDEA | CONICA | LEPTOTHECATAE | LEPTOLIDA | HYDROZOA | CNIDARIA | CNIDARIA | Animalia | |
| D5250 | <i>Halecium beanii</i> | <i>Halecium</i> | Haleciidae | Haleciidae | HALECIOIDEA | HALECIOIDEA | HALECIOIDEA | HALECIOIDEA | CONICA | LEPTOTHECATAE | LEPTOLIDA | HYDROZOA | CNIDARIA | CNIDARIA | Animalia | |
| D5260 | <i>Halecium halecinum</i> | <i>Halecium</i> | Haleciidae | Haleciidae | HALECIOIDEA | HALECIOIDEA | HALECIOIDEA | HALECIOIDEA | CONICA | LEPTOTHECATAE | LEPTOLIDA | HYDROZOA | CNIDARIA | CNIDARIA | Animalia | |
| D5520 | <i>Aglaophenia kirchenpaueri</i> | <i>Aglaophenia</i> | Aglaopheniidae | Aglaopheniidae | PLUMULARIOIDEA | PLUMULARIOIDEA | PLUMULARIOIDEA | PLUMULARIOIDEA | CONICA | LEPTOTHECATAE | LEPTOLIDA | HYDROZOA | CNIDARIA | CNIDARIA | Animalia | |
| D5660 | <i>Lytocarpia myriophyllum</i> | <i>Lytocarpia</i> | Aglaopheniidae | Aglaopheniidae | PLUMULARIOIDEA | PLUMULARIOIDEA | PLUMULARIOIDEA | PLUMULARIOIDEA | CONICA | LEPTOTHECATAE | LEPTOLIDA | HYDROZOA | CNIDARIA | CNIDARIA | Animalia | |
| D5850 | <i>Kirchenpaueria pinnata</i> | <i>Kirchenpaueria</i> | Kirchenpaueriinae | Kirchenpaueriinae | PLUMULARIOIDEA | PLUMULARIOIDEA | PLUMULARIOIDEA | PLUMULARIOIDEA | CONICA | LEPTOTHECATAE | LEPTOLIDA | HYDROZOA | CNIDARIA | CNIDARIA | Animalia | |
| D5910 | <i>Monotheca obliqua</i> | <i>Monotheca</i> | Plumulariinae | Plumulariinae | PLUMULARIOIDEA | PLUMULARIOIDEA | PLUMULARIOIDEA | PLUMULARIOIDEA | CONICA | LEPTOTHECATAE | LEPTOLIDA | HYDROZOA | CNIDARIA | CNIDARIA | Animalia | |
| D5970 | <i>Nemertesia antennina</i> | <i>Nemertesia</i> | Plumulariinae | Plumulariinae | PLUMULARIOIDEA | PLUMULARIOIDEA | PLUMULARIOIDEA | PLUMULARIOIDEA | CONICA | LEPTOTHECATAE | LEPTOLIDA | HYDROZOA | CNIDARIA | CNIDARIA | Animalia | |
| D5990 | <i>Nemertesia ramosa</i> | <i>Nemertesia</i> | Plumulariinae | Plumulariinae | PLUMULARIOIDEA | PLUMULARIOIDEA | PLUMULARIOIDEA | PLUMULARIOIDEA | CONICA | LEPTOTHECATAE | LEPTOLIDA | HYDROZOA | CNIDARIA | CNIDARIA | Animalia | |
| D6260 | <i>Abietinaria abietina</i> | <i>Abietinaria</i> | Sertulariidae | Sertulariidae | SERTULARIOIDEA | SERTULARIOIDEA | SERTULARIOIDEA | SERTULARIOIDEA | CONICA | LEPTOTHECATAE | LEPTOLIDA | HYDROZOA | CNIDARIA | CNIDARIA | Animalia | |
| D6270 | <i>Abietinaria filicula</i> | <i>Abietinaria</i> | Sertulariidae | Sertulariidae | SERTULARIOIDEA | SERTULARIOIDEA | SERTULARIOIDEA | SERTULARIOIDEA | CONICA | LEPTOTHECATAE | LEPTOLIDA | HYDROZOA | CNIDARIA | CNIDARIA | Animalia | |
| D6320 | <i>Amphisbetia operculata</i> | <i>Amphisbetia</i> | Sertulariidae | Sertulariidae | SERTULARIOIDEA | SERTULARIOIDEA | SERTULARIOIDEA | SERTULARIOIDEA | CONICA | LEPTOTHECATAE | LEPTOLIDA | HYDROZOA | CNIDARIA | CNIDARIA | Animalia | |
| D6370 | <i>Diphasia alata</i> | <i>Diphasia</i> | Sertulariidae | Sertulariidae | SERTULARIOIDEA | SERTULARIOIDEA | SERTULARIOIDEA | SERTULARIOIDEA | CONICA | LEPTOTHECATAE | LEPTOLIDA | HYDROZOA | CNIDARIA | CNIDARIA | Animalia | |
| D6380 | <i>Diphasia attenuata</i> | <i>Diphasia</i> | Sertulariidae | Sertulariidae | SERTULARIOIDEA | SERTULARIOIDEA | SERTULARIOIDEA | SERTULARIOIDEA | CONICA | LEPTOTHECATAE | LEPTOLIDA | HYDROZOA | CNIDARIA | CNIDARIA | Animalia | |
| D6420 | <i>Diphasia pinaster</i> | <i>Diphasia</i> | Sertulariidae | Sertulariidae | SERTULARIOIDEA | SERTULARIOIDEA | SERTULARIOIDEA | SERTULARIOIDEA | CONICA | LEPTOTHECATAE | LEPTOLIDA | HYDROZOA | CNIDARIA | CNIDARIA | Animalia | |
| D6430 | <i>Diphasia rosacea</i> | <i>Diphasia</i> | Sertulariidae | Sertulariidae | SERTULARIOIDEA | SERTULARIOIDEA | SERTULARIOIDEA | SERTULARIOIDEA | CONICA | LEPTOTHECATAE | LEPTOLIDA | HYDROZOA | CNIDARIA | CNIDARIA | Animalia | |
| D6530 | <i>Hydrallmania falcata</i> | <i>Hydrallmania</i> | Sertulariidae | Sertulariidae | SERTULARIOIDEA | SERTULARIOIDEA | SERTULARIOIDEA | SERTULARIOIDEA | CONICA | LEPTOTHECATAE | LEPTOLIDA | HYDROZOA | CNIDARIA | CNIDARIA | Animalia | |
| D6670 | <i>Sertularella gayi</i> | <i>Sertularella</i> | Sertulariidae | Sertulariidae | SERTULARIOIDEA | SERTULARIOIDEA | SERTULARIOIDEA | SERTULARIOIDEA | CONICA | LEPTOTHECATAE | LEPTOLIDA | HYDROZOA | CNIDARIA | CNIDARIA | Animalia | |
| D6690 | <i>Sertularella polyzonias</i> | <i>Sertularella</i> | Sertulariidae | Sertulariidae | SERTULARIOIDEA | SERTULARIOIDEA | SERTULARIOIDEA | SERTULARIOIDEA | CONICA | LEPTOTHECATAE | LEPTOLIDA | HYDROZOA | CNIDARIA | CNIDARIA | Animalia | |
| D6710 | <i>Sertularella tenella</i> | <i>Sertularella</i> | Sertulariidae | Sertulariidae | SERTULARIOIDEA | SERTULARIOIDEA | SERTULARIOIDEA | SERTULARIOIDEA | CONICA | LEPTOTHECATAE | LEPTOLIDA | HYDROZOA | CNIDARIA | CNIDARIA | Animalia | |
| D6770 | <i>Sertularia cupressina</i> | <i>Sertularia</i> | Sertulariidae | Sertulariidae | SERTULARIOIDEA | SERTULARIOIDEA | SERTULARIOIDEA | SERTULARIOIDEA | CONICA | LEPTOTHECATAE | LEPTOLIDA | HYDROZOA | CNIDARIA | CNIDARIA | Animalia | |
| D6890 | <i>Tamariscia tamariscia</i> | <i>Tamariscia</i> | Sertulariidae | Sertulariidae | SERTULARIOIDEA | SERTULARIOIDEA | SERTULARIOIDEA | SERTULARIOIDEA | CONICA | LEPTOTHECATAE | LEPTOLIDA | HYDROZOA | CNIDARIA | CNIDARIA | Animalia | |
| D700 | <i>Chryseora hyssocella</i> | <i>Chryseora</i> | Pelagiidae | Pelagiidae | SEMAEOSTOMEA | SEMAEOSTOMEA | SEMAEOSTOMEA | SEMAEOSTOMEA | SCYPHOMEDUSAE | SCYPHOMEDUSAE | SCYPHOZOA | CNIDARIA | CNIDARIA | CNIDARIA | Animalia | |
| D7280 | <i>Obelia sp.</i> | <i>Obelia</i> | Obeliinae | Obeliinae | CAMPANULARIOIDEA | CAMPANULARIOIDEA | CAMPANULARIOIDEA | CAMPANULARIOIDEA | PROBOSCOIDA | PROBOSCOIDA | LEPTOTHECATAE | LEPTOLIDA | HYDROZOA | CNIDARIA | CNIDARIA | Animalia |
| D7290 | <i>Obelia bidentata</i> | <i>Obelia</i> | Obeliinae | Obeliinae | CAMPANULARIOIDEA | CAMPANULARIOIDEA | CAMPANULARIOIDEA | CAMPANULARIOIDEA | PROBOSCOIDA | PROBOSCOIDA | LEPTOTHECATAE | LEPTOLIDA | HYDROZOA | CNIDARIA | CNIDARIA | Animalia |
| D7300 | <i>Obelia dichotoma</i> | <i>Obelia</i> | Obeliinae | Obeliinae | CAMPANULARIOIDEA | CAMPANULARIOIDEA | CAMPANULARIOIDEA | CAMPANULARIOIDEA | PROBOSCOIDA | PROBOSCOIDA | LEPTOTHECATAE | LEPTOLIDA | HYDROZOA | CNIDARIA | CNIDARIA | Animalia |
| D7320 | <i>Obelia longissima</i> | <i>Obelia</i> | Obeliinae | Obeliinae | CAMPANULARIOIDEA | CAMPANULARIOIDEA | CAMPANULARIOIDEA | CAMPANULARIOIDEA | PROBOSCOIDA | PROBOSCOIDA | LEPTOTHECATAE | LEPTOLIDA | HYDROZOA | CNIDARIA | CNIDARIA | Animalia |
| D7430 | <i>Rhizocaulus verticillatus</i> | <i>Rhizocaulus</i> | Campanulariinae | Campanulariinae | CAMPANULARIOIDEA | CAMPANULARIOIDEA | CAMPANULARIOIDEA | CAMPANULARIOIDEA | PROBOSCOIDA | PROBOSCOIDA | LEPTOTHECATAE | LEPTOLIDA | HYDROZOA | CNIDARIA | CNIDARIA | Animalia |
| P13750 | <i>Chaetopterus variopedatus</i> | <i>Chaetopterus</i> | Chaetopteridae | Chaetopteridae | CHAETOPTEROIDEA | CHAETOPTEROIDEA | CHAETOPTEROIDEA | CHAETOPTEROIDEA | SPIONIDA | POLYCHAETA | ANNELIDA | ANNELIDA | ANNELIDA | ANNELIDA | Animalia | |
| P270 | <i>Aphrodite aculeata</i> | <i>Aphrodite</i> | Aphroditidae | Aphroditidae | APHRODITOIDEA | APHRODITOIDEA | APHRODITOIDEA | APHRODITOIDEA | PHYLLODOIDA | POLYCHAETA | ANNELIDA | ANNELIDA | ANNELIDA | ANNELIDA | Animalia | |
| P8420 | <i>Perinereis cultrifera</i> | <i>Perinereis</i> | Nereididae | Nereididae | NEREIDOIDEA | NEREIDOIDEA | NEREIDOIDEA | NEREIDOIDEA | PHYLLODOIDA | POLYCHAETA | ANNELIDA | ANNELIDA | ANNELIDA | ANNELIDA | Animalia | |
| Q750 | <i>Pycnogonum littorale</i> | <i>Pycnogonum</i> | Pycnogonidae | Pycnogonidae | PYCNOGONIDA | PYCNOGONIDA | PYCNOGONIDA | PYCNOGONIDA | PYCNOGONIDA | PYCNOGONIDA | CHELICERATA | CHELICERATA | CHELICERATA | CHELICERATA | Animalia | |
| S21440 | <i>Decapoda</i> | <i>Decapoda</i> | DECAPODA | DECAPODA | DECAPODA | DECAPODA | DECAPODA | DECAPODA | DECAPODA | DECAPODA | CRUSTACEA | CRUSTACEA | CRUSTACEA | CRUSTACEA | Animalia | |
| S24650 | <i>Pagurus bernhardus</i> | <i>Pagurus</i> | Paguridae | Paguridae | PAGUROIDEA | PAGUROIDEA | PAGUROIDEA | PAGUROIDEA | ANOMURA | EUCARIDA | EUMALACOSTRACA | CRUSTACEA | CRUSTACEA | CRUSTACEA | Animalia | |
| S24700 | <i>Pagurus prideaux</i> | <i>Pagurus</i> | Paguridae | Paguridae | PAGUROIDEA | PAGUROIDEA | PAGUROIDEA | PAGUROIDEA | ANOMURA | EUCARIDA | EUMALACOSTRACA | CRUSTACEA | CRUSTACEA | CRUSTACEA | Animalia | |
| S24850 | <i>Galathea dispersa</i> | <i>Galathea</i> | Galatheididae | Galatheididae | GALATHEOIDEA | GALATHEOIDEA | GALATHEOIDEA | GALATHEOIDEA | ANOMURA | EUCARIDA | EUMALACOSTRACA | CRUSTACEA | CRUSTACEA | CRUSTACEA | Animalia | |
| S24860 | <i>Galathea intermedia</i> | <i>Galathea</i> | Galatheididae | Galatheididae | GALATHEOIDEA | GALATHEOIDEA | GALATHEOIDEA | GALATHEOIDEA | ANOMURA | EUCARIDA | EUMALACOSTRACA | CRUSTACEA | CRUSTACEA | CRUSTACEA | Animalia | |
| S24900 | <i>Galathea singosa</i> | <i>Galathea</i> | Galatheididae | Galatheididae | GALATHEOIDEA | GALATHEOIDEA | GALATHEOIDEA | GALATHEOIDEA | ANOMURA | EUCARIDA | EUMALACOSTRACA | CRUSTACEA | CRUSTACEA | CRUSTACEA | Animalia | |
| S25020 | <i>Pisidia longicornis</i> | <i>Pisidia</i> | Porcellanidae | Porcellanidae | GALATHEOIDEA | GALATHEOIDEA | GALATHEOIDEA | GALATHEOIDEA | ANOMURA | EUCARIDA | EUMALACOSTRACA | CRUSTACEA | CRUSTACEA | CRUSTACEA | Animalia | |
| S25530 | <i>Maja squinado</i> | <i>Maja</i> | Majidae | Majidae | MAJOIDEA | MAJOIDEA | MAJOIDEA | MAJOIDEA | ANOMURA | EUCARIDA | EUMALACOSTRACA | CRUSTACEA | CRUSTACEA | CRUSTACEA | Animalia | |
| S25660 | <i>Achaeus cranchii</i> | <i>Achaeus</i> | Inachinae | Inachinae | MAJOIDEA | MAJOIDEA | MAJOIDEA | MAJOIDEA | ANOMURA | EUCARIDA | EUMALACOSTRACA | CRUSTACEA | CRUSTACEA | CRUSTACEA | Animalia | |
| S25760 | <i>Inachus dorsettensis</i> | <i>Inachus</i> | Inachinae | Inachinae | MAJOIDEA | MAJOIDEA | MAJOIDEA | MAJOIDEA | ANOMURA | EUCARIDA | EUMALACOSTRACA | CRUSTACEA | CRUSTACEA | CRUSTACEA | Animalia | |
| S25770 | <i>Inachus leptochirus</i> | <i>Inachus</i> | Inachinae | Inachinae | MAJOIDEA | MAJOIDEA | MAJOIDEA | MAJOIDEA | ANOMURA | EUCARIDA | EUMALACOSTRACA | CRUSTACEA | CRUSTACEA | CRUSTACEA | Animalia | |
| S25830 | <i>Macropodia deflexa</i> | <i>Macropodia</i> | Inachinae | Inachinae | MAJOIDEA | MAJOIDEA | MAJOIDEA | MAJOIDEA | ANOMURA | EUCARIDA | EUMALACOSTRACA | CRUSTACEA | CRUSTACEA | CRUSTACEA | Animalia | |
| S25840 | <i>Macropodia linearesi</i> | <i>Macropodia</i> | Inachinae | Inachinae | MAJOIDEA | MAJOIDEA | MAJOIDEA | MAJOIDEA | ANOMURA | EUCARIDA | EUMALACOSTRACA | CRUSTACEA | CRUSTACEA | CRUSTACEA | Animalia | |
| S25850 | <i>Macropodia rostrata</i> | <i>Macropodia</i> | Inachinae | Inachinae | MAJOIDEA | MAJOIDEA | MAJOIDEA | MAJOIDEA | ANOMURA | EUCARIDA | EUMALACOSTRACA | CRUSTACEA | CRUSTACEA | CRUSTACEA | Animalia | |
| S25860 | <i>Macropodia tenuirostris</i> | <i>Macropodia</i> | Inachinae | Inachinae | MAJOIDEA | MAJOIDEA | MAJOIDEA | MAJOIDEA | ANOMURA | EUCARIDA | EUMALACOSTRACA | CRUSTACEA | CRUSTACEA | CRUSTACEA | Animalia | |
| S26200 | <i>Coryistes cassivelaunus</i> | <i>Coryistes</i> | Coryistidae | Coryistidae | CANCROIDEA | CANCROIDEA | CANCROIDEA | CANCROIDEA | ANOMURA | EUCARIDA | EUMALACOSTRACA | CRUSTACEA | CRUSTACEA | CRUSTACEA | Animalia | |
| S26460 | <i>Cancer pagurus</i> | <i>Cancer</i> | Cancridae | Cancridae | CANCROIDEA | CANCROIDEA | CANCROIDEA | CANCROIDEA | ANOMURA | EUCARIDA | EUMALACOSTRACA | CRUSTACEA | CRUSTACEA | CRUSTACEA | Animalia | |
| S26660 | <i>Liocarcinus sp.</i> | <i>Liocarcinus</i> | Polybiinae | Polybiinae | PORTUNOIDEA | PORTUNOIDEA | PORTUNOIDEA | PORTUNOIDEA | ANOMURA | EUCARIDA | EUMALACOSTRACA | CRUSTACEA | CRUSTACEA | CRUSTACEA | Animalia | |
| S26680 | <i>Liocarcinus corrugatus</i> | <i>Liocarcinus</i> | Polybiinae | Polybiinae | PORTUNOIDEA | PORTUNOIDEA | PORTUNOIDEA | PORTUNOIDEA | ANOMURA | EUCARIDA | EUMALACOSTRACA | CRUSTACEA | CRUSTACEA | CRUSTACEA | Animalia | |
| S26690 | <i>Liocarcinus depurator</i> | <i>Liocarcinus</i> | Polybiinae | Polybiinae | PORTUNOIDEA | PORTUNOIDEA | PORTUNOIDEA | PORTUNOIDEA | ANOMURA | EUCARIDA | EUMALACOSTRACA | CRUSTACEA | CRUSTACEA | CRUSTACEA | Animalia | |
| S26700 | <i>Liocarcinus holtsatus</i> | <i>Liocarcinus</i> | Polybiinae | Polybiinae | PORTUNOIDEA | PORTUNOIDEA | PORTUNOIDEA | PORTUNOIDEA | ANOMURA | EUCARIDA | EUMALACOSTRACA | CRUSTACEA | CRUSTACEA | CRUSTACEA | Animalia | |
| S26710 | <i>Liocarcinus marmoreus</i> | <i>Liocarcinus</i> | Polybiinae | Polybiinae | PORTUNOIDEA | PORTUNOIDEA | PORTUNOIDEA | PORTUNOIDEA | ANOMURA | EUCARIDA | EUMALACOSTRACA | CRUSTACEA | CRUSTACEA | CRUSTACEA | Animalia | |
| S26720 | <i>Necora puber</i> | <i>Necora</i> | Polybiinae | Polybiinae | PORTUNOIDEA | PORTUNOIDEA | PORTUNOIDEA | PORTUNOIDEA | ANOMURA | EUCARIDA | EUMALACOSTRACA | CRUSTACEA | CRUSTACEA | CRUSTACEA | Animalia | |
| S26730 | <i>Liocarcinus pusillus</i> | <i>Liocarcinus</i> | Polybiinae | Polybiinae | PORTUNOIDEA | PORTUNOIDEA | PORTUNOIDEA | PORTUNOIDEA | ANOMURA | EUCARIDA | EUMALACOSTRACA | CRUSTACEA | CRUSTACEA | CRUSTACEA | Animalia | |
| S26735 | <i>Liocarcinus vernalis</i> | <i>Liocarcinus</i> | Polybiinae | Polybiinae | PORTUNOIDEA | PORTUNOIDEA | PORTUNOIDEA | PORTUNOIDEA | ANOMURA | EUCARIDA | EUMALACOSTRACA | CRUSTACEA | CRUSTACEA | CRUSTACEA | Animalia | |
| S26840 | <i>Polybius henslowii</i> | <i>Polybius</i> | Polybiinae | Polybiinae | PORTUNOIDEA | PORTUNOIDEA | PORTUNOIDEA | PORTUNOIDEA | ANOMURA | EUCARIDA | EUMALACOSTRACA | CRUSTACEA | CRUSTACEA | CRUSTACEA | Animalia | |
| W10940 | <i>Akera bullata</i> | <i>Akera</i> | Akeridae | Akeridae | APLYSIAE | APLYSIAE | APLYSIAE | APLYSIAE | ANASPIDA | GASTROPODA | MOLLUSCA | MOLLUSCA | MOLLUSCA | MOLLUSCA | Animalia | |
| W17170 | <i>Glycymeris glycymeris</i> | <i>Glycymeris</i> | Glycymeridae | Glycymeridae | LIMOPSACEA | LIMOPSACEA | LIMOPSACEA | LIMOPSACEA | ARCOIDA | PELECYPODA | MOLLUSCA | MOLLUSCA | MOLLUSCA | MOLLUSCA | Animalia | |
| W17250 | <i>Atrina fragilis</i> | <i>Atrina</i> | Pinnidae | Pinnidae | PINNACEA | PINNACEA | PINNACEA | PINNACEA | PTERIOIDA | PELECYPODA | MOLLUSCA | MOLLUSCA | MOLLUSCA | MOLLUSCA | Animalia | |
| W17780 | <i>Pallidulum ligatum</i> | <i>Pallidulum</i> | Pectinidae | Pectinidae | PECTINACEA | PECTINACEA | PECTINACEA | PECTINACEA | OSTREOIDA | PELECYPODA | MOLLUSCA | MOLLUSCA | MOLLUSCA | MOLLUSCA | Animalia | |
| W18050 | <i>Aequipecten opercularis</i> | <i>Aequipecten</i> | Pectinidae | Pectinidae | PECTINACEA | PECTINACEA | PECTINACEA | PECTINACEA | OSTREOIDA | PELECYPODA | MOLLUSCA | MOLLUSCA | MOLLUSCA | MOLLUSCA | Animalia | |
| W18090 | <i>Pecten maximus</i> | <i>Pecten</i> | Pectinidae | Pectinidae | PECTINACEA | PECTINACEA | PECTINACEA | PECTINACEA | OSTREOIDA | PELECYPODA | MOLLUSCA | MOLLUSCA | MOLLUSCA | MOLLUSCA | Animalia | |
| W18150 | <i>Anomia ephippium</i> | <i>Anomia</i> | Anomidae | Anomidae | ANOMIACEA | ANOMIACEA | ANOMIACEA | ANOMIACEA | OSTREOIDA | PELECYPODA | MOLLUSCA | MOLLUSCA | MOLLUSCA | MOLLUSCA | Animalia | |
| W19690 | <i>Acanthocardia echinata</i> | <i>Acanthocardia</i> | Cardidae | Cardidae | CARDIACEA | CARDIACEA | CARDIACEA | CARDIACEA | VENEROIDA | PELECYPODA | MOLLUSCA | MOLLUSCA | MOLLUSCA | MOLLUSCA | Animalia | |
| W23930 | <i>Sepia officinalis</i> | <i>Sepia</i> | Sepiidae | Sepiidae | SEPIOIDEA | SEPIOIDEA | SEPIOIDEA | SEPIOIDEA | SEPIOIDEA | CEPHALOPODA | MOLLUSCA | MOLLUSCA | MOLLUSCA | MOLLUSCA | Animalia | |
| W24190 | <i>Rossia macrosoma</i> | <i>Rossia</i> | Rossiidae | Rossiidae | SEPIOIDEA | SEPIOIDEA | SEPIOIDEA | SEPIOIDEA | SEPIOIDEA | CEPHALOPODA | MOLLUSCA | MOLLUSCA | MOLLUSCA | MOLLUSCA | Animalia | |
| W24290 | <i>Loliginidae</i> | <i>Loliginidae</i> | Loliginidae | Loliginidae | TEUTHOIDEA | TEUTHOIDEA | TEUTHOIDEA | TEUTHOIDEA | TEUTHOIDEA | CEPHALOPODA | MOLLUSCA | MOLLUSCA | MOLLUSCA | MOLLUSCA | Animalia | |
| W24300 | <i>Loligo sp.</i> | <i>Loligo</i> | Loliginidae | Loliginidae | TEUTHOIDEA | TEUTHOIDEA | TEUTHOIDEA | TEUTHOIDEA | TEUTHOIDEA | CEPHALO | | | | | | |

Table C.2. Classification (across fifteen levels and including Taxon ID) of encountered species, part 2; *Echinus sp* to *Zostera marina* etc.

| Taxon ID | species | Genus | Subfamily | Family | Superfamily | Section | Infraorder | Suborder | Order | Subclass | Class | Superclass | SubPhylum | Phylum | Kingdom |
|----------|----------------------------------|-----------------------|-----------------|-----------------|-------------------|-------------------|-------------------|-------------------|-------------------|-----------------|----------------|---------------|---------------|---------------|----------|
| ZB3590 | <i>Echinus sp</i> | <i>Echinus</i> | Echinidae | Echinidae | ECHINOIDA | ECHINOIDA | ECHINOIDA | ECHINOIDA | ECHINOIDA | ECHINOIDEA | ECHINOIDEA | ECHINODERMATA | ECHINODERMATA | ECHINODERMATA | Animalia |
| ZB3600 | <i>Echinus acutus</i> | <i>Echinus</i> | Echinidae | Echinidae | ECHINOIDA | ECHINOIDA | ECHINOIDA | ECHINOIDA | ECHINOIDA | ECHINOIDEA | ECHINOIDEA | ECHINODERMATA | ECHINODERMATA | ECHINODERMATA | Animalia |
| ZB3610 | <i>Echinus elegans</i> | <i>Echinus</i> | Echinidae | Echinidae | ECHINOIDA | ECHINOIDA | ECHINOIDA | ECHINOIDA | ECHINOIDA | ECHINOIDEA | ECHINOIDEA | ECHINODERMATA | ECHINODERMATA | ECHINODERMATA | Animalia |
| ZB3620 | <i>Echinus esculentus</i> | <i>Echinus</i> | Echinidae | Echinidae | ECHINOIDA | ECHINOIDA | ECHINOIDA | ECHINOIDA | ECHINOIDA | ECHINOIDEA | ECHINOIDEA | ECHINODERMATA | ECHINODERMATA | ECHINODERMATA | Animalia |
| ZB4010 | <i>Spatangus purpureus</i> | <i>Spatangus</i> | Spatangidae | Spatangidae | SPATANGOIDA | SPATANGOIDA | SPATANGOIDA | SPATANGOIDA | SPATANGOIDA | SPATANGOIDA | SPATANGOIDA | ECHINODERMATA | ECHINODERMATA | ECHINODERMATA | Animalia |
| ZB410 | <i>Astropecten irregularis</i> | <i>Astropecten</i> | Astropectinidae | Astropectinidae | PAXILLOSIDA | PAXILLOSIDA | PAXILLOSIDA | PAXILLOSIDA | PAXILLOSIDA | ASTEROIDEA | ASTEROIDEA | ECHINODERMATA | ECHINODERMATA | ECHINODERMATA | Animalia |
| ZB4520 | <i>Holothuria forskali</i> | <i>Holothuria</i> | Holothuriidae | Holothuriidae | ASPIDOCHIROTIDA | ASPIDOCHIROTIDA | ASPIDOCHIROTIDA | ASPIDOCHIROTIDA | ASPIDOCHIROTIDA | HOLOTHURIOIDEA | HOLOTHURIOIDEA | ECHINODERMATA | ECHINODERMATA | ECHINODERMATA | Animalia |
| ZB660 | <i>Luidia sp</i> | <i>Luidia</i> | Luidiidae | Luidiidae | PAXILLOSIDA | PAXILLOSIDA | PAXILLOSIDA | PAXILLOSIDA | PAXILLOSIDA | ASTEROIDEA | ASTEROIDEA | ECHINODERMATA | ECHINODERMATA | ECHINODERMATA | Animalia |
| ZB670 | <i>Luidia ciliaris</i> | <i>Luidia</i> | Luidiidae | Luidiidae | PAXILLOSIDA | PAXILLOSIDA | PAXILLOSIDA | PAXILLOSIDA | PAXILLOSIDA | ASTEROIDEA | ASTEROIDEA | ECHINODERMATA | ECHINODERMATA | ECHINODERMATA | Animalia |
| ZB950 | <i>Hippasteria phrygiana</i> | <i>Hippasteria</i> | Goniasteridae | Goniasteridae | VALVATIDA | VALVATIDA | VALVATIDA | VALVATIDA | VALVATIDA | ASTEROIDEA | ASTEROIDEA | ECHINODERMATA | ECHINODERMATA | ECHINODERMATA | Animalia |
| ZD2090 | <i>Botryllus schlosseri</i> | <i>Botryllus</i> | Styelidae | Styelidae | STOLIDOBRANCHIATA | STOLIDOBRANCHIATA | STOLIDOBRANCHIATA | STOLIDOBRANCHIATA | STOLIDOBRANCHIATA | PLEUROGONA | ASCIDIACEA | ASCIDIACEA | TUNICATA | TUNICATA | Animalia |
| ZD340 | <i>Polycrinum aurantium</i> | <i>Polycrinum</i> | Polycrinidae | Polycrinidae | APLOUSOBRANCHIATA | APLOUSOBRANCHIATA | APLOUSOBRANCHIATA | APLOUSOBRANCHIATA | APLOUSOBRANCHIATA | ENTEROGONA | ASCIDIACEA | ASCIDIACEA | TUNICATA | TUNICATA | Animalia |
| ZF1350 | <i>Raja brachyura</i> | <i>Raja</i> | Rajidae | Rajidae | RAJIFORMES | RAJIFORMES | RAJIFORMES | RAJIFORMES | RAJIFORMES | ELASMOBRANCHII | CHONDRICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZF1360 | <i>Raja clavata</i> | <i>Raja</i> | Rajidae | Rajidae | RAJIFORMES | RAJIFORMES | RAJIFORMES | RAJIFORMES | RAJIFORMES | ELASMOBRANCHII | CHONDRICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZF1410 | <i>Raja microcellata</i> | <i>Raja</i> | Rajidae | Rajidae | RAJIFORMES | RAJIFORMES | RAJIFORMES | RAJIFORMES | RAJIFORMES | ELASMOBRANCHII | CHONDRICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZF1420 | <i>Raja montagui</i> | <i>Raja</i> | Rajidae | Rajidae | RAJIFORMES | RAJIFORMES | RAJIFORMES | RAJIFORMES | RAJIFORMES | ELASMOBRANCHII | CHONDRICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZF1430 | <i>Raja naevus</i> | <i>Raja</i> | Rajidae | Rajidae | RAJIFORMES | RAJIFORMES | RAJIFORMES | RAJIFORMES | RAJIFORMES | ELASMOBRANCHII | CHONDRICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZF1460 | <i>Raja radiata</i> | <i>Raja</i> | Rajidae | Rajidae | RAJIFORMES | RAJIFORMES | RAJIFORMES | RAJIFORMES | RAJIFORMES | ELASMOBRANCHII | CHONDRICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZF1470 | <i>Raja undulata</i> | <i>Raja</i> | Rajidae | Rajidae | RAJIFORMES | RAJIFORMES | RAJIFORMES | RAJIFORMES | RAJIFORMES | ELASMOBRANCHII | CHONDRICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZF400 | <i>Scyliorhinus canicula</i> | <i>Scyliorhinus</i> | Scyliorhinidae | Scyliorhinidae | CARCHARHINIFORMES | CARCHARHINIFORMES | CARCHARHINIFORMES | CARCHARHINIFORMES | CARCHARHINIFORMES | ELASMOBRANCHII | CHONDRICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZF410 | <i>Scyliorhinus stellaris</i> | <i>Scyliorhinus</i> | Scyliorhinidae | Scyliorhinidae | CARCHARHINIFORMES | CARCHARHINIFORMES | CARCHARHINIFORMES | CARCHARHINIFORMES | CARCHARHINIFORMES | ELASMOBRANCHII | CHONDRICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZF550 | <i>Mustelus mustelus</i> | <i>Mustelus</i> | Triakidae | Triakidae | CARCHARHINIFORMES | CARCHARHINIFORMES | CARCHARHINIFORMES | CARCHARHINIFORMES | CARCHARHINIFORMES | ELASMOBRANCHII | CHONDRICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZF560 | <i>Mustelus astenias</i> | <i>Mustelus</i> | Triakidae | Triakidae | CARCHARHINIFORMES | CARCHARHINIFORMES | CARCHARHINIFORMES | CARCHARHINIFORMES | CARCHARHINIFORMES | ELASMOBRANCHII | CHONDRICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG1090 | <i>Alepocephalus bairdi</i> | <i>Alepocephalus</i> | Alepocephalidae | Alepocephalidae | SALMONIFORMES | SALMONIFORMES | SALMONIFORMES | SALMONIFORMES | SALMONIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG1350 | <i>Lophius budegassa</i> | <i>Lophius</i> | Lophiidae | Lophiidae | LOPHIIFORMES | LOPHIIFORMES | LOPHIIFORMES | LOPHIIFORMES | LOPHIIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG1360 | <i>Lophius piscatorius</i> | <i>Lophius</i> | Lophiidae | Lophiidae | LOPHIIFORMES | LOPHIIFORMES | LOPHIIFORMES | LOPHIIFORMES | LOPHIIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG1730 | <i>Gadus morhua</i> | <i>Gadus</i> | Gadidae | Gadidae | GADIFORMES | GADIFORMES | GADIFORMES | GADIFORMES | GADIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG1820 | <i>Melanogrammus aeglefinus</i> | <i>Melanogrammus</i> | Gadidae | Gadidae | GADIFORMES | GADIFORMES | GADIFORMES | GADIFORMES | GADIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG1860 | <i>Merlangius merlangus</i> | <i>Merlangius</i> | Gadidae | Gadidae | GADIFORMES | GADIFORMES | GADIFORMES | GADIFORMES | GADIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG1900 | <i>Micromesistius pouassou</i> | <i>Micromesistius</i> | Gadidae | Gadidae | GADIFORMES | GADIFORMES | GADIFORMES | GADIFORMES | GADIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG1960 | <i>Molva molva</i> | <i>Molva</i> | Gadidae | Gadidae | GADIFORMES | GADIFORMES | GADIFORMES | GADIFORMES | GADIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG2080 | <i>Pollachius pollachius</i> | <i>Pollachius</i> | Gadidae | Gadidae | GADIFORMES | GADIFORMES | GADIFORMES | GADIFORMES | GADIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG2090 | <i>Pollachius virens</i> | <i>Pollachius</i> | Gadidae | Gadidae | GADIFORMES | GADIFORMES | GADIFORMES | GADIFORMES | GADIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG2180 | <i>Trisopterus luscus</i> | <i>Trisopterus</i> | Gadidae | Gadidae | GADIFORMES | GADIFORMES | GADIFORMES | GADIFORMES | GADIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG2190 | <i>Trisopterus minutus</i> | <i>Trisopterus</i> | Gadidae | Gadidae | GADIFORMES | GADIFORMES | GADIFORMES | GADIFORMES | GADIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG220 | <i>Conger conger</i> | <i>Conger</i> | Congridae | Congridae | ANGUILLIFORMES | ANGUILLIFORMES | ANGUILLIFORMES | ANGUILLIFORMES | ANGUILLIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG2240 | <i>Merluccius merluccius</i> | <i>Merluccius</i> | Merlucciidae | Merlucciidae | GADIFORMES | GADIFORMES | GADIFORMES | GADIFORMES | GADIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG3160 | <i>Zeus faber</i> | <i>Zeus</i> | Zeidae | Zeidae | ZEIFORMES | ZEIFORMES | ZEIFORMES | ZEIFORMES | ZEIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG3210 | <i>Capros aper</i> | <i>Capros</i> | Caproidae | Caproidae | ZEIFORMES | ZEIFORMES | ZEIFORMES | ZEIFORMES | ZEIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG4030 | <i>Aspitrigla cuculus</i> | <i>Aspitrigla</i> | Trigidae | Trigidae | SCORPAENIFORMES | SCORPAENIFORMES | SCORPAENIFORMES | SCORPAENIFORMES | SCORPAENIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG4040 | <i>Aspitrigla obscura</i> | <i>Aspitrigla</i> | Trigidae | Trigidae | SCORPAENIFORMES | SCORPAENIFORMES | SCORPAENIFORMES | SCORPAENIFORMES | SCORPAENIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG4080 | <i>Eutrigla gurnardus</i> | <i>Eutrigla</i> | Trigidae | Trigidae | SCORPAENIFORMES | SCORPAENIFORMES | SCORPAENIFORMES | SCORPAENIFORMES | SCORPAENIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG4160 | <i>Trigla lucerna</i> | <i>Trigla</i> | Trigidae | Trigidae | SCORPAENIFORMES | SCORPAENIFORMES | SCORPAENIFORMES | SCORPAENIFORMES | SCORPAENIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG4210 | <i>Trigloporus lastoviza</i> | <i>Trigloporus</i> | Trigidae | Trigidae | SCORPAENIFORMES | SCORPAENIFORMES | SCORPAENIFORMES | SCORPAENIFORMES | SCORPAENIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG430 | <i>Alosa sp</i> | <i>Alosa</i> | Clupeidae | Clupeidae | CLUPEIFORMES | CLUPEIFORMES | CLUPEIFORMES | CLUPEIFORMES | CLUPEIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG4480 | <i>Agonus cataphractus</i> | <i>Agonus</i> | Agonidae | Agonidae | SCORPAENIFORMES | SCORPAENIFORMES | SCORPAENIFORMES | SCORPAENIFORMES | SCORPAENIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG4730 | <i>Dicentrarchus labrax</i> | <i>Dicentrarchus</i> | Percichthyidae | Percichthyidae | PERCIFORMES | PERCIFORMES | PERCIFORMES | PERCIFORMES | PERCIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG490 | <i>Clupea harengus</i> | <i>Clupea</i> | Clupeidae | Clupeidae | CLUPEIFORMES | CLUPEIFORMES | CLUPEIFORMES | CLUPEIFORMES | CLUPEIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG5080 | <i>Trachurus trachurus</i> | <i>Trachurus</i> | Carangidae | Carangidae | PERCIFORMES | PERCIFORMES | PERCIFORMES | PERCIFORMES | PERCIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG530 | <i>Sardina pilchardus</i> | <i>Sardina</i> | Clupeidae | Clupeidae | CLUPEIFORMES | CLUPEIFORMES | CLUPEIFORMES | CLUPEIFORMES | CLUPEIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG5680 | <i>Mullus surmuletus</i> | <i>Mullus</i> | Mullidae | Mullidae | PERCIFORMES | PERCIFORMES | PERCIFORMES | PERCIFORMES | PERCIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG570 | <i>Sprattus sprattus</i> | <i>Sprattus</i> | Clupeidae | Clupeidae | CLUPEIFORMES | CLUPEIFORMES | CLUPEIFORMES | CLUPEIFORMES | CLUPEIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG5840 | <i>Mugil sp</i> | <i>Mugil</i> | Mugilidae | Mugilidae | PERCIFORMES | PERCIFORMES | PERCIFORMES | PERCIFORMES | PERCIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG5860 | <i>Labridae</i> | <i>Labridae</i> | Labridae | Labridae | PERCIFORMES | PERCIFORMES | PERCIFORMES | PERCIFORMES | PERCIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG620 | <i>Engraulis encrasicolus</i> | <i>Engraulis</i> | Engraulidae | Engraulidae | CLUPEIFORMES | CLUPEIFORMES | CLUPEIFORMES | CLUPEIFORMES | CLUPEIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG6860 | <i>Ammodytes tobianus</i> | <i>Ammodytes</i> | Ammodytidae | Ammodytidae | PERCIFORMES | PERCIFORMES | PERCIFORMES | PERCIFORMES | PERCIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG6990 | <i>Callionymus sp</i> | <i>Callionymus</i> | Callionymidae | Callionymidae | PERCIFORMES | PERCIFORMES | PERCIFORMES | PERCIFORMES | PERCIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG8000 | <i>Scomber scombrus</i> | <i>Scomber</i> | Scombridae | Scombridae | PERCIFORMES | PERCIFORMES | PERCIFORMES | PERCIFORMES | PERCIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG830 | <i>Osmerus eperlanus</i> | <i>Osmerus</i> | Osmeridae | Osmeridae | SALMONIFORMES | SALMONIFORMES | SALMONIFORMES | SALMONIFORMES | SALMONIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG8500 | <i>Lepidionomus whiffiagonis</i> | <i>Lepidionomus</i> | Scophthalmidae | Scophthalmidae | PLEURONECTIFORMES | PLEURONECTIFORMES | PLEURONECTIFORMES | PLEURONECTIFORMES | PLEURONECTIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG8630 | <i>Scophthalmus rhombus</i> | <i>Scophthalmus</i> | Scophthalmidae | Scophthalmidae | PLEURONECTIFORMES | PLEURONECTIFORMES | PLEURONECTIFORMES | PLEURONECTIFORMES | PLEURONECTIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG8720 | <i>Arnoglossus impenalis</i> | <i>Arnoglossus</i> | Bothidae | Bothidae | PLEURONECTIFORMES | PLEURONECTIFORMES | PLEURONECTIFORMES | PLEURONECTIFORMES | PLEURONECTIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG8730 | <i>Arnoglossus laterna</i> | <i>Arnoglossus</i> | Bothidae | Bothidae | PLEURONECTIFORMES | PLEURONECTIFORMES | PLEURONECTIFORMES | PLEURONECTIFORMES | PLEURONECTIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG8910 | <i>Limanda limanda</i> | <i>Limanda</i> | Pleuronectidae | Pleuronectidae | PLEURONECTIFORMES | PLEURONECTIFORMES | PLEURONECTIFORMES | PLEURONECTIFORMES | PLEURONECTIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG8950 | <i>Microstomus kitt</i> | <i>Microstomus</i> | Pleuronectidae | Pleuronectidae | PLEURONECTIFORMES | PLEURONECTIFORMES | PLEURONECTIFORMES | PLEURONECTIFORMES | PLEURONECTIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG8990 | <i>Platichthys flesus</i> | <i>Platichthys</i> | Pleuronectidae | Pleuronectidae | PLEURONECTIFORMES | PLEURONECTIFORMES | PLEURONECTIFORMES | PLEURONECTIFORMES | PLEURONECTIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG9030 | <i>Pleuronectes platessa</i> | <i>Pleuronectes</i> | Pleuronectidae | Pleuronectidae | PLEURONECTIFORMES | PLEURONECTIFORMES | PLEURONECTIFORMES | PLEURONECTIFORMES | PLEURONECTIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZG9290 | <i>Solea solea</i> | <i>Solea</i> | Soleidae | Soleidae | PLEURONECTIFORMES | PLEURONECTIFORMES | PLEURONECTIFORMES | PLEURONECTIFORMES | PLEURONECTIFORMES | TELEOSTEI | OSTEICHTHYES | GNATHOSTOMATA | PISCES | PISCES | Animalia |
| ZM10390 | <i>Heterosiphonia plumosa</i> | <i>Heterosiphonia</i> | Dasyaceae | Dasyaceae | CERAMIALES | CERAMIALES | CERAMIALES | CERAMIALES | CERAMIALES | FLORIDOPHYCIDAE | RHODOPHYCEAE | RHODOPHYCOTA | RHODOPHYCOTA | RHODOPHYCOTA | Plantae |
| ZM11050 | <i>Polysiphonia elongata</i> | <i>Polysiphonia</i> | Rhodomelaceae | Rhodomelaceae | CERAMIALES | CERAMIALES | CERAMIALES | CERAMIALES | CERAMIALES | FLORIDOPHYCIDAE | RHODOPHYCEAE | RHODOPHYCOTA | RHODOPHYCOTA | RHODOPHYCOTA | Plantae |
| ZM11160 | <i>Polysiphonia nigra</i> | <i>Polysiphonia</i> | Rhodomelaceae | Rhodomelaceae | CERAMIALES | CERAMIALES | CERAMIALES | CERAMIALES | CERAMIALES | FLORIDOPHYCIDAE | RHODOPHYCEAE | RHODOPHYCOTA | RHODOPHYCOTA | RHODOPHYCOTA | Plantae |
| ZM1255 | <i>Geldidium crinale</i> | <i>Geldidium</i> | Gelidiaceae | Gelidiaceae | GELIDIALES | GELIDIALES | GELIDIALES | GELIDIALES | GELIDIALES | FLORIDOPHYCIDAE | RHODOPHYCEAE | RHODOPHYCOTA | RHODOPHYCOTA | RHODOPHYCOTA | Plantae |
| ZM2230 | <i>Pterocladia capillacea</i> | <i>Pterocladia</i> | Gelidiaceae | Gelidiaceae | GELIDIALES | GELIDIALES | GELIDIALES | GELIDIALES | GELIDIALES | FLORIDOPHYCIDAE | RHODOPHYCEAE | RHODOPHYCOTA | RHODOPHYCOTA | RHODOPHYCOTA | Plantae |
| ZM2420 | <i>Palmaria palmata</i> | <i>Palmaria</i> | Palmariales | Palmariales | PALMARIALES | PALMARIALES | PALMARIALES | PALMARIALES | PALMARIALES | FLORIDOPHYCIDAE | RHODOPHYCEAE | RHODOPHYCOTA | RHODOPHYCOTA | RHODOPHYCOTA | Plantae |
| ZM3230 | <i>Callophyllis laciniosa</i> | <i>Callophyllis</i> | Kallymeniaceae | Kallymeniaceae | GIGARTINALES | GIGARTINALES | GIGARTINALES | GIGARTINALES | GIGARTINALES | FLORIDOPHYCIDAE | RHODOPHYCEAE | RHODOPHYCOTA | RHODOPHYCOTA | RHODOPHYCOTA | Plantae |
| ZM5050 | <i>Mastocarpus stellatus</i> | <i>Mastocarpus</i> | Phylloporaceae | Phylloporaceae | GIGARTINALES | GIGARTINALES | GIGARTINALES | GIGARTINALES | GIGARTINALES | FLORIDOPHYCIDAE | RHODOPHYCEAE | RHODOPHYCOTA | RHODOPHYCOTA | RHODOPHYCOTA | Plantae |
| ZM6110 | <i>Chondrus crispus</i> | <i>Chondrus</i> | Gigartinales | Gigartinales | GIGARTINALES | GIGARTINALES | GIGARTINALES | GIGARTINALES | GIGARTINALES | FLORIDOPHYCIDAE | | | | | |

Appendix D

D Total sample weight and its variation

D.1 Introduction

There were several reasons why the total sample weight (shown in Figure 3.3, page 61, above) might have varied. Clearly, the simplest explanation relates to the basket not being full; potentially the case since the majority of basket weights ($n = 68$) or 77 % were < 38 kg. Only 23 % of the samples ($n = 20$) were > 38 kg. Although plausible this was highly unlikely since the aim of the study was to analyse a full fish basket. Alternatively, the packing of the basket may have been important. Relatively soft and small items, such as squid would be expected to pack better than large or hard objects, such as large cod, or urchins. The hypothesis was that there should be no significant difference between total sample weight, although the distribution shown in Figure 3.3 suggests that there was indeed a marked degree of variability in this measure.

D.2 Methods

In order to explore the variability in the total sample weight in greater detail, a General Linear Model (GLM) of total sample weight was constructed for a range of meta-data factors and variables, which may be responsible for the variation. Significant interactions

were then further examined.

D.3 Results

The results of the GLM are presented in Table D.1.

Table D.1. Full factor GLM testing total sample weight (g) to the factors of: wind = wind speed (knots), dur = duration of tow, (mins), dep = depth of haul, (m), speed = speed of tow (ms^{-1}), vol-bas = haul size as number of baskets of fish, trip # = sequential trip aboard that particular boat, sample # = sequential sample number (1 to 88), port & type = port of operation and type of trawling (pair or single boat), d/n/t = time of haul (day/night/twilight), q = quarter of the year, and interactions. Note that covariances are not dealt with as interactions, and that the interaction of port & type * d/n/t * q returned zero d.f. Significant interactions are highlighted.

| source | d.f. | F value | P value |
|-------------------------|------|---------|---------|
| corrected model | 37 | 3.190 | < 0.001 |
| intercept | 1 | 11.583 | 0.006 |
| wind | 1 | 0.291 | 0.592 |
| dur | 1 | 4.841 | 0.032 |
| dep | 1 | < 0.001 | 0.997 |
| speed | 1 | 0.111 | 0.741 |
| vol-bas | 1 | 1.303 | 0.259 |
| trip # | 1 | 4.380 | 0.041 |
| sample # | 1 | 4.514 | 0.039 |
| port & type | 5 | 3.199 | 0.014 |
| d/n/t | 2 | 0.194 | 0.825 |
| q | 3 | 4.071 | 0.012 |
| port & type * d/n/t | 3 | 1.138 | 0.343 |
| port & type * q | 12 | 1.638 | 0.111 |
| d/n/t * q | 4 | 1.181 | 0.330 |
| port & type * d/n/t * q | 0 | | |
| error | 50 | | |
| total | 88 | | |
| corrected total | 87 | | |

In the GLM port of sailing and type of trawling were not kept separate (as two factors) but were treated as a single one (containing six categories) as it was not possible to nest these since pair trawling was not sampled from Newlyn and Salcombe. Table 9.2 (page 279, above) describes the results of a GLM where port of sailing and type of trawling had to be treated separately and interactions of type of trawling generated zero d.f.).

The model as depicted by Table D.1 is on the borderline of being valid since the Levene's test for equality of error variance returned $P = 0.049$, thus the output of the GLM should be treated with caution. Nevertheless it appears that duration of tow, the trip number (number of times onboard each boat), the sequential haul number, the port and type of trawling and the quarter of the year produced a significant interaction with the total sample weight, if the GLM described by Table D.1 is considered valid. These significant interactions are presented in order of their relevance.

D.3.1 Variation in total sample weight with port and type of trawling

According to port and type of trawling total sample size data did not universally approximate normal distributions according to the A-D test; (N S, $A^2 = 0.791$, $n = 42$, $P = 0.037$; and P P, $A^2 = 0.708$, $n = 8$, $P = 0.039$). The degree to which the averages of total sample weight according to port and type of trawling required further analysis with the Kruskal-Wallis (K-W) test. Table D.2 shows the results of the medians of total sample weight according to port and type of trawling.

Table D.2. Kruskal-Wallis test of median of total sample weight (g) according to port and type of trawling, N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling. $H = 28.03$, d.f. = 5, $P < 0.001$ (adjusted for ties).

| port and type of trawling | <i>n</i> | median | average rank | Z |
|---------------------------|----------|--------|--------------|--------|
| N S | 42 | 29,963 | 31.1 | - 4.69 |
| L S | 11 | 35,289 | 44.5 | 0.01 |
| L P | 9 | 34,060 | 58.2 | 1.70 |
| P S | 8 | 34,978 | 58.3 | 1.60 |
| P P | 8 | 39,931 | 73.4 | 3.35 |
| S S | 10 | 33,200 | 54.1 | 1.26 |
| overall | 88 | | 44.5 | |

Table D.2 shows that sample medians from Newlyn were smaller and those from pair trawled Plymouth samples larger, compared to the rest. The significance of this was

confirmed by the *post hoc* Dunn's Test for Multiple Comparisons (see Table D.3).

Table D.3. Results of Kruskal-Wallis *post hoc* Dunn's Test for Multiple Comparisons (Q) of median total sample weight (g) according to port and type of trawling, N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling according to 2 d.p. $K = 2.94$ and significantly different pairs are highlighted.

| | | | | | |
|-----|------|------|------|------|------|
| N S | 1.55 | 2.89 | 2.76 | 4.29 | 2.56 |
| L S | | 1.19 | 1.16 | 2.43 | 0.86 |
| L P | | | 0.01 | 1.22 | 0.35 |
| P S | | | | 1.18 | 0.35 |
| P P | | | | | 1.59 |
| | L S | L P | P S | P P | S S |

Table D.3 shows that only the median total sample sizes from Newlyn and Plymouth pair trawled samples were significantly different (despite $P = 0.014$ for this interaction from the GLM in Table D.1, above) though the values for Newlyn were consistently (though not significantly) different to the others. This is perhaps the most important interaction from the GLM described in Table D.1 (above) and described in more detail (on page 357) below.

Duration of tow was a covariable in the GLM (in Table D.1, above) therefore its relationship with total sample weight can be further explored by regression analysis. Figure D.1 shows a plot of total sample weight against duration of tow.

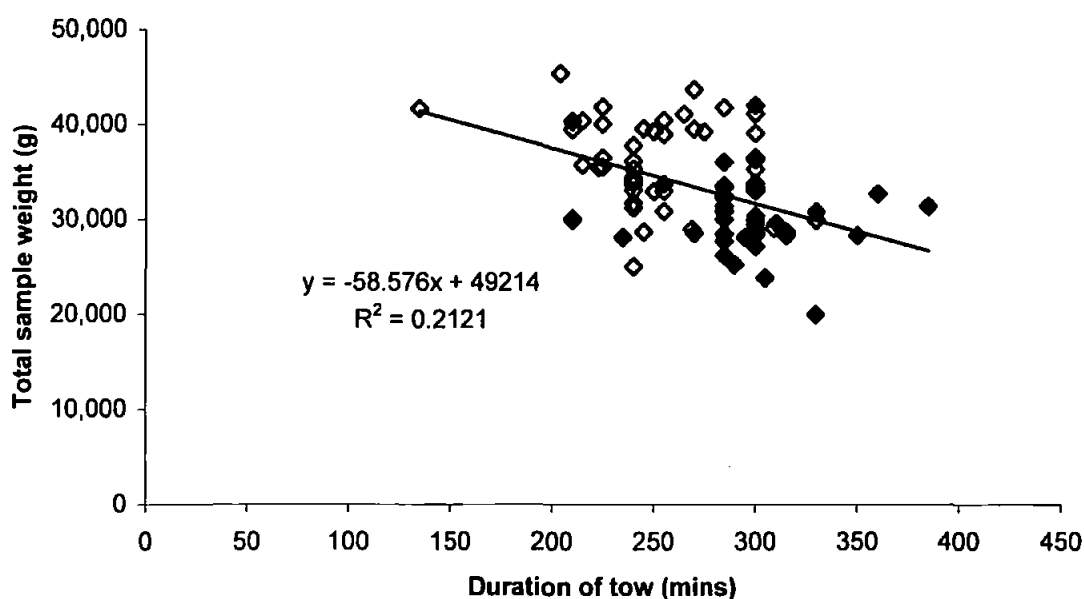


Figure D.1. The relationship between total sample weight (g) and duration of tow (minutes), $n = 88$. Filled points represent Newlyn samples, open represent all others. The trend line is fitted through all data.

Figure D.1 shows that there was a negative relationship of total sample weight against duration of tow. Also, while this fit was low as shown by the R^2 value on Figure D.1 the regression was nevertheless very highly statistically significant, $P < 0.001$ and valid with the residuals of the regression approximating a normal distribution according to the A-D test; ($A^2 = 0.494$, $n = 88$, $P = 0.210$). The interactive relationship between relatively long tow duration and relatively small total sample weights for the samples collected from Newlyn is also apparent from Figure D.1.

D.3.2 Variation in total sample weight with duration of tow

Like total sample weight tow duration according to port and type of trawling does not universally approximate normal distributions according to the A-D test; (N S, $A^2 = 0.2459$, $n = 42$, $P < 0.005$; P S, $A^2 = 1.080$, $n = 8$, $P < 0.005$) therefore this single factor also required analysis with the K-W test. Table D.4 showed the results of the medians of

tow duration according to port and type of trawling.

Table D.4. Kruskal-Wallis test of tow duration (min) according to port and type of trawling, N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling. $H = 31.98$, d.f. = 5, $P < 0.001$ (adjusted for ties).

| port and type of trawling | <i>n</i> | median | average rank | Z |
|---------------------------|----------|--------|--------------|--------|
| N S | 42 | 300.0 | 58.2 | 4.80 |
| L S | 11 | 300.0 | 51.0 | 0.90 |
| L P | 9 | 240.0 | 24.6 | - 2.47 |
| P S | 8 | 240.0 | 21.8 | - 2.64 |
| P P | 8 | 247.5 | 27.7 | - 1.95 |
| S S | 10 | 247.5 | 29.5 | - 1.97 |
| overall | 88 | | 44.5 | |

Table D.4 reinforces the pattern observed in Figure D.1. Table D.5 shows the permutation results of the *post hoc* Dunn's Test for Multiple Comparisons.

Table D.5. Results of Kruskal-Wallis *post hoc* Dunn's Test for Multiple Comparisons (*Q*) of median total sample size according to port and type of trawling, N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling according to 2 d.p. $K = 2.94$ and significantly different pairs are highlighted.

| | | | | | |
|-----|------|------|------|------|------|
| N S | 0.83 | 3.58 | 3.69 | 3.09 | 3.19 |
| L S | | 2.30 | 2.46 | 1.96 | 1.93 |
| L P | | | 0.23 | 0.25 | 0.42 |
| P S | | | | 0.46 | 0.64 |
| P P | | | | | 0.15 |
| | L S | L P | P S | P P | S S |

Table D.5 shows that tow duration for the Newlyn hauls were significantly different (longer) to all the others (except the Looe single boat hauls). This explains interrelationship between tow duration, total sample weight and port and type of trawling with port and type of trawling being the link between the others and with the significance as shown in Table D.1, above due to the Newlyn hauls being longer in duration but resulting in smaller total sample weights. Table D.1, above did not examine the interrelationship between these values, as tow duration was a covariate (not a factor) in the GLM.

D.3.3 Variation in total sample weight with quarter of the year

Table D.1, above showed a significant association between total sample weight and quarter of the year. This suggests a degree of seasonality in the total sample weight measurements. Table D.6 shows the results of a K-W test on total sample weight and quarter of the year as the factor.

Table D.6. Kruskal-Wallis test of quarter of the year according to port and type of trawling, N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling. $H = 20.85$, d.f. = 3, $P < 0.001$.

| quarter of the year | <i>n</i> | median | average rank | Z |
|---------------------|----------|--------|--------------|-------|
| 1 | 11 | 39,483 | 62.7 | 2.53 |
| 2 | 28 | 32,967 | 46.1 | 0.40 |
| 3 | 38 | 30,045 | 32.3 | -3.89 |
| 4 | 11 | 35,536 | 64.2 | 2.73 |
| overall | 88 | | 44.5 | |

Table D.6 appears to show that the samples taken during the middle two quarters of the year were much smaller. Table D.7 shows the permutation results of the *post hoc* Dunn's Test for Multiple Comparisons.

Table D.7. Results of Kruskal-Wallis *post hoc* Dunn's Test for Multiple Comparisons (Q) of median total sample weight (g) according to quarter of the year in which the sample was taken. Data are shown to 2 d.p. $K = 2.94$ and significantly different pairs are highlighted.

| | | | |
|---|------|------|------|
| 1 | 1.83 | 3.48 | 0.14 |
| 2 | | 2.17 | 1.99 |
| 3 | | | 3.65 |
| | 2 | 3 | 4 |

Table D.7 shows as expected significant differences between total sample weight between quarters 1 and 3, and 3 and 4, (though not between quarters 1 and 2, and 2 and 4 as might have been expected). Nevertheless it appears that it was the influence of the generally smaller sample weights taken onboard boats operating from Newlyn, which were only

sampled during quarters 2 and 3 (see Table 3.2, page 49, above).

It seems likely that the generally smaller sample weights taken onboard boats operating from Newlyn was also responsible for the significant association between total sample weight and sequential sample number in the GLM described in Table D.1 above.

D.3.4 Variation in total sample weight with trip number and sequential haul number

Whilst Table D.1, above showed significant interactions between both total sample weight with trip number (number of times onboard a boat) sequential haul numbers these interaction are spurious. Total sample weight according to trip number all approximate normal distributions according to the A-D test therefore the variation in total sample weight according to trip number was examined by one-way ANOVA. $F = 2.02$, d.f. = 3, $P = 0.117$ therefore this interaction was not significant. Similarly whilst Table D.1, above showed a significant interaction between the total sample weight and sequential haul number this was due to the distribution of the generally smaller total sample weights from Newlyn being taken relatively early on through the whole sampling period (see Table 3.2, page 49, above). The next section examines the Newlyn samples in more detail.

D.3.5 Explanation for difference in total sample weight between Newlyn and the other ports

Table D.2 (page 352, above) shows that the hauls taken from Newlyn were amongst those with the smallest total sample weight, and that those samples from the other four ports group more closely. To emphasize this, the mean weights from the four ports were: Newlyn = 30,643g, $n = 42$; Looe = 34,643g, $n = 20$; Plymouth = 37,352g, $n = 16$;

Salcombe = 35,363g, $n = 10$. The reason for the average sample weight from Newlyn being smaller than from other ports could be explained by two reasons. Firstly, the generally more rough conditions experienced further offshore might mean that it was more difficult to fill, and keep full, the fish basket. Also that it might be harder to move the weight about on deck, however this was unlikely and supported by the lack of significant interaction between total sample weight and wind speed as described by the GLM in Table D.1, above. The alternative idea is based around the hypothesis that the further offshore fishes were larger; as suggested by Cushing, (1975) but based on much earlier ideas (Heincke, 1913) and thus the fish did not pack so well into the fish basket. This analysis was based on the 26 species, which were present in samples from all of the four ports. Table D.8 shows the average length and weight of those species that are arranged alphabetically by species code.

Table D.8. Average length "l" (cm) and weight "w" (g) of twenty-six species (present in samples from all ports) according to port. The data are shown to 0 d.p. See Table 3.3, page 51, above for an explanation of the species codes.

| species | Newlyn | | Looe | | Plymouth | | Salcombe | |
|---------|--------|-------|------|-------|----------|-------|----------|-------|
| | l | w | l | w | l | w | l | w |
| BIB | 24 | 243 | 27 | 302 | 26 | 282 | 26 | 275 |
| BLR | 42 | 1,384 | 42 | 1,469 | 41 | 1,611 | 41 | 1,521 |
| CRE | 18 | 804 | 20 | 1,105 | 25 | 1,957 | 24 | 1,814 |
| CTL | 8 | 162 | 9 | 227 | 17 | 1,273 | 12 | 582 |
| CUR | 47 | 882 | 46 | 708 | 39 | 435 | 31 | 187 |
| DAB | 21 | 91 | 25 | 182 | 24 | 159 | 19 | 73 |
| DET | 23 | 92 | 22 | 73 | 22 | 78 | 24 | 125 |
| GUG | 26 | 168 | 24 | 122 | 23 | 122 | 26 | 206 |
| GUX | 25 | 159 | 23 | 126 | 23 | 125 | 24 | 144 |
| HKE | 31 | 208 | 33 | 254 | 35 | 310 | 36 | 313 |
| HOM | 25 | 160 | 23 | 112 | 24 | 130 | 22 | 92 |
| JOD | 30 | 708 | 27 | 569 | 27 | 504 | 37 | 1,050 |
| LEM | 26 | 218 | 29 | 351 | 27 | 266 | 29 | 359 |
| LIN | 43 | 426 | 31 | 165 | 36 | 244 | 37 | 276 |
| LSD | 56 | 760 | 46 | 392 | 49 | 487 | 52 | 573 |
| MEG | 35 | 383 | 30 | 275 | 37 | 404 | 32 | 301 |
| MON | 44 | 1,518 | 44 | 1,293 | 56 | 2,950 | 39 | 901 |
| PCO | 14 | 31 | 15 | 37 | 17 | 54 | 15 | 36 |
| PLE | 37 | 608 | 34 | 445 | 30 | 320 | 30 | 337 |
| POG | 14 | 19 | 15 | 23 | 13 | 15 | 11 | 10 |
| SOL | 34 | 381 | 27 | 229 | 22 | 131 | 18 | 99 |
| SQC | 15 | 191 | 16 | 321 | 17 | 211 | 21 | 460 |
| SQC(F) | 18 | 262 | 19 | 325 | 19 | 310 | 20 | 367 |
| SQC(V) | 18 | 335 | 19 | 315 | 21 | 440 | 22 | 530 |
| THR | 38 | 1,625 | 43 | 1,867 | 44 | 1,821 | 32 | 893 |
| WHG | 31 | 271 | 31 | 269 | 30 | 231 | 33 | 323 |

The data in Table D.8 were averages of the measurement according to each haul. These were then averaged by each haul from each port. Table D.9 shows which of these measures (by port) do or do not approximate a normal distribution according to the A-D test.

Table D.9. Results of Anderson-Darling test of normality on the length and weight measurements for all species present in Table D.8 according to port, ($n = 26$ in all cases).

| | Newlyn | | Looe | | Plymouth | | Salcombe | |
|-------|--------|---------|-------|---------|----------|---------|----------|---------|
| | l | w | l | w | l | w | l | w |
| A^2 | 0.246 | 1.911 | 0.432 | 2.635 | 0.691 | 3.420 | 0.190 | 1.746 |
| P | 0.733 | < 0.001 | 0.282 | < 0.001 | 0.063 | < 0.001 | 0.890 | < 0.001 |

Table D.9 shows that the weight data do not approximate a normal distribution according to port. Transforming these data did not improve the fit. Table D.9 also shows that the

length data did approximate a normal distribution. Also the variances are not significantly different for the length measurements according to Bartlett's test ($B_c = 1.032$, d.f. = 3, $P = 0.794$) therefore length can be analysed by ANOVA while weight required the K-W test, however, neither the average length nor median of weight for one port were significantly different to the others; $F = 0.08$, d.f. = 3, $P = 0.973$ for length and $H = 0.09$, d.f. = 3, $P = 0.994$ for weight, though the mean average length values by port and species were greatest for Newlyn at 28.57 cm. The other values were Looe, 27.66; Plymouth, 28.51 and Salcombe, 27.47 cm.

Table D.10 shows the tally of rank-order of average length and weight of all species described in Table D.8 according to port. These were generated by ranking the average length and weight by each species across the four ports.

Table D.10. Tally of rank-order of length and weight of each species across the four ports, N = Newlyn, L = Looe, P = Plymouth and S = Salcombe. The most common rank-orders are highlighted.

| rank size | | Newlyn | | Looe | | Plymouth | | Salcombe | |
|-----------|---|--------|---|------|---|----------|----|----------|---|
| | | l | w | l | w | l | w | l | w |
| largest | 1 | 9 | 9 | 4 | 6 | 6 | 4 | 7 | 7 |
| ↓ | 2 | 3 | 3 | 11 | 9 | 7 | 10 | 5 | 4 |
| ↓ | 3 | 7 | 7 | 7 | 7 | 7 | 6 | 5 | 6 |
| smallest | 4 | 7 | 7 | 4 | 4 | 6 | 6 | 9 | 9 |

Table D.10 shows that for the both the length and weight measurements Newlyn had the greatest number of the largest specimens according to species. The most common size ranking for Looe was size 2 according to both length and weight. The situation for Plymouth is similar for weight but two sizes (rank 2 and 3) both shared the mode. These species were most commonly the smallest in rank from the Salcombe samples, thus while it is not possible to statistically show why the Newlyn samples were smaller in total weight they did most commonly contain the largest individuals on a species by species basis.

Appendix E

E Test of the validity of tidal information

E.1 Methods

In order to validate the VICTOR tidal model the magnitude of the tidal strengths at thirty-three tidal diamonds from Charts 1148 ($n = 14$), (Anon, 1999); Chart 1267 ($n = 10$), (Anon, 1984); and Chart 1613 ($n = 9$) (Anon, 1992) were compared to their nearest available position given by the VICTOR model. Where the position of an Admiralty tidal diamond was equidistant between two positions on the VICTOR grid the southerly or westerly position on the VICTOR grid was chosen. In order to account for potential differences in the model due to the quarter diurnal the distance from the Admiralty tidal diamond position to the nearest point of land was additionally recorded. The nearest point of land was taken as the nearest surveyed continuous coastline as described in section IC of Anon, (1991). Thus drying heights or outcrops of rock, (such as The Manacles, Eddystone Rocks, (Figure 3.1, page 47, above), or the Great Mewstone off Plymouth) do not count for this purpose. The magnitude given for the Admiralty tidal diamond was in knots, which were converted to ms^{-1} . Table E.1 shows these data.

Table E.1. Comparative positions and velocity magnitudes of thirty-three Admiralty tidal diamonds (see text for details of the charts) and comparative positions on the VICTOR grid.

| position # | chart # | ◇ | Admiralty tidal diamond | | | | | VICTOR position | | | | |
|------------|---------|---|-------------------------|----------------------|------------------------|----------|---------------------|---------------------|----------------------|------------------------------|--|--|
| | | | lat degree & minute | long degree & minute | distance to land (n m) | velocity | | lat degree & minute | long degree & minute | velocity (ms ⁻¹) | | |
| | | | | | | (kt) | (ms ⁻¹) | | | | | |
| 11 | 1148 | L | 49 55.8 | -6 13.3 | 1.2 | 2.9 | 1.49 | 49 56.0 | -6 13.2 | 0.82 | | |
| 8 | 1148 | H | 49 59.3 | -6 12.2 | 2.6 | 2.3 | 1.18 | 49 59.2 | -6 12.0 | 0.58 | | |
| 14 | 1148 | P | 49 46.3 | -6 19.5 | 7.0 | 1.9 | 0.98 | 49 46.4 | -6 19.2 | 0.51 | | |
| 7 | 1148 | G | 50 00.2 | -5 46.6 | 4.2 | 2.5 | 1.29 | 50 00.0 | -5 46.8 | 0.83 | | |
| 9 | 1148 | J | 49 58.5 | -5 48.5 | 1.2 | 2.2 | 1.13 | 49 58.4 | -5 48.0 | 0.68 | | |
| 10 | 1148 | K | 49 57.0 | -6 05.8 | 5.7 | 2.0 | 1.03 | 49 56.8 | -6 06.0 | 0.59 | | |
| 5 | 1148 | E | 50 07.2 | -5 49.5 | 4.5 | 2.5 | 1.29 | 50 07.2 | -5 49.2 | 0.93 | | |
| 18 | 1267 | D | 50 08.5 | -5 01.5 | 0.3 | 0.8 | 0.41 | 50 08.8 | -5 01.2 | 0.07 | | |
| 15 | 1267 | A | 50 02.4 | -5 02.3 | 1.0 | 1.7 | 0.88 | 50 02.4 | -5 02.4 | 0.55 | | |
| 12 | 1148 | M | 49 54.1 | -6 19.0 | 6.2 | 1.7 | 0.88 | 49 54.4 | -6 19.2 | 0.60 | | |
| 2 | 1148 | B | 50 15.1 | -6 09.9 | 19.2 | 1.7 | 0.88 | 50 15.2 | -6 09.6 | 0.62 | | |
| 22 | 1267 | H | 50 18.3 | -4 10.8 | 0.7 | 1.0 | 0.52 | 50 18.4 | -4 10.8 | 0.31 | | |
| 25 | 1613 | A | 50 18.3 | -4 10.8 | 0.7 | 1.0 | 0.52 | 50 18.4 | -4 10.8 | 0.31 | | |
| 23 | 1267 | J | 50 18.3 | -4 07.7 | 0.9 | 0.9 | 0.46 | 50 18.4 | -4 07.2 | 0.26 | | |
| 26 | 1613 | B | 50 18.3 | -4 07.7 | 0.9 | 0.9 | 0.46 | 50 18.4 | -4 07.2 | 0.26 | | |
| 6 | 1148 | F | 50 03.5 | -6 04.5 | 9.0 | 1.5 | 0.77 | 50 03.2 | -6 04.8 | 0.58 | | |
| 21 | 1267 | G | 50 17.0 | -4 26.6 | 3.2 | 0.9 | 0.46 | 50 16.8 | -4 26.4 | 0.28 | | |
| 16 | 1267 | B | 50 02.5 | -4 58.7 | 3.1 | 1.3 | 0.67 | 50 02.4 | -4 58.8 | 0.49 | | |
| 32 | 1613 | H | 50 28.5 | -3 22.5 | 4.1 | 1.1 | 0.57 | 50 28.8 | -3 22.8 | 0.40 | | |
| 13 | 1148 | N | 49 53.0 | -5 54.9 | 12.9 | 1.2 | 0.62 | 49 52.8 | -5 55.2 | 0.47 | | |
| 30 | 1613 | F | 50 13.0 | -3 37.0 | 0.9 | 2.5 | 1.29 | 50 12.8 | -3 37.2 | 1.14 | | |
| 3 | 1148 | C | 50 09.4 | -5 58.8 | 10.6 | 1.7 | 0.88 | 50 09.6 | -5 58.8 | 0.73 | | |
| 4 | 1148 | D | 50 08.0 | -6 15.0 | 9.2 | 1.3 | 0.67 | 50 08.0 | -6 15.6 | 0.54 | | |
| 17 | 1267 | C | 50 02.7 | -4 54.8 | 5.5 | 1.1 | 0.57 | 50 02.4 | -4 55.2 | 0.46 | | |
| 33 | 1613 | J | 50 18.0 | -3 20.0 | 7.5 | 1.5 | 0.77 | 50 17.6 | -3 20.4 | 0.71 | | |
| 24 | 1267 | K | 50 12.5 | -4 05.2 | 5.4 | 1.0 | 0.52 | 50 12.8 | -4 04.8 | 0.47 | | |
| 31 | 1613 | G | 50 17.0 | -3 35.0 | 2.1 | 1.2 | 0.62 | 50 16.8 | -3 34.8 | 0.59 | | |
| 19 | 1267 | E | 50 08.0 | -4 52.3 | 4.1 | 0.7 | 0.36 | 50 08.0 | -4 52.8 | 0.34 | | |
| 28 | 1613 | D | 50 07.8 | -3 55.2 | 6.4 | 1.4 | 0.72 | 50 08.0 | -3 55.2 | 0.76 | | |
| 29 | 1613 | E | 50 10.0 | -3 38.8 | 3.1 | 2.1 | 1.08 | 50 10.4 | -3 38.4 | 1.13 | | |
| 20 | 1267 | F | 50 12.1 | -4 30.0 | 7.3 | 0.5 | 0.26 | 50 12.0 | -4 30.0 | 0.32 | | |
| 1 | 1148 | A | 50 19.0 | -5 52.0 | 12.8 | 1.4 | 0.72 | 50 19.2 | -5 51.6 | 0.82 | | |
| 27 | 1613 | C | 50 12.5 | -4 05.2 | 5.2 | 1.0 | 0.52 | 50 12.0 | -6 04.8 | 0.64 | | |

These tidal magnitudes were compared using the paired *t*-test (Dytham, 1999, p73), though prior to this the data were tested for approximation to a normal distribution using the Anderson-Darling (A-D test), (Dytham, 1999, p72) and the variances of the two data sets were compared using the *F*-test (Fowler & Cohen, 1996).

E.2 Results

Both the Admiralty tidal diamond data and the data generated by the VICTOR model approximated normal distribution according to the A-D test; ($A^2 = 0.629$, $n = 33$, $P = 0.093$ for the Admiralty data, and $A^2 = 0.310$, $n = 33$, $P = 0.538$ for the VICTOR model). Also the variances of the two data sets were not significantly different ($F = 1.636$, d.f. = 1, $P = 0.169$). According to the paired t -test the pairs of magnitudes at each location were significantly different, ($t = 5.96$, $n = 33$, $P < 0.001$). Figure E.1 shows a frequency histogram of the two data sets.

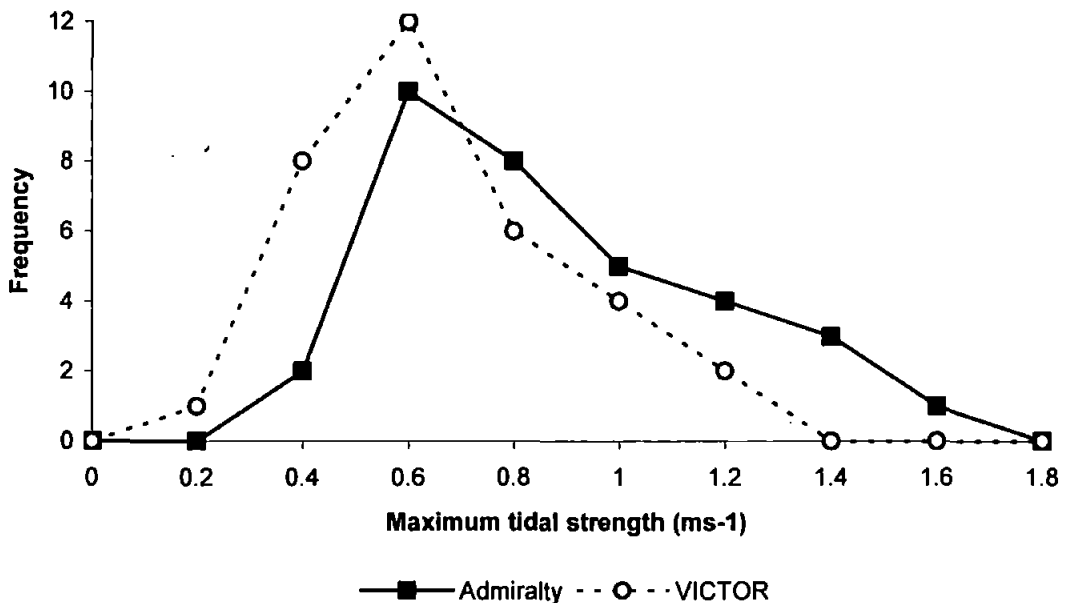


Figure E.1. Frequency histogram of the tidal strengths from the Admiralty tidal diamonds and the VICTOR model, ($n = 33$).

Figure E.1 shows that there was some similarity between the distributions though they were offset. Given that the data were not meant not to be significantly different, an explanation was needed. Table E.2 shows the key differences between the two data sets.

Table E.2. Average, minimum and maximum values of maximum tidal strengths (ms^{-1}) of the thirty-three tidal diamond locations and their nearest position according to the VICTOR model.

| measure | Admiralty | VICTOR | difference |
|---------|-----------|--------|------------|
| average | 0.77 | 0.57 | -0.20 |
| minimum | 0.26 | 0.07 | -0.67 |
| maximum | 1.49 | 1.14 | 0.13 |

It can be seen from Table E.2 and Figure E.1 that on average the VICTOR model produced values consistently lower than the on the Admiralty chart. Several explanations were put forward. The Hydrographic Office (Webb *pers com*) suggested that the tidal strengths generated by them may have some degree of overestimation, thus it would not be expected that there could be tidal values larger than displayed on the chart, thus they should be towards the upper extreme of possible Spring Tides. George (*pers com*) suggested that the comparison was made complicated due to the quarter diurnal tides which have a greater significance of effect when comparisons are made between points which are close to salient points on the land. The suggesting put forward by (Webb *pers com*) was difficult to test though Figure E.2 graphically shows the test of suggestion put forward to George (*pers com*).

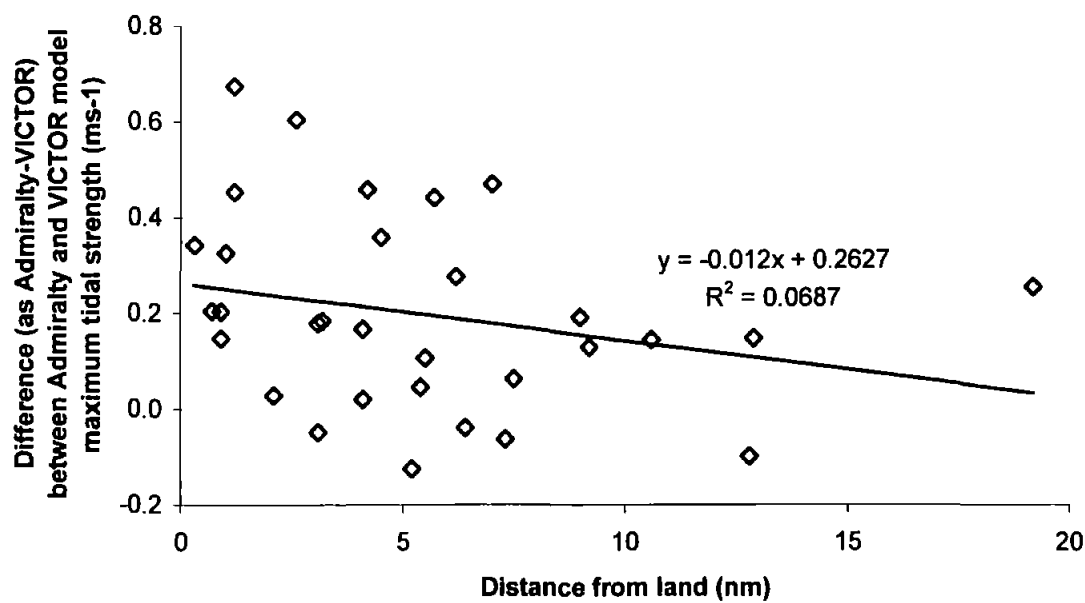


Figure E.2. The difference between the Admiralty tidal diamond and data generated from the VICTOR model as a function of distance from the land (in nautical miles), $n = 33$.

Figure E.2 shows that there was a degree of association as proposed by George (*pers com.*) between the difference between the Admiralty tidal strengths and the tidal strengths generated by the VICTOR model with distance from shore with the difference diminishing with distance from the land although the regression as described on Figure E.2 was not significant, $P = 0.141$, though valid as the residuals of the regression approximated a normal distribution according to the A-D test, ($A^2 = 0.440$, $n = 33$, $P = 0.247$).

The greatest differences between the two data sets occurred for diamonds L, H, P, G, J, K, and E on Chart 1148. These points are all around The Isles of Scilly. The points which differ the next most greatly are D then A on Chart 1267. These locations refer to near The Manacles and the entrance to Falmouth. In contrast those locations which differ the least from the Admiralty tidal diamonds to the data generated by the VICTOR model include Diamond D on chart 1613, in the area of West Rutts, (5.2 nm offshore), diamond A on Chart 1148 (12 nm NW of Cape Cornwall and diamond F on Chart 1267 (south of Middle rocks and 7.3 nm south of Downend point).

Dividing the thirty three points into those that differ the most ($n = 16$) and those that differs least, ($n = 17$) reinforces the picture as described in Figure E.2 as those that differ the most have an average distance from land of 4.1 nm, while those that differ the least have an average distance from land of 6.1 nm, so there does at least seem to be some relationship between the difference between the two data sets and the influence of the quarter diurnal.

Appendix F

F Comparison of trawl length by ArcMap and according to speed, distance and time calculations

The creation of the ArcMap trawl track layer enabled the comparison of the trawl track length by GIS and according to speed, (v), distance (d) and time (t) to be made (where $d = v.t$). The trawl track lengths determined by calculated difference and by GIS were compared by a non-parametric paired Wilcoxon signed ranks test, (Dytham, 1999, p75).

Figure F.1 shows a frequency histogram of trawl track length according to the data generated by the GIS (ESRI, 1999) and according to calculated distance.

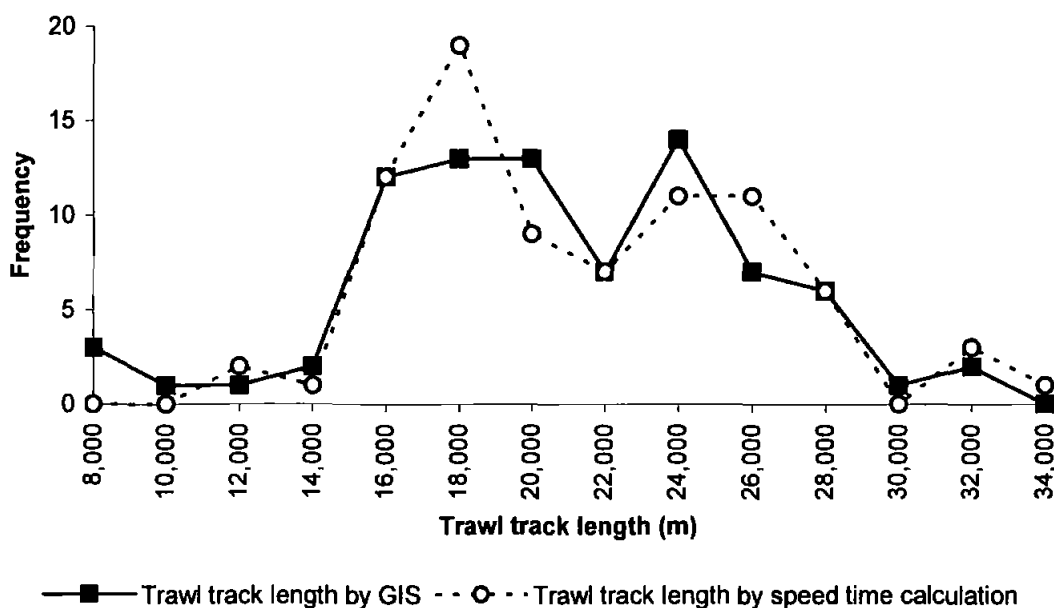


Figure F.1. Frequency histogram of trawl track length according to the GIS layer and by estimation by speed distance calculation, ($n = 78$).

Figure F.1 shows general agreement in trawl track length between the two methods in calculation though note that only 78 of the hauls had could be assessed in this way. The trawl track length data by GIS approximated a normal distribution according to the A-D test, ($A^2 = 0.509$, $n = 78$, $P = 0.193$), though the trawl track length according to calculated distance did not ($A^2 = 1.222$, $n = 78$, $P = 0.003$). According to the Wilcoxon's signed ranks test $Z = -1.462$ (2 tailed), $n = 78$, $P = 0.144$), and therefore the two methods for generating the trawl track lengths has not produced values that overall are significantly different.

The greatest difference between the trawl track length according to the GIS and the speed distance calculation were the two circular hauls off Salcombe; haul 77 (Salcombe, 29 October 1999 number 1) 6,406 m according to the GIS and 17,594 m according to the speed, time calculation, and haul 84 (Salcombe, 20 January 2000, number 1), 6,087 according to the GIS, and 16,371 m according to the speed, time calculation. The reason for this was because the trawl length consisted of many circles (as shown on Figure 2.4, page 28 above) while the GIS plot only has sufficient points to cross the large range in maximum tidal strength, see Figure F.2.

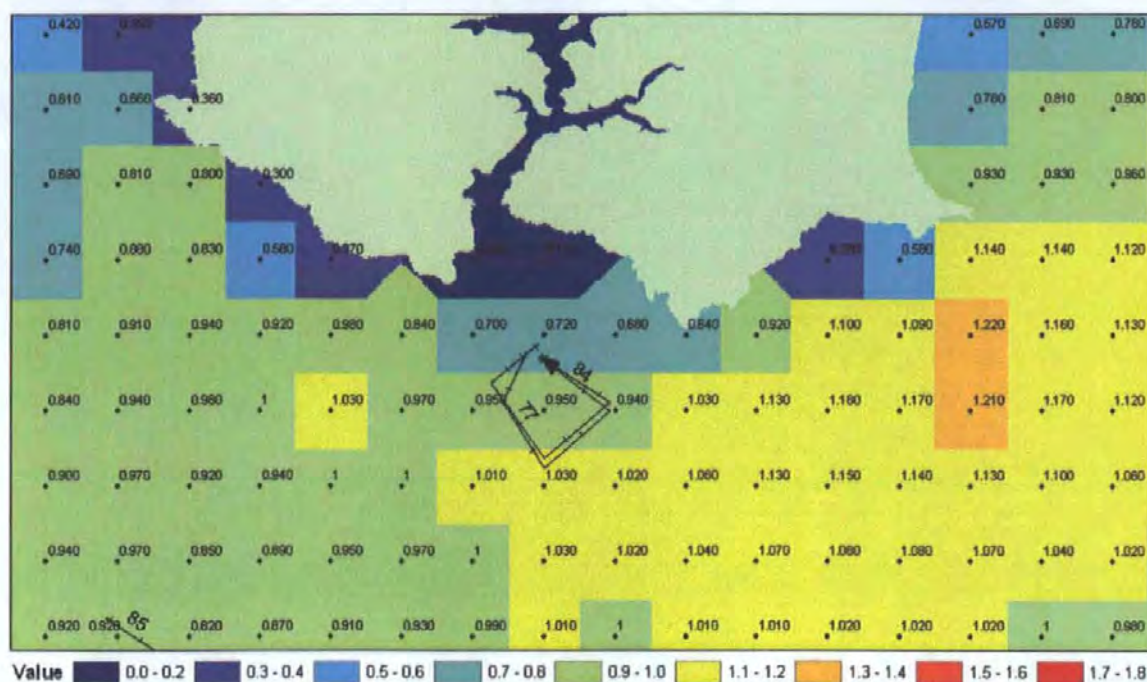


Figure F.2. Trawl tracks for hauls 77 and 84 just south of Salcombe.

It was perhaps surprising that the plotted and calculated trawl track lengths did not generate significantly different values since the speed of vessel used to calculate the distance was infrequently recorded (though additional observations were taken to determine whether there had been much change in speed. Often the boat speed was recorded off the boat's GPS, thus recording speed over the ground. The usual practice of trawling with the prevailing tide means that a generally consistent speed of towing was observed.

Appendix G

G Transformations appropriate for the PRIMER analysis

G.1 Introduction

Chapter 5 and Chapter 6 examine patterns between and within the sample; Chapter 7 and Chapter 8 explored the relationship between the biotic and abiotic data; and Chapter 9 focused on comparing the sample data with the hauls data. In these analyses (and others using the PRIMER-E (Clarke & Warwick, 2001a) suite of routines) it was necessary to apply transformations to the data. PRIMER-E offers a variety of transformations and these were explored and rigorously evaluated. The $\log_{10}(x+1)$ (hereafter called the log in the text but more correctly $\log_{10}(x+1)$ in figure legends) was shown to be the best at preserving the underlying pattern in the data while reducing heteroclasticity. The employment of data transformation in this instance was for the purpose of validating the statistical assumptions for parametric techniques. Analysing the biomass data for patterns in fish and benthos between port, type (and other factors) and combining this with the influence of the environmental data requires that transformations again are examined. PRIMER-E offers a range of power transformations and Clarke & Warwick, (2001a p9-1) offers advice on transformation. In avoiding “data snooping” they warn against using a different transformation for different sub-groups of data, (such as different

transformations for data collected from different sites) and that the requirements of a transformation are to remove “gross departures of parametric assumptions” rather than “precisely stabilising variance” or totally removing non-normality, (Clarke & Warwick, 2001a, p9-1). However, the purpose of transformation in multivariate analysis (on rank-order data) “is the separate, (but equally important) role in...defining the balance between contributions from common and rarer species in the measure of similarity of two samples.” Clarke & Warwick, (2001a, p9-2).

G.2 Finding the appropriate transformation – the full sample

Clarke & Warwick, (2001a) suggest a method to determine an appropriate transformation regardless of whether the data is to be examined by univariate (parametric or non-parametric tests) or multivariate (non-parametric rank-order analysis). They advocate examining the resultant slope (β) of the plot between log standard deviation against log mean of the raw data. They show that, approximately, if the power transformation function is set roughly equal to $1 - \beta$, the transformation data will have a constant variance. That is a slope of zero implies no transformation (only the commoner species contribute to the similarity in rank-order analysis); 0.5 implies the square root, (allows the intermediate abundance species to play a part in rank-order analysis); 0.75 the fourth root ($\sqrt[4]{x}$); and, 1 the \log_{10} (or more correctly $\log_{10}(x+1)$) transformation (which takes some account of the rarer species in rank-order analysis). These latter two transformations are considered together for rank-order analysis because there is no practical difference in cluster and ordination results between these two, though the double square root should be preferred over the log transformation when the Bray-Curtis measure is employed, (Clarke

& Warwick, 2001a, p9-3). Table G.1 shows the categories and break points between the various slope (β) values.

Table G.1. Values and the ranges of slopes and equivalent transformations.

| slope (β) values | | | preferred transformation |
|--------------------------|-----------|-------------|---------------------------------|
| lower value | mid-point | upper value | |
| 0 | * | < 0.250 | None |
| 0.250 | 0.500 | < 0.625 | $\sqrt{}$ |
| 0.625 | 0.750 | < 0.875 | $\sqrt{\sqrt{}}$ |
| 0.875 | * | 1.000 | \log_{10} or $\log_{10}(x+1)$ |

The values in Table G.1 are derived so that the categories are equally spaced around the advocated mid-points. Figure G.1 shows the log standard deviation against log mean for the landed component of the haul and raised landed part of the sample.

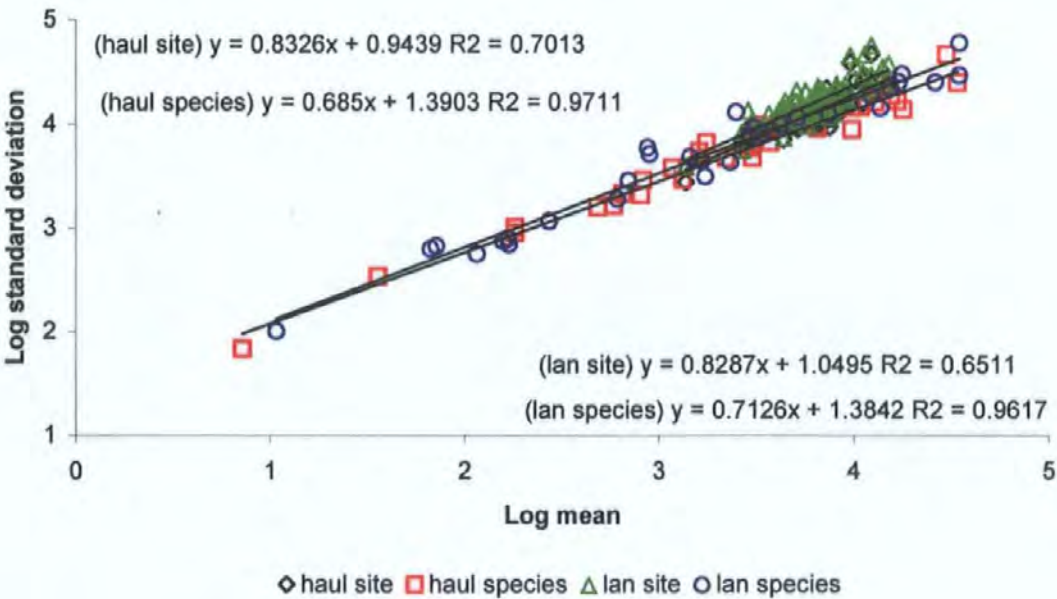


Figure G.1. $\log_{10}(x+1)$ standard deviation against $\log_{10}(x+1)$ mean for the haul composition (haul) and raised landed part of the sample (lan), by site (haul) and variable (species) including trend lines.

This analysis of the data by site (haul number) suggests that the choice of log transformation is well made, although this was chosen by other means. Analysis of the data by variables (species) suggests that the more appropriate transformation would be through the square root.

Most of the analysis of the ranked data is on the sample rather than the total haul data. There are very many more species encountered in the sample (which includes the invertebrate benthos in addition to the fish (also, some of which were grouped for analysis), see the species accumulation curves, Figure 3.2 (page 59, above) and associated text. The same process as described above and shown in graphically Figure G.1 was undertaken for the sample data to choose an appropriate transformation for the up- or down-weighting of rare species. Figure G.2 shows the log standard deviation against log mean for the sample data according to site.

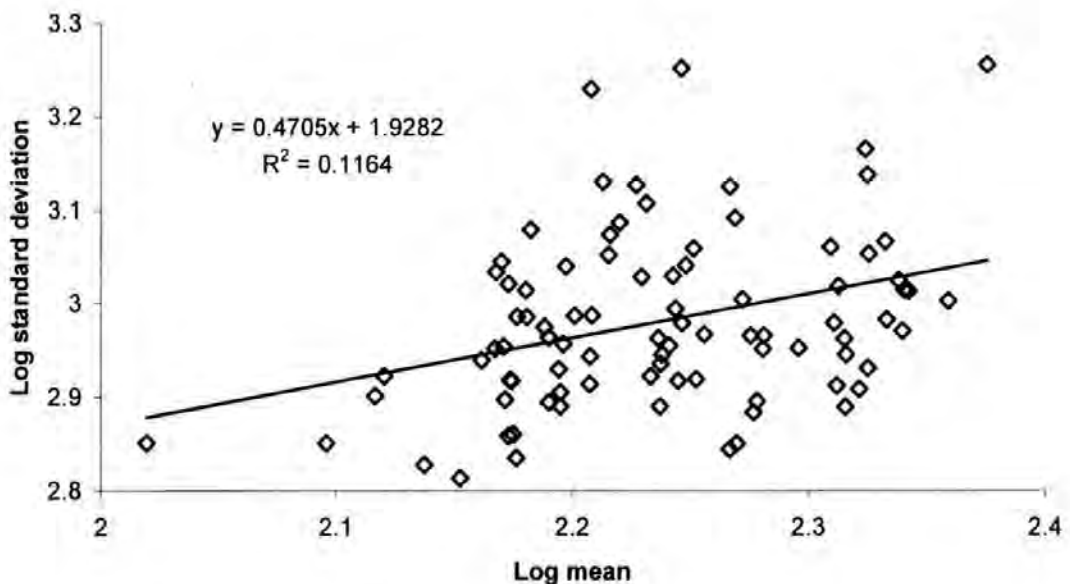


Figure G.2. $\text{Log}_{10}(x+1)$ standard deviation against $\text{log}_{10}(x+1)$ mean for sample data according to site, $n = 88$.

The fit for the data in Figure G.2 is low although the regression is statistically significant ($P = 0.001$), though not strictly valid as the residuals do not approximate a normal distribution according to the A-D test, ($A^2 = 1.071$, $n = 88$, $P = 0.008$). The reason for this is because the sample size was a fixed volume, with the aim that its weight should be fairly constant. Figure 3.3 (on page 61, above) shows a frequency histogram of the sample weight, for comparison. Nevertheless, the slope of the line in Figure G.2 is 0.471 suggesting that (according to Table G.1) a square root transformation is the most

appropriate for examining the sample data, according to sites, further. The log mean against log standard deviation data according to species is shown in Figure G.3. Unlike Figure G.1, above, which shows both set of data these are split as separate graphs because of the very different scale of the data according to species.

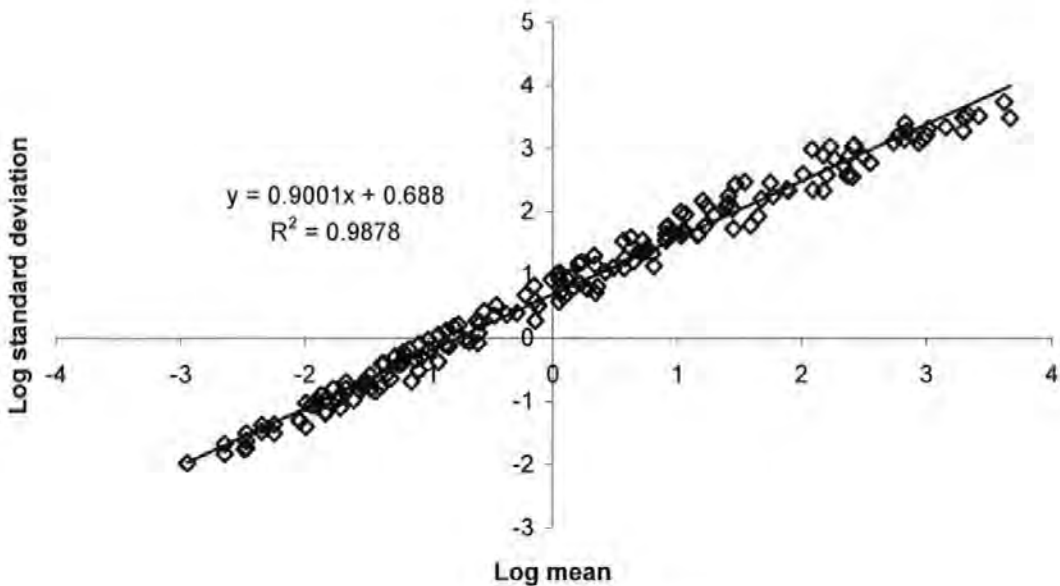


Figure G.3. $\log_{10}(x+1)$ standard deviation against $\log_{10}(x+1)$ mean for sample data according to species, $n = 191$.

The slope of the trend line on Figure G.3 is close to one, therefore when comparing the sample data by species, (rather than sites) the log, or $\log_{10}(x+1)$ transformation should be used.

G.3 Finding the appropriate transformation – sub-sets of the data

Further dividing the sample data in the PRIMER-E analysis is primarily carried out into the fish and non-fish material. Employing this division is useful to see which category is

more responsible for producing the pattern between the various factors of the haul and their locations. The fish material is irrespective of whether the fish were to be landed or discarded and the non-fish material is the benthic invertebrates and other material. Again the data are examined to decide whether, and if so which, transformation is appropriate. Figure G.4 shows the fish only data by sample and Figure G.5 shows the fish only data by species. Again these plots are shown separately due to the different scales of the data.

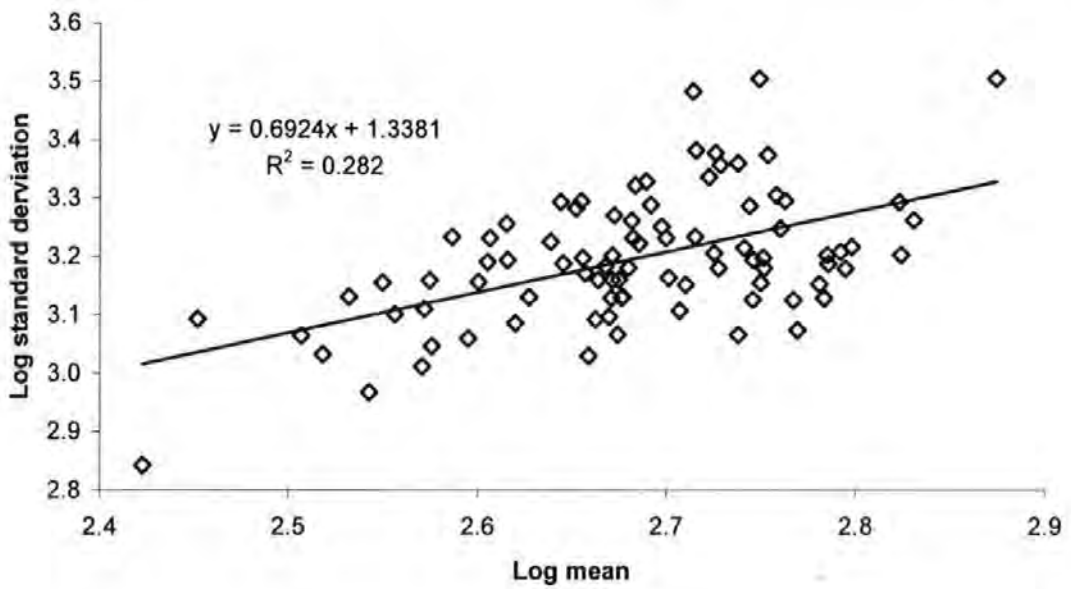


Figure G.4. $\log_{10}(x+1)$ standard deviation against $\log_{10}(x+1)$ mean for the fish only part of the sample data according to site, $n = 88$.

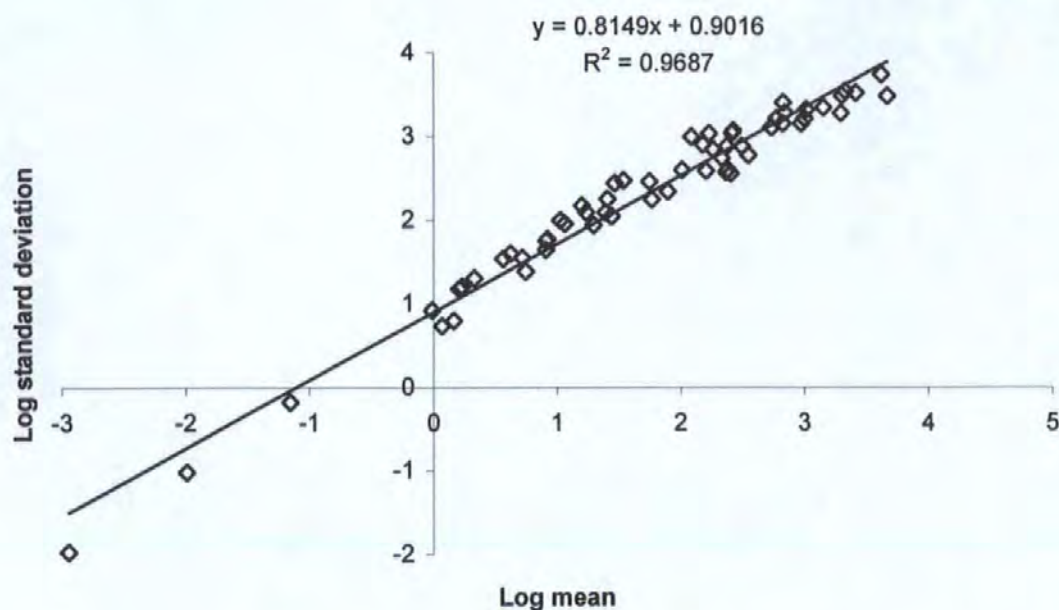


Figure G.5. $\text{Log}_{10}(x+1)$ standard deviation against $\text{log}_{10}(x+1)$ mean for the fish only part of the sample according to species, $n = 59$.

Figure G.4 and Figure G.5 show that for the fish only part of the sample it is appropriate to use the double square root transformation for examining the data by site and also by species. Figure G.6 shows the non-fish part of the sample by site and species.

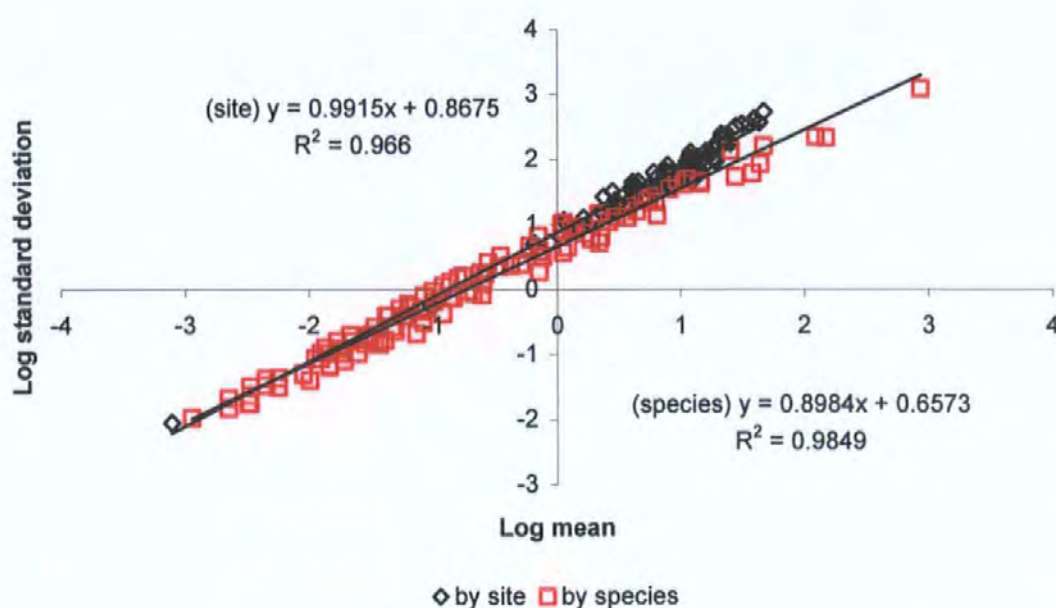


Figure G.6. $\text{Log}_{10}(x+1)$ standard deviation against $\text{log}_{10}(x+1)$ mean for the non-fish only part of the sample according to site, $n = 59$, and species, $n = 128$.

For the non-fish part of the sample Figure G.6 suggests that the best transformation for the non-fish part of the sample is the log.

G.4 Summary of transformations

Table G.2 summarises all the data groups and transformations discussed above.

Table G.2. Type of data, (as whether by site or by species) showing the value for slope and resultant transformation of the data according to Clarke & Warwick, (2001a).

| type | measure | haul | (raised landed part of the sample) | sample | | |
|--------------------|-------------------------|-----------------------|--|---------------------------|--------------|---------------------------|
| | | (haul composition) | | full sample | fish only | non-fish only |
| data by site | slope transformation | 0.833 √√ | 0.828 √√ | 0.471 √ | 0.692 √√ | 0.992 $\log_{10}(x+1)$ |
| data by species | slope transformation | 0.685 √√ | 0.713 √√ | 0.900 $\log_{10}(x+1)$ | 0.815 √√ | 0.898 $\log_{10}(x+1)$ |

Table G.2 shows that there are a variety of transformations which are most appropriate to different aspects of the data. Importantly it shows that in dividing the full sample into the fish only and the non-fish components there are different factors which are influential. Firstly considering the data by site the fish-only part of the full sample is more influential than the non-fish part of the sample. It is likely that this is due to the relative proportions according to the weight, (see Figure 3.4, on page 63, above). Secondly the reverse is true for the data by species; the most appropriate transformation is the same for the full sample and the non-part of the sample, and a different transformation (the double square root) is most appropriate for the fish only.

G.5 Choosing the most suitable transformations

There are two contradictory factors at work in relation to these transformations. Firstly, the most appropriate transformation yields the best up- or down-weighting of the data; however, as stated it is not ideal to choose different transformations for different sub-sets of the data, and this is the greater driving factor. These incongruous factors need to be resolved. As described above there are good statistical reasons for choosing the double square root over the log transformation in multivariate analyses and for this type of analysis no great difference in the output from cluster or ordination methods. The logical step is to analyse all data where the above figures had suggested that the most appropriate transformation to be log as double square root values. This means using the same transformation for all data by species in the multivariate analyses, leaving only the data by site (full sample) to be ideally transformed by single square root, or to employ the double square root transformation in keeping with the other transformations. The rationale for this decision is now explored, based on whether using the double square root transformation (making all transformations the same) produces a markedly different (in fact unacceptably different) picture to that obtained by the most appropriate (square root) transformation). While Clarke & Warwick, (2001a) warn against a circular process of ‘snooping’ into the data to search for patterns which explain why the data shows what it does it is necessary to determine, (by a robust method) which of the two transformations are appropriate.

Broadly it was decided to compare the various transformations for the fish only part of the sample (for which the double root transformation is appropriate) with the full sample to see if similar trends were evident between the various transformations. If the trends can be considered similar then there is no particular reason for not choosing the double square root transformation for all data sets, rather than retain different

transformations because they describe the data differently. Two tests were undertaken and are described below.

The first measure under scrutiny was the stress values generated from MDS plots for the four transformations (none, square root, double square root and log) between the two data sets. These are shown in Table G.3.

Table G.3. Comparison of transformations for multidimensional scaling (MDS) based on resulting stress value, according to data type and MDS view.

| MDS | | transformation | | | |
|--------|------|----------------|----------------------|-----------------------------|------------------|
| data | type | none | $\sqrt{}$ | $\sqrt{\sqrt{}}$ | $\log_{10}(x+1)$ |
| full | 3d | 0.16 | 0.15 | 0.16 | 0.16 |
| sample | 2d | 0.21 | 0.20 | 0.20 | 0.21 |
| fish | 3d | 0.15 | 0.15 | 0.15 | 0.16 |
| only | 2d | 0.21 | 0.20 | 0.20 | 0.21 |

The stress values for the 3d MDS plots is included because it is usually possible for this type of MDS plot to better explain the data and it usually has a lower stress value. It appears from Table G.3 that the double square root transformation is no less appropriate in terms of portraying the data (in terms of MDS) than the square root transformation. The reason behind this is because while the plot of log standard deviation against log mean produced a slope of 0.471 this was largely due to the fact that the samples were all (approximately, and intentionally) the same size, thus flattening the slope of Figure G.2, above. The process of transforming, calculating the similarity matrix between sites and ordination of this data for the MDS plot has negated this feature. Thus, it is likely that any similar multivariate process undertaken on the rank-order of the data will have similar outcomes.

The second test was to examine the similarities between the ports and types of trawling at the different (as used above) transformations. This was undertaken according to the ANOSIM routine in PRIMER-E. It is not intended to fully explain what the results show here, instead the intention is to examine whether the square root transformed data explains the data better than the double square root transformation to the detriment of

using the same transformation for all the data. Again the benchmark was the fish only part of the sample (for which the double root transformation is appropriate) with the full sample to see if similar trends were evident between the various transformations. Simply the ANOSIM calculates the similarity between different parts of the sample according to various criteria; as above those chosen here were the port and type of trawling. The ANOSIM was generated according to the port and type of trawling, the four transformations and the two data sets. In total then eight ANOSIMs were generated. Table G.4 shows two of these, for single and double square root transformed data for the fish only set of the data. Also included are the mean, median, lower and upper quartile values for these ANOSIMs.

Table G.4. [Left] average ANOSIM (%) values (to 1 d.p.) and descriptive values according to two different transformations, and [right] permutation of ANOSIM (%) values according to port and type of trawling, N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling to similar ports and types.

| transformation | measure | value | port & type to port & type ANOSIM value | | | | | |
|----------------|----------------|-------|---|-----|-----|-----|------|-----|
| √ | | | N S | 0 | 0 | 0 | 0 | 0 |
| | mean | 5.21 | L S | | 0.7 | 2.1 | 58.4 | 6.2 |
| | median | 0.30 | L P | | | 0.2 | 4.2 | 0.2 |
| | lower quartile | 0.15 | P S | | | | 3.9 | 0.3 |
| | upper quartile | 29.05 | P P | | | | | 2.0 |
| √√ | | | N S | 0 | 0 | 0 | 0 | 0 |
| | mean | 6.98 | L S | | 1.1 | 3.3 | 75.7 | 3.9 |
| | median | 0.50 | L P | | | 0.5 | 2.8 | 0.2 |
| | lower quartile | 0.25 | P S | | | | 14.9 | 0.2 |
| | upper quartile | 37.60 | P P | | | | | 2.1 |
| | | | L S | L P | P S | P P | S S | |

Table G.4 shows that some of the better described (or more similar (higher) ANOSIM values) according to port and type categories grossly affect the upper quartile, while leaving the other values relatively unaltered, although the average of the $\sqrt{}$ transformations = 5.2 while the average of the $\sqrt{\sqrt{}}$ transformations = 7.0. Figure G.7 shows the average ANOSIM values across all ports and types of trawling for the two data groups according to the four transformations.



Figure G.7. Average % ANOSIM level for the four transformations (none, square root, double square root and $\log_{10}(x+1)$) according to the two data groups (full and fish only).

It is apparent from Figure G.7 that there is a marked difference in the outcome of the four transformations for the double square root and log transformation suggesting that the square root transformation is better, since there is a degree of difference between the higher order transformations, however the higher order transformations may ‘explain’ the data better, but there is also greater variation in raw data as described in Table G.4. Being wary of expressing parametric confidence intervals of non-parametrically derived data it is nevertheless necessary to describe this variation – the upper quartile was chosen because this feature describes the “best fit” part of the model which rises above the generally noisier part of the matrix shown in Table G.4. Table G.5 shows the full data set for mean, median, lower and upper quartiles for the two data sets.

Table G.5. Mean, median, lower and upper quartile ANOSIM (%) values according to port and type of trawling for the full sample and fish only part of the sample according to four (none, $\sqrt{}$, $\sqrt[3]{}$, and $\log_{10}(x+1)$) transformations.

| data type | measure | transformation | | | |
|-----------|----------------|----------------|----------------------|-------------------------|------------------|
| | | none | $\sqrt{}$ | $\sqrt[3]{}$ | $\log_{10}(x+1)$ |
| full | mean | 4.91 | 5.31 | 5.31 | 5.68 |
| | median | 0.40 | 0.30 | 0.30 | 0.30 |
| | lower quartile | 0.20 | 0.15 | 0.15 | 0.15 |
| | upper quartile | 23.55 | 33.95 | 32.20 | 30.60 |
| fish only | mean | 4.93 | 5.21 | 6.98 | 8.14 |
| | median | 0.30 | 0.30 | 0.50 | 1.10 |
| | lower quartile | 0.15 | 0.15 | 0.25 | 0.55 |
| | upper quartile | 15.15 | 29.05 | 37.60 | 38.00 |

Table G.5 shows that for all the transformations the median and lower quartiles do not vary much. The situation for the means is explained in Figure G.7, (above), but it is the upper quartile that expresses the alteration in the data the most and this is effectively due to outliers or parts of the data which the ANOSIM describes as being most similar. This is due to the improved fit of the data, though taken together with the representation of the MDS plot, (through the stress value) it is deemed that in conclusion the case for maintaining the use of the double square root transformation is stronger than striving for the most appropriate fit, (as described in Table G.2, above).

Lastly, there is the possibility that regardless of the transformation an inconclusive picture may subsequently be reached. In this case advice from Field *et al.*, (1982) is taken. Field *et al.*, (1982) suggest that before the data are transformed the rarer species are removed. Though what they proposed is rather arbitrary they recommend removing all species which never constitute more than a certain (small) percentage of the total whether abundance or biomass of any sample where the actual value is chosen to retain 50 or 60 species with the highest total abundance Clarke & Warwick, (2001a) advises that "...this [process] is preferable to retaining the 50 or 60 species with the highest total abundance across all samples since the latter strategy may result in omitting several species which are key constituents of a site which is characterised by a low total number of individuals." This additional process is stated here though its validity cannot easily be demonstrated. Instead it can be employed as necessary prior to a transformation.

Appendix H

H Development of the aggregation file

Appendix C (Table C.1, page 348 and Table C.2, page 349, above) show the full species list and taxonomy used to create the master data aggregation file for Primer-E. This was based on the Access97 "SpeciesA.mdb" file (Picton & Howson, 1999) and the classifications was built up according to the parent child method described with reference to Table 2.2, page 43, above, though as this section made clear not all classification levels are present for all species. Also, the identification of some items could or were not carried to the species level. This was the case, for example, for the phylum PORIFERA; all items of the bryozoan *Cellaria sp* that were only identified to the genus level; and wrasses were only identified to the family Labridae level. Table H.1 shows a simplified version of the data used to populate the Primer-E aggregation file arranged using the taxonomic levels present for the two species featured on Table 2.2, above and the three groups mentioned above.

Table H.1. Taxonomic level and number for five groups, part 1: initial situation. Used taxonomic levels are highlighted.

| taxonomic | | examples of groups | | | | |
|---------------|-----|--------------------|-----------------------------|--------------------|--------------------------------|---------------|
| level | # | 1 | 2 | 3 | 4 | 5 |
| | | PORIFERA | <i>Liocarcinus holsatus</i> | <i>Cellaria sp</i> | <i>Marthasterias glacialis</i> | Labridae |
| kingdom | 1 | Animalia | Animalia | Animalia | Animalia | Animalia |
| phylum | 2 | PORIFERA | CRUSTACEA (higher) | BRYOZOA | ECHINODERMATA | CHORDATA |
| sub-phylum | 3 | | | | | PISCES |
| super-class | 4 | | | | | GNATHOSTOMATA |
| class | 5 | | EUMALACOSTRACA | GYMNOLAEMATA | ASTEROIDEA | OSTEICHTHYES |
| sub-class | 6 | | EUCARIDA | | | TELEOSTEI |
| super-order | 7 | | | | | |
| extra-order | 8a | | | | | |
| order | 8 | | DECAPODA | CHEILOSTOMATIDA | FORCIPULATIDA | PERCIFORMES |
| sub-order | 9 | | PLEOCYEMATA | NEOCHEILOSTOMATINA | | |
| infra-order | 10 | | BRACHYURA | | | |
| section | 11 | | BRACHYRHYNCHA | | | |
| super-family | 12 | | PORTUNOIDEA | CELLARIOIDEA | | |
| family | 13 | | Portunidae | Cellariidae | Asteriidae | Labridae |
| sub-family | 14 | | Polybiinae | | | |
| tribe | 15 | | | | | |
| genus | 16 | | <i>Liocarcinus</i> | <i>Cellaria</i> | <i>Marthasterias</i> | |
| sub-genus | 17 | | | | | |
| extra-species | 18a | | | | | |
| species | 18 | | <i>Holsatus</i> | | <i>glacialis</i> | |
| sub-species | 19 | | | | | |
| variety | 20 | | | | | |
| [spare] | 21 | | | | | |
| synonym | 22 | | | | | |

It should be noted that Table H.1 and its subsequent derivatives are transposed in orientation to the final aggregation matrix shown in Appendix C (Table C.1, page 348 and Table C.2, page 349, above). The purpose of this was for display clarity.

The purpose of the aggregation file is to allow the path length to be mapped between any two species (or items) and therefore to work correctly there must not be any blanks along any path. Three solutions presented themselves which are described along with their strengths and weaknesses.

Solution 1:

Only use those levels of classification which were present in all groups. Applying this method would use kingdom, phylum, class, order, family, genus and species for those groups which were identified to species level (number 2 and 4 shown on Table H.1). Despite the calculation of various biodiversity measures (such as average taxonomic distinctness, AvTD, Δ^+), being quite robust to the any chosen taxonomic levels (Somerfield, *pers com.*) much information would be lost using this system. It would also create a difficult situation for groups 1, 3 and 5 on Table H.1, though this method would be useful where all the species came from the same class such as was the case for Rogers *et al.*, (1999).

In order to be included in the aggregation file all groups have to be present in the finest taxonomic level which was the species level (taxonomic number 18 here). Therefore in order to retain these groups it was necessary to fill down from the finest level present on Table H.1 to the species level. This potentially made phylum Porifera, genus *Cellaria* and family Labridae into species. This was not a particular problem since it meant that higher level taxon names (and taxon ID numbers) became species as well as also being present at coarser taxonomic levels. Table H.2 shows the simplified aggregation file with all examples carried down to species. The arrows on Table H.2 show the direction of the filled levels.

Table H.2. Taxonomic level and number for five groups, part 2: all groups carried to species level. The arrow shows the direction of the filled levels. Used taxonomic levels are highlighted.

| taxonomic | | examples of groups | | | | |
|---------------|-----|--------------------|-----------------------------|--------------------|--------------------------------|---------------|
| level | # | 1 | 2 | 3 | 4 | 5 |
| | | PORIFERA | <i>Liocarcinus holsatus</i> | <i>Cellaria sp</i> | <i>Marthasterias glacialis</i> | Labridae |
| kingdom | 1 | Animalia | Animalia | Animalia | Animalia | Animalia |
| phylum | 2 | PORIFERA ↓ | CRUSTACEA (higher) | BRYOZOA | ECHINODERMATA | CHORDATA |
| sub-phylum | 3 | PORIFERA ↓ | | | | PISCES |
| super-class | 4 | PORIFERA ↓ | | | | GNATHOSTOMATA |
| class | 5 | PORIFERA ↓ | EUMALACOSTRACA | GYMNOLAEMATA | ASTEROIDEA | OSTEICHTHYES |
| sub-class | 6 | PORIFERA ↓ | EUCARIDA | | | TELEOSTEI |
| super-order | 7 | | | | | |
| extra-order | 8a | | | | | |
| order | 8 | PORIFERA ↓ | DECAPODA | CHEILOSTOMATIDA | FORCIPULATIDA | PERCIFORMES |
| sub-order | 9 | PORIFERA ↓ | PLEOCYEMATA | NEOCHEILOSTOMATINA | | |
| infra-order | 10 | PORIFERA ↓ | BRACHYURA | | | |
| section | 11 | PORIFERA ↓ | BRACHYRHYNCHA | | | |
| super-family | 12 | PORIFERA ↓ | PORTUNOIDEA | CELLARIOIDEA | | |
| family | 13 | PORIFERA ↓ | Portunidae | Cellariidae | Asteriidae | Labridae ↓ |
| sub-family | 14 | PORIFERA ↓ | Polybiinae | | | Labridae ↓ |
| tribe | 15 | | | | | |
| genus | 16 | PORIFERA ↓ | <i>Liocarcinus</i> | <i>Cellaria</i> ↓ | <i>Marthasterias</i> | Labridae ↓ |
| sub-genus | 17 | | | | | |
| extra-species | 18a | | | | | |
| species | 18 | PORIFERA | <i>Holsatus</i> | <i>Cellaria</i> | <i>glacialis</i> | Labridae |
| sub-species | 19 | | | | | |
| variety | 20 | | | | | |
| [spare] | 21 | | | | | |
| synonym | 22 | | | | | |

The embryonic aggregation file shown in Table H.2 requires the remaining gaps to be populated. There are two ways to do this.

Solution 2:

Somerfield (*pers com.*) suggested using the present taxonomic levels and filling the gaps in between in both directions. While this method best retains the purity of the taxonomic structure it has the drawback in that taxonomic levels are encountered before they should be (though where there was one gap between two populated levels this need not be the case). Table H.3 shows a small example of this.

Table H.3. Taxonomic level and number for two groups (3 and 4), part 3: Somerfield's method for populating the aggregation file. The arrow shows the direction of the filled levels. Levels with "•" are at their correct level. Used taxonomic levels are highlighted.

| taxonomic | | examples of groups | |
|--------------|----|----------------------|-----------------|
| level | # | 3 | 4 |
| kingdom | 1 | Animalia • | Animalia • |
| phylum | 2 | BRYOZOA • | ECHINODERMATA • |
| sub-phylum | 3 | BRYOZOA ↓ | ECHINODERMATA ↓ |
| super-class | 4 | GYMNOLAEMATA ↑ | ASTEROIDEA ↑ |
| class | 5 | GYMNOLAEMATA • | ASTEROIDEA • |
| sub-class | 6 | GYMNOLAEMATA ↓ | ASTEROIDEA ↓ |
| super-order | 7 | | |
| extra-order | 8a | | |
| order | 8 | CHEILOSTOMATIDA • | FORCIPULATIDA • |
| sub-order | 9 | NEOCHEILOSTOMATINA • | FORCIPULATIDA ↓ |
| infra-order | 10 | NEOCHEILOSTOMATINA ↓ | FORCIPULATIDA ↓ |
| section | 11 | CELLARIOIDEA ↑ | Asteriidae ↑ |
| super-family | 12 | CELLARIOIDEA • | Asteriidae ↑ |
| family | 13 | Cellariidae • | Asteriidae • |
| sub-family | 14 | Cellariidae ↓ | Asteriidae ↓ |
| tribe | 15 | | |
| genus | 16 | Cellaria • | Marthasterias • |

It was decided that this method was generally too complex and despite the robustness of the approach overall this method contradicts the filled down examples described above.

Solution 3:

The alternative method was to populate the aggregation file only by filing each level from above (the coarser level). Table H.4 shows this, for the same data presented in Table H.3.

Table H.4. Taxonomic level and number for two groups (3 and 4), part 4: the chosen method for populating the aggregation file. The arrow shows the direction of the filled levels. Levels with “●” are at their correct level. Used taxonomic levels are highlighted.

| taxonomic | | examples of groups | |
|--------------|----|----------------------|--------------------------------|
| level | # | 3 | 4 |
| | | <i>Cellaria sp</i> | <i>Marthasterias glacialis</i> |
| kingdom | 1 | Animalia ● | Animalia ● |
| phylum | 2 | BRYOZOA ● | ECHINODERMATA ● |
| sub-phylum | 3 | BRYOZOA ↓ | ECHINODERMATA ↓ |
| super-class | 4 | BRYOZOA ↓ | ECHINODERMATA ↓ |
| class | 5 | GYMNOLAEMATA ● | ASTEROIDEA ● |
| sub-class | 6 | GYMNOLAEMATA ↓ | ASTEROIDEA ↓ |
| super-order | 7 | | |
| extra-order | 8a | | |
| order | 8 | CHEILOSTOMATIDA ● | FORCIPULATIDA ● |
| sub-order | 9 | NEOCHEILOSTOMATINA ● | FORCIPULATIDA ↓ |
| infra-order | 10 | NEOCHEILOSTOMATINA ↓ | FORCIPULATIDA ↓ |
| section | 11 | NEOCHEILOSTOMATINA ↓ | FORCIPULATIDA ↓ |
| super-family | 12 | CELLARIOIDEA ● | FORCIPULATIDA ↓ |
| family | 13 | Cellariidae ● | Asteriidae ● |
| sub-family | 14 | Cellariidae ↓ | Asteriidae ↓ |
| tribe | 15 | | |
| genus | 16 | <i>Cellaria</i> ● | <i>Marthasterias</i> ● |

The method shown in Table H.4 treated all examples of groups equally (regardless of their finest taxonomic level) and importantly ensures that taxonomic levels are not encountered until their correct level is reached.

Compared to the study by Rogers *et al.*, (1999) the species encountered here came from a wider taxonomic range. While it could be argued that the presences of certain components of the sample are non native to the location of the sample (for example angiosperm leaves) the taxonomy maintained the kingdom Plantae due to the inclusion of *Zostera marina* and various red, brown and green algae. Thus fifteen taxonomic levels were retained as shown in Appendix C (Table C.1, page 348 and Table C.2, page 349, above), and these were highlighted (where relevant) on Table H.1, Table H.2, Table H.3 and Table H.4. Taxonomic levels 7, 8a, 15, 17, 18a and 19 – 22 (named on Table H.1)

were never used here as these levels remained empty throughout the entire classification. Different assemblages of species might include these less-used taxonomic levels however those which are unused here are not essential in describing the taxonomy and are not generally required if the classification of by Picton & Howson, (1999) is employed.

Appendix I

I Branch length weighting

I.1 Background

Rogers *et al.*, (1999) used a weighted branch length (Clarke & Warwick, 1999) in preparing their Δ^+ values and justify doing this because “there is a degree of arbitrariness about a constant path length of one unit between each taxonomic level.” However, their study while species rich ($n = 93$) examined species from only two classes. This study collected examples from twenty-one classes and employing the otherwise sensible measure of Rogers *et al.*, (1999, table 1.) would unfavourably skew branch lengths across very distant parts of the taxonomic tree therefore the arbitrary branch length of one unit was retained since it is not currently possible to use different branch length values for different part of the taxonomic tree between the same taxonomic levels. The alternative method is to allow the TAXDTEST routine to calculate the taxon richness based on the actual species count. This method was not chosen since as groups of species were excluded and reintroduced (see Figure 6.10 and Figure 6.11, above) changes occur in the remaining taxon richness each time. If this method had been adopted then without the path length between two species altering the Δ^+ value (or any other similar measure) would not be fixed, but would change as other species were excluded and reintroduced around them. The outcome describes the quantitative and qualitative differences between the two methods of branch length weighting.

I.2 Outcome

The choice of weighting the branch length affects the resulting null and generated Δ^+ and Λ^+ values which has further important implications for comparing the data set with those of other studies. Figure I.1 portrays the plot of null (expected) and generated average taxonomic distinctness (Δ^+ , Δ^+) values and comparable variation in taxonomic distinctness (Λ^+ , Λ^+) values based around the fixed branch length values of 1 and where the weightings were generated by the master species list.

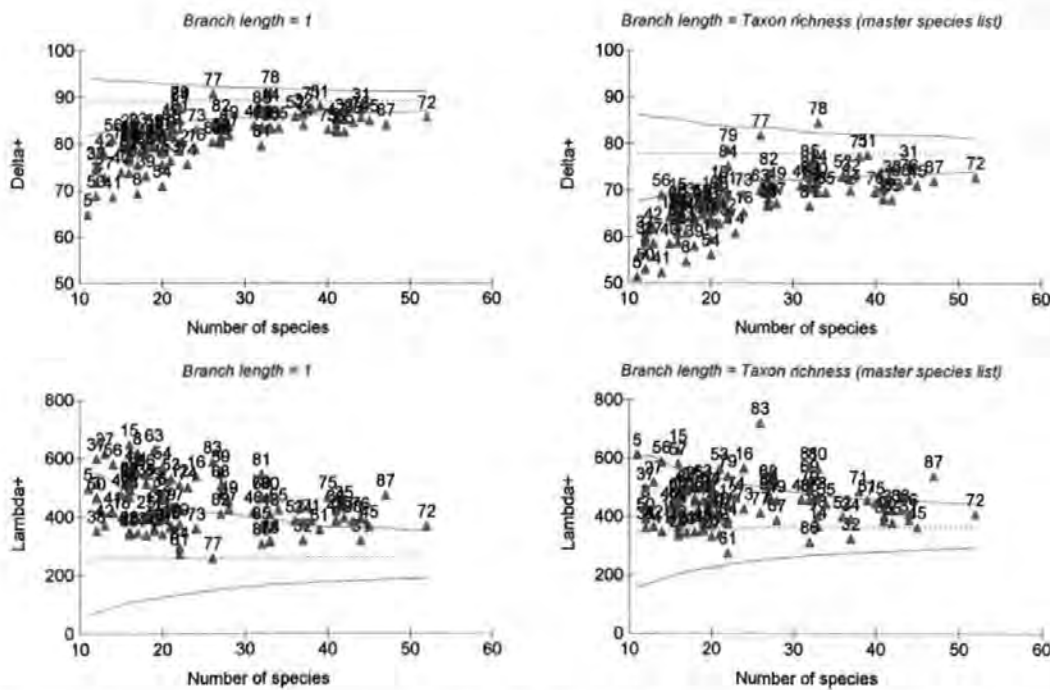


Figure I.1. Average taxonomic distinctness, (Δ^+ , top), and variation in taxonomic distinctness (Λ^+) values (bottom) plotted against the observed number of species for the full sample according to two different methods of weighting of branch lengths; branch length = 1 (left) and branch length is determined by the taxon richness from the master species list (right). The dashed line indicates the simulated mean Δ^+ or Λ^+ value for 1,000 selections of a random number of species from the master list of 188 species. Intervals within which the 95 % of the simulated Δ^+ or Λ^+ lie (the expected range of Δ^+ or Λ^+ for a given number of species) are constructed for each sub list (random sample) and represented as a probability funnel (continuous lines). Note that a different y axis scale has been used on the Δ^+ plots to those displayed in Chapter 6.

Figure I.1 shows that employing the weighting of fixed branch lengths generally resulted in higher null (expected) average taxonomic distinctness (Δ^+) values and lower variation in taxonomic distinctness (Λ^+) values when compared to weighting branch lengths according to the variable taxon richness based around the master species list when the two methods are compared using the same full sample data. The produced Δ^+ and Λ^+ values are similarly affected by the two weighting methods. The Δ^+ values are generally larger though occupy a smaller range employing fixed branch length weighting when compared to the variable taxon richness based around the master species list. However, regardless of the method the relationship is relatively fixed for Δ^+ values between samples. In other words for average taxonomic distinctness the two methods produce plots of Δ^+ values against numbers of species (Figure I.1, top row) where the samples retain their orientation to each other whichever branch length weighting is used though each method introduces a skew to the data.

There is a greater qualitative difference in generated variation in taxonomic distinctness values depending on which weighting method was chosen. Figure I.1 (bottom) shows that fixed branch lengths resulted in more samples falling outside and above the null funnel of expected Λ^+ values such that more samples appeared to be uneven from a taxonomic point of view though the relationship for the Λ^+ values between samples is far more complex than was the case for the Δ^+ values. This is borne out by the differences between the average Λ^+ values on Figure I.1 (bottom) being not great. Mean and 95 % confidence intervals for Λ^+ values where the branch length was 1 = 437 ± 19 while where the master species list derived the branch length the similar average and variability were 440 ± 16 .

Appendix J

J Raising the sample weight to the haul: a choice of two methods

J.1 Introduction

In order to be able to examine the species presence and abundance in individual sample and haul dataset (see Figure 9.1) and compare one species / haul dataset with another (or a number of others) it was necessary to raise the sample dataset so that the resulting model regression would have generated a slope tending towards $\beta = 1$. The reason for this was that although the sample size (of landed and discarded fish and non-fish material) was ideally a fixed volume (though it did vary) the amount of the landed fishes within the sample varied. Additionally, the amount of landed part of the haul varied depending on the success of the boat, its size and whether single or pair trawling was being undertaken. The application of the raising factor also needed to ensure that deviation of the slope from one could occur equally with the slope becoming steeper or shallower as on a haul by haul basis as species were over or under represented.

Two types of raising factors were calculated. These are first briefly described then a more detailed analysis is presented including the advantages and disadvantages of each, enabling a rational choice to be made, as neither was perfect.

J.2 Methods

1. The first raising factor relied on knowing the estimated number of baskets in the landed component of the haul and calculating the proportion of the landed component of the sample, “l”.
2. The second raising factor is simpler and only requires knowing the weights of the species in the sample “l” the haul “L” and the sum of all species in the haul.

J.2.1 Raising factor 1

The first raising factor was calculated as follows:

$$LAN = \frac{1}{\left(\frac{l}{\sum l + d + n} \right)} \times lan \times b$$

Where LAN = the raised weight for a particular species.

l = the weight of the landed component of the sample, “l”.

d = the weight of the discarded component of the sample, “d”.

n = the weight of the non-fish component of the sample, “n”.

lan = the weight of a particular species in the in the landed component of the sample “l”.

b = the estimated number of full baskets of fish landed.

The following example shows the raising of 4,150 g of BIB to 24,459 g (to the nearest gram) encountered in haul 1, where a total of 5 baskets of fish were landed.

$$24,459 = \frac{1}{\left(\frac{30,927}{\sum 30,927 + 4,541 + 991} \right)} \times 4,150 \times 5$$

J.2.1.1 Examination of raising factor 1

A possible source of error in the above equation is that while all the values of fishes were ungutted examples or were gutted fishes whose weight was raised to be ungutted the number of baskets was an estimate of gutted fishes. Whilst this may indeed have induced an error the estimated the number of baskets was almost always ($n = 72$, or 84%) a whole number and was generally estimated up, which may help account for the difference between the gutted and the ungutted weight.

Chapter 3, page 350 to 360 (above), (including Figure 3.3, page 61) describe the sample size or fullness of the fish basket used to sample the haul. In a similar manner, it was possible to examine the fullness of the estimated number of baskets of landed fish to the overall size of the gutted component of the landed part of the haul. The simplest way to examine this was to generate a frequency histogram (Figure J.1) of the average weight of the estimated fish basket, worked out by dividing the total weight of the landed component by the number of estimated baskets.

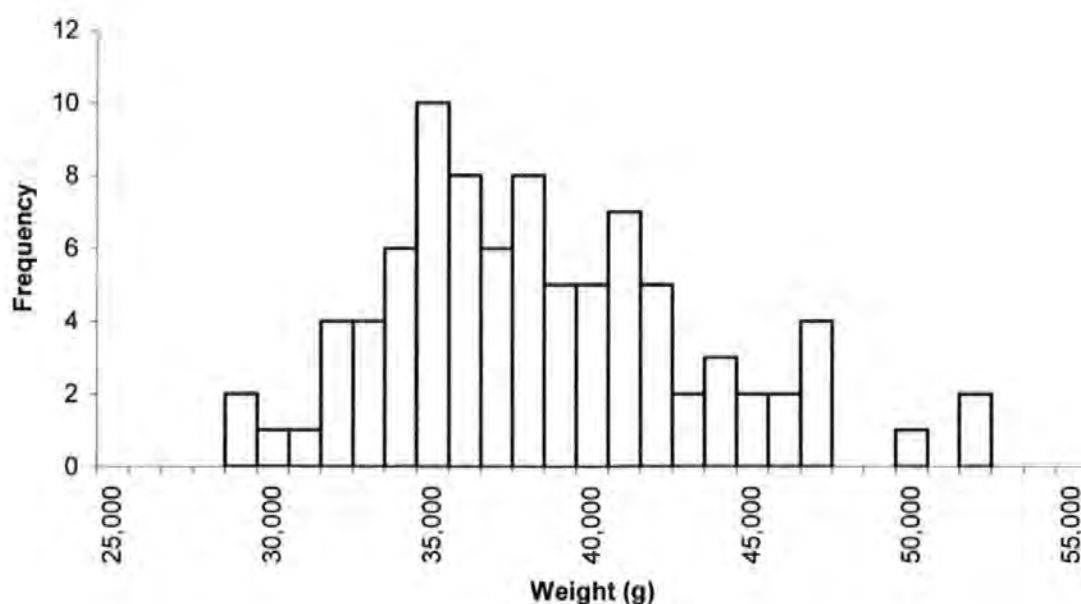


Figure J.1. Frequency histogram of the estimated weight (g) per basket for all samples, ($n = 88$). Note that the bin size is 1,000 g and the values on the x axis are the upper level of the bin.

The average estimated weight was surprisingly close to 38 kg at 37,915 g, with a minimal value of 28,059 g and a maximum of 51,750 g. It may seem that the maximum values are very high indeed, but it must be remembered that these values were only estimated, and that 97% of the values are within 10 kg of the average. Figure J.1 shows that for very few hauls the estimated sample size was more than 10 kg away from the expected average weight of a fish basket though suggests that the estimate is generally within about 75% of the full 38 kg fish basket. Whether the large outliers (Seber, 1977) are included the histogram in Figure J.1 has positive skew, ($g_1 = 0.626$ with outliers and $g_1 = 0.272$ without). Again, this may negate the fact that the estimates of basket size are gutted rather than ungutted fishes.

J.2.2 Raising factor 2

The alternative (second type of raising factor) was simpler and used only data about the haul and sample and does not include any estimation. The second raising factor was calculated as follows:

$$LAN = \frac{\sum "L"}{\sum "l"} \times lan$$

Where LAN = the raised weight for a particular species.

l = the weight of the landed component of the sample, "l".

L = the weight of the landed component of the haul, "L".

lan = the weight of a particular species in the in the landed component of the sample "l".

The following example shows the raising of 4,150 g of BIB to 26,312 g (to the nearest gram) encountered in haul 1.

$$26,312 = \frac{196,107}{30,927} \times 4,150$$

J.2.2.1 Examination of factor 2

The advantages of this raising factor were due to its simplicity in that it relies on neither the estimated number of baskets caught nor the proportion of the sample weight that was the landed component. Instead, it uses the weights directly. Also, it is comparing ungutted fish in the sample with gutted to ungutted calculated weights of fish. The important and significant disadvantage of this raising factor however, is that it employs the sum of the weights in the landed component, "L" for both the weight of the landed component of the haul, (obviously) but also the sum of the raised weight in the landed component of the sample "l". In other words plotting the weight by species of raised landed fish in the sample against the weight by species of the landed component in the haul "L" would automatically approximate a slope of 1.

J.2.3 Comparison of the performance or raising factors 1 and 2

Ideally raising factor 1 would be chosen over raising factor 2 because the former's advantages outweigh those of the latter. Figure J.2 shows the difference in these two raising factors according to all the hauls.

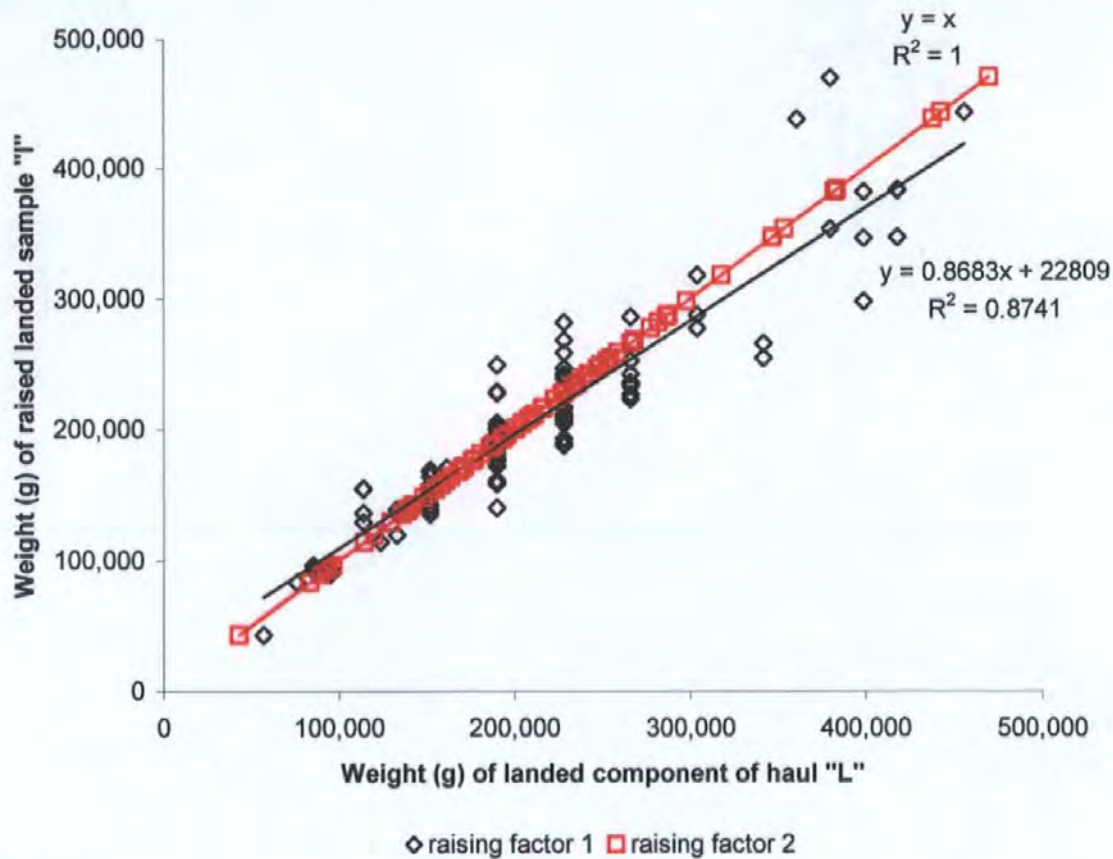


Figure J.2. Weight of raised landed sample “I” against weight of landed component of haul “L”, for all hauls, $n = 88$. The trend line equations are shown as close as possible to the lines themselves.

Figure J.2 suggests that raising factor 1 overestimated the raised weight at low levels and underestimates the raised weight at higher weight when compared to raising factor 2. The preference of raising factor 1 exists only if the trend lines as described in Figure J.2 are not significantly different for intercept and more importantly slope. A comparison of regression lines, undertaken in Statgraphics, (Manguistics, 2000) shows that the intercepts of the trend lines in Figure J.2 are not significantly different for intercept, but they are significantly different for slope (ANCOVA intercept $P = 0.0839$; slope $P < 0.001$, d.f. = 1). Thus raising factor 2 was chosen in preference.

It could be argued that the axes as shown in Figure J.2 (above) could be the other way around. Dytham, (1999, p163) points out that “...if it is difficult to decide which is the dependent and which the independent variable then linear regression [and analysis based on this] is almost certainly not appropriate.” The orientation of the axes are as

shown on Figure J.2 with the landed component of the haul “L” as the independent variable both because this data was altered less in magnitude, only being corrected from gutted to ungutted weights, but also raising the sample data depends on the independent haul data. The dependent variable thus was the weight of the raised landed component of the sample “I”.

As described above raising factor 2 was chosen. However, it might not always be the method of choice, particularly if the weight of the landed component in the sample “I” is particularly small when compared to the weight of the landed component of the haul “L”. Figure J.3 shows how this might be the case for data from this study.

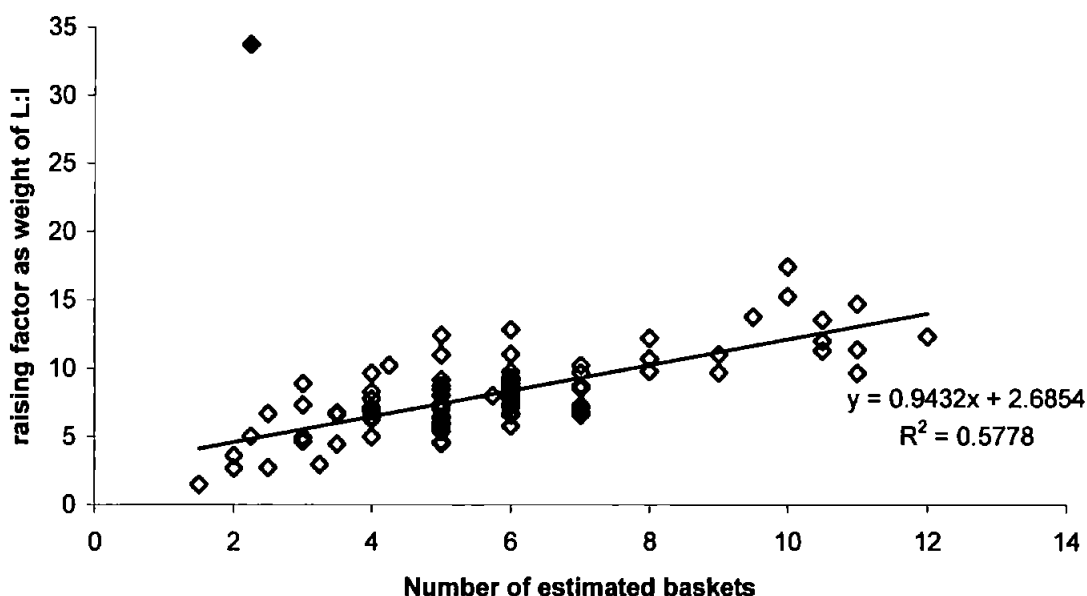


Figure J.3. Values for raising factor 2 (as ratio of weight of landed component of haul “L” to landed weight of sample “I”) against raising factor 1 (as number of estimated baskets), ($n = 88$). The outlier (filled) was not included in the trend line. Had this been the case the trend equation would be $y = 0.7331x + 4.2197$. $R^2 = 0.1887$.

Figure J.3 shows that for by far the majority of the hauls the two raising factors did not produce qualitatively different results. This is illustrated by the trend line equation being fairly close to $y = x$, as described above. The outlier (shown in light blue on Figure J.3) was haul 79. This haul was quite unlike the others in that the sample comprised much less landed than discarded fish (landed = 25,646 g; discarded = 2,749 g). This is in stark

contrast to the majority picture described by Figure 3.4, page 63 (above) and Figure J.3. The trend for the 87 points described by the equation in Figure J.3 was very highly significant $P < 0.001$ and this regression is valid as the residuals approximate a normal distribution according to the A-D test; ($A^2 = 0.577, n = 87, P = 0.130$).

Appendix K

K Transforming the sample and haul data

K.1 Introduction

This appendix sets out to describe whether and if so, which data transformations were required for the parametric analysis in Chapter 9.

This appendix begins by examining the features of the dataset through presenting the full data set. Next, the data that represent species present in the sample but not in the haul, present in the haul but not in the sample and absent from both were examined. A transformation which retained the data representing the species present in the haul but absent from the sample is described and it is shown why this could not be the basis for further analysis and these data had to be excluded. It is also shown that a data transformation was required based on regression assumptions. Outlying data points were examined to establish whether their exclusion may be more appropriate though this idea was rejected on data integrity grounds.

Once the data set had been finalised a transformation rationale is described where the benchmark was to produce a transformation which produced a better fit than with the non-transformed equivalent data set though yielded less alteration in variance with increase in the predicted values than initially present. A weighted least squared regression was applied (which had the advantage of allowing the full data set to be utilised though this was not found to be useful).

In order to establish the best transformation Box-Cox transformations were generated on both the sample and haul data and while their application on both the dependent and independent data was not strictly valid this method enabled appropriate transformations to be identified and critically evaluated. Finally an artefact present in the haul data is explored.

K.2 Dataset examination

Figure K.1 shows the full dataset.

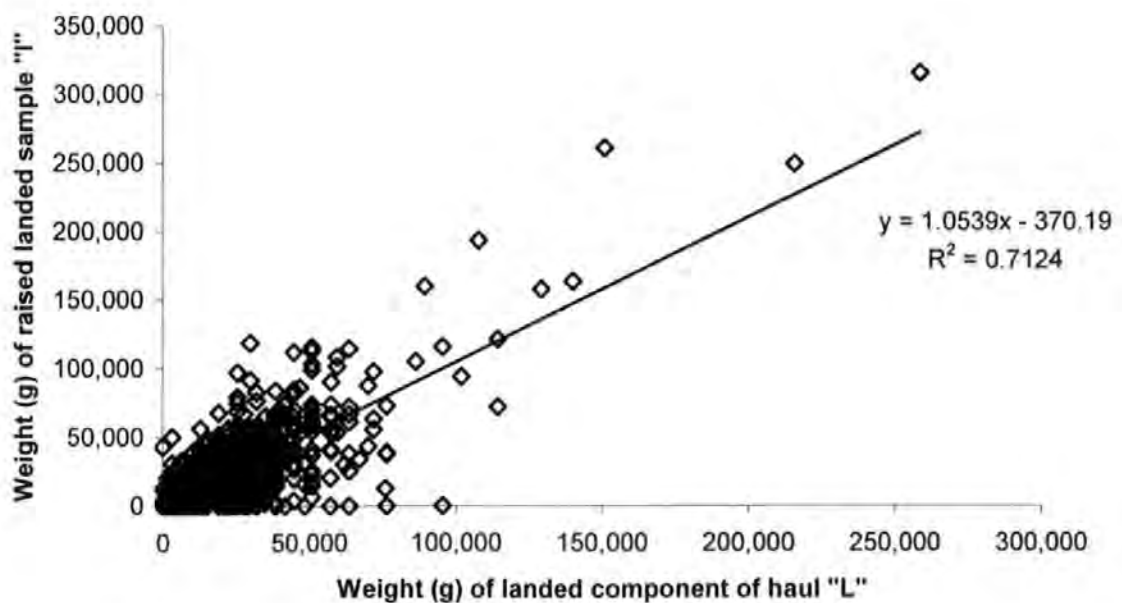


Figure K.1. Weight of raised landed sample "l" against weight of landed component of haul "L", $n = 2,728$.

As described above (according to Figure 9.1) the data points in Figure K.1 on $y = 0$ are fish included in the haul which were not included in the sample. Likewise (according to Figure 9.1) data points on Figure K.1 where $x = 0$ are fish found in the sample but which did not occur in the haul. While the former are acceptable, the latter are not. By plotting the data

sets as the double $\log_{10}(+1)$ the extent of the bias introduced by these features can be seen in the data. This is shown in Figure K.2.

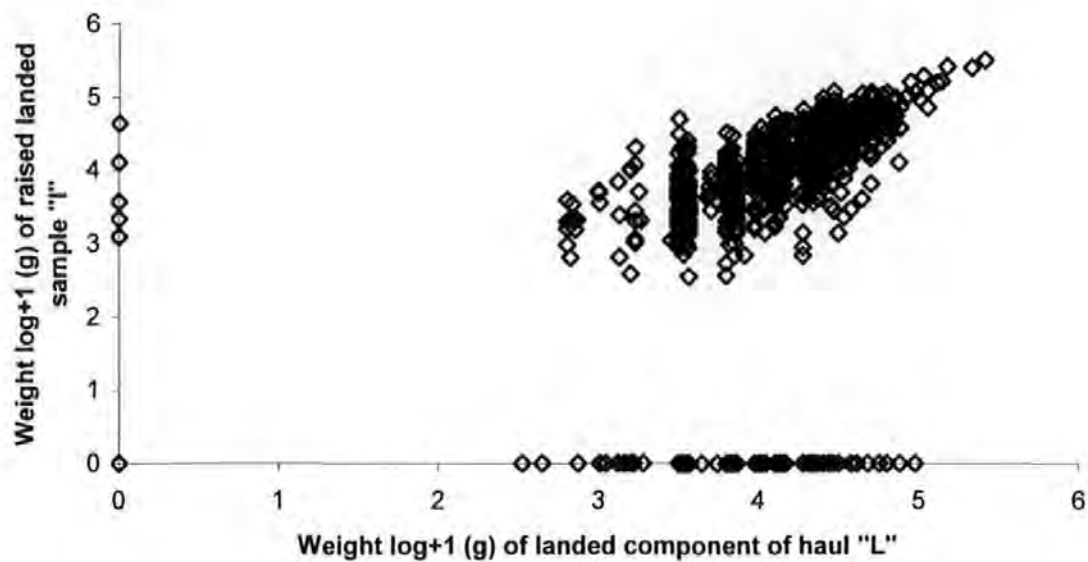


Figure K.2. Weight as $\log_{10}(+1)$ of raised landed sample “I” against weight as $\log_{10}(+1)$ of landed component of haul “L”, $n = 2,728$.

Summing the 88 hauls and 33 species or groups of species produced a possible 2,728 cells for the two site-species matrices, one for the hauls composition “L” and one for the sample composition “I”. Unsurprisingly these matrices were not fully populated. Table K.1 shows how many cells were occupied from the two site-species matrices.

Table K.1. The population of cells in the two site species matrices.

| haul composition “L” | sample composition “I” | number of occurrences |
|-------------------------|---------------------------|-----------------------|
| 0 | 0 | 1,676 |
| 0 | 1 | 5 |
| 1 | 0 | 270 |
| 1 | 1 | 777 |
| total | | 2,728 |

The 1,676 empty cells, equates to 61% of the matrix being empty. The 270 occurrences where fish are found in the haul but not the sample (which is equivalent to $y = 0$ on Figure

9.1, Figure K.1 and Figure K.2 (above) are not a major problem. It would be more surprising if in every case all the species recorded in the haul were also found in the sample. The opposite situation with fish found in the sample but not in the haul (equivalent to $x = 0$ Figure 9.1, Figure K.1, and Figure K.2 (above) was more serious. Table K.2 shows the five data in more detail.

Table K.2. The five examples of species encountered in the sample where there was no corresponding data in the haul.

| sequential haul number | date, port and haul | species code | weight in haul composition, "L" (g) | weight in raised landed sample "I" (g) | weight in sample (g) | lengths in sample (cm) |
|------------------------|---------------------|--------------|-------------------------------------|--|----------------------|------------------------|
| 5 | 24/05/1998 N 3 | BLL | 0 | 43,292 | 5,416.96 | 58, 46 |
| 11 | 24/05/1998 N 9 | HER | 0 | 3,695 | 422.97 | 28, 24, 26 |
| 20 | 29/08/1998 N 3 | LSD | 0 | 12,792 | 1,590.15 | 60, 62 |
| 38 | 05/05/1999 N 2 | SCX | 0 | 2,157 | 231.59 | 11 |
| 39 | 05/05/1999 N 3 | SCX | 0 | 1,243 | 174.00 | 10 |

Looking at the data in Table K.2 the first thing to notice is that all the data came from Newlyn hauls. Next, the oversight of the brill (BLL) was most important. There were only two fish of this species encountered in the sample and it is possible that they were the only two brill caught. Brill made up about 7% of the weight of this sample but is it highly unlikely that this species comprised the same proportion of the haul. There is no suggestion of deliberate misreporting here but it is odd that these two large fish were unobserved. It is easier to explain the oversight of the other items in Table K.2. It is not difficult to overlook three herrings (HER). Similarly, dogfish (LSD) were commonly landed from Newlyn and Salcombe, but this species was usually only sold locally for bait, so the inclusion of this species in the landed component did not always happen. Scallops (SCX) were almost as likely to be landed as discarded. Like the herring, it was not surprising that two scallops were found in the sample basket across two hauls and yet they were overlooked in records of the haul. Therefore the removal of these five points at $x = 0$ is acceptable on the ground of satisfying the model.

The trend line shown in Figure K.1 (above) included all 2,728 points. While on Figure K.1 the trend line is not forced through the origin of the graph it effectively is however due to the 1,676 points at $x = 0, y = 0$. Removing these (and the five points at $x = 0$) produces a situation as shown in Figure K.3.

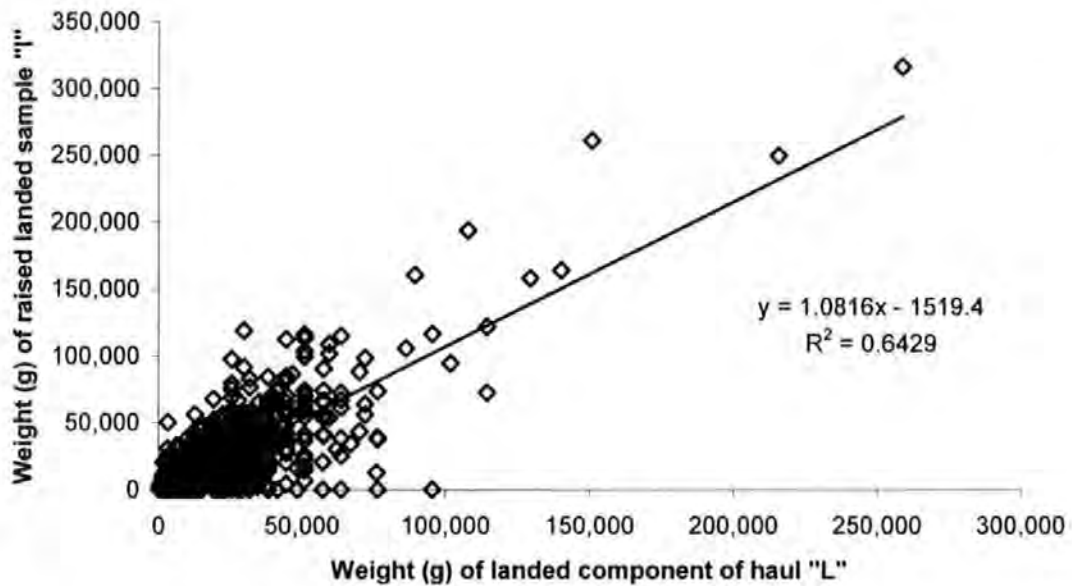


Figure K.3. Weight of raised landed sample "I" against weight of landed component of haul "L", $n = 1,047$.

As expected, the fit as described in Figure K.3 was not as good as in Figure K.1, (above). This is of course due to the loss of the points at $x = 0, y = 0$, which inevitably relaxed the forcing of the trend through the origin.

There were now essentially two versions of the data set. The smaller ($n = 777$) comprised positive weights in both the sample "I" and the haul "L". The larger dataset ($n = 1,047$) included the additional 270 data points with positive weights in the haul "L" but which were not found in the sample "I". This distinction is important in the analysis below.

In order that the relationship between the raised landed weight in the sample and the landed haul composition could be examined for its validity, it was necessary to test whether the slope and intercept for each haul significantly differed from the average.

Rather than compare the fit of each haul to the hypothetical trend line where $y = x$, which while the ideal according to raising factor and the model depicted in Figure J.2 and Figure 9.1 (above) it was significantly different to the average trend line as shown in Figure J.2, for slope, but not for intercept, (ANCOVA slope $P = 0.001$; intercept $P = 0.901$, d.f. = 1). In order to be correct in comparing the trend lines for each haul in Appendix L to the hypothetical it would have to be not significantly different to $y = x$ for both slope and intercept, and particularly slope.

Instead, the slope (and intercept) for each haul was tested for difference against the average for all the other hauls as described in Figure 9.4, page 281, above. However, prior to this, there were two additional hurdles.

Firstly, so far all the analysis has been conducted on the normal, untransformed dataset. However as Figure K.4 shows (which shows a plot of the residuals against the predicted values of the regression plotted in Figure K.3) there may be a good reason to conduct a transformation, or at least explore the increased possibility in the data that transformations would afford. Secondly, the regression for the raised weight in the sample to the haul composition must be significant and valid. Transformation of the data may help in this situation.

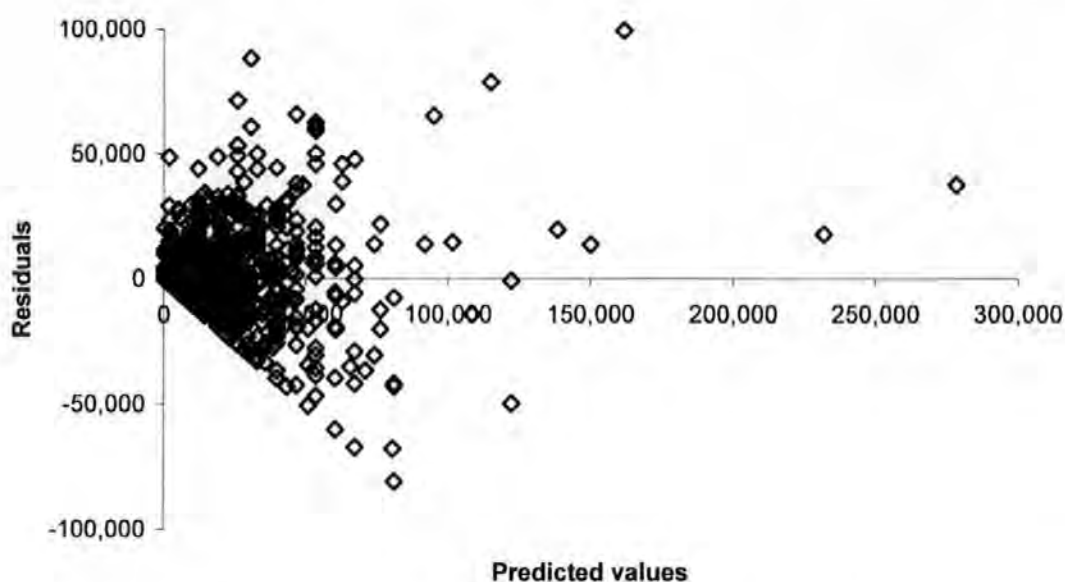


Figure K.4. Residuals of the linear regression shown in Figure K.3 against the predicted values, $n = 1,047$.

The plot of residuals against predicted values in Figure K.3 does not have the typical “band” of uniform width that would be expected. Instead, the variance of the residuals increased with the predicted values. The cone-shaped nature of the cloud on Figure K.4 is more pronounced when ignoring the values towards the larger predicted values of Figure K.1. One of the assumptions of regression is that there is the same variation in y for all values of x , (Dytham, 1999, p164; Zar, 1999, p332-333, 353), and it appears that this is violated in Figure K.4. Additionally, there are a number of particularly large residuals (outliers), which were values that the model has either over or under estimated. Seber, (1977, p165) described a procedure to reject the most extreme residuals. The essence of his method is to reject values where the residual is more than three times the x -value (in this case the haul composition) provided $n > 20$. Seber, (1977) also describes the empirical solution to this problem. Figure K.5 shows a frequency histogram of the residuals divided by the haul composition weights.

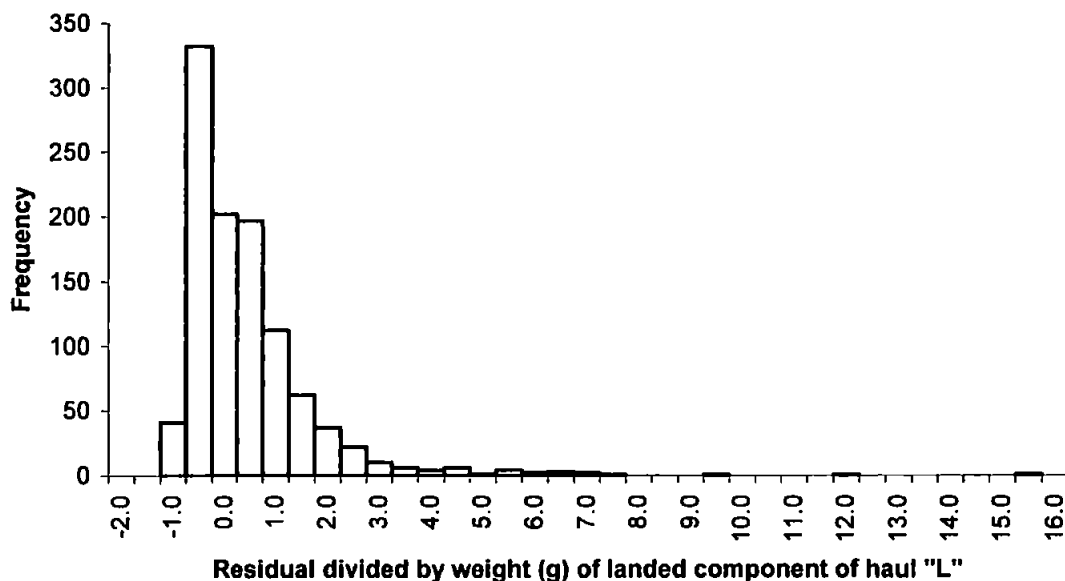


Figure K.5. Frequency histogram of residuals divided by weight of landed component of haul “L”, $n = 1,047$. Note that the bin size is 0.5 and the label represents the upper level of each bin.

Figure K.5 shows an extremely right skewed ($g_1 = 3.863$) distribution and it is in this skewed portion where the outliers lie, though only $n = 42$ of the values ($n = 1,047$) fall outside the range (≥ 3) suggested by Seber, (1977), thus fall into the category of being outliers according to this definition. This equates to $\sim 4\%$ of the residuals being classed as true outliers. While so described these were retained in the data set because removing them at this stage may prejudice the significance of the regressions haul by haul against the average. Nevertheless, the skew in Figure K.5 suggests the increase in variance with increasing weight in the haul composition “L” both suggest a transformation of the data should be undertaken.

Figure K.6 shows a double $\log_{10}(+1)$ transformation of the larger ($n = 1,047$) data set.

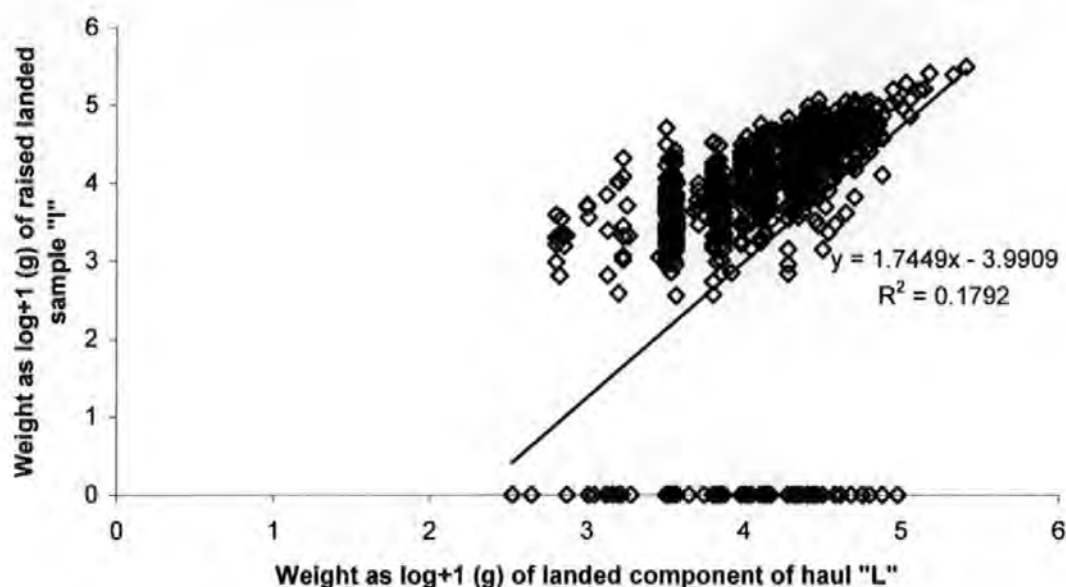


Figure K.6. Double log (+1) transformed raised sample weight against haul weight, $n = 1,047$.

Figure K.6 shows that the removal of the 270 points where $y = 0$ (occurrence of species in the haul but not corresponding in the sample) was necessary before a transformation could be undertaken. This is an unfortunate disadvantage as there was no reason to presuppose these data points were any more “incorrect” than any other and they are real in every sense of the word and were not collected with any less degree of precision. Merely they are a product of the sampling estimation of the haul. However, for this analysis to be carried further it was necessary to exclude these data here, though non-parametric matrix analysis (contained within Chapter 9) allows these data, as well as the other data removed here to be retained.

K.3 Transformation rationale

After removal of the $y = 0$ the benchmark was to produce a transformation which produces a better fit than produced with the non-transformed small ($n = 777$) data set (Figure K.7)

and less alteration in variance with increase in the predicted values than shown in Figure K.8.

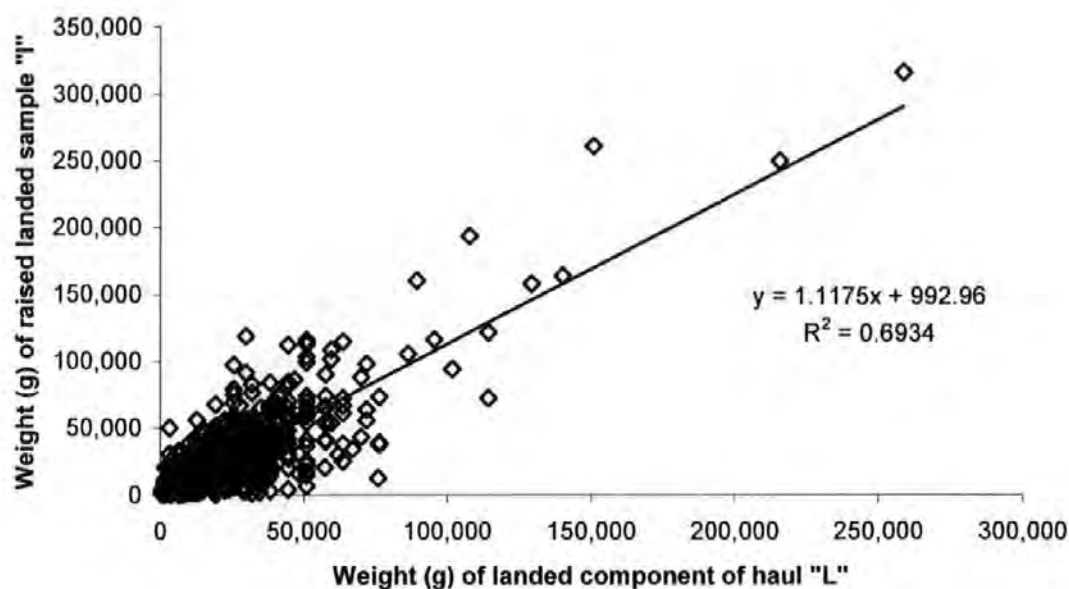


Figure K.7. Weight of raised landed sample "I" against weight of landed component of haul "L" for all positive values, $n = 777$. The regression equation and fit is shown on the figure.

The fit is better in Figure K.7 than Figure K.8 (below) due to the removal of the points at $y = 0$.

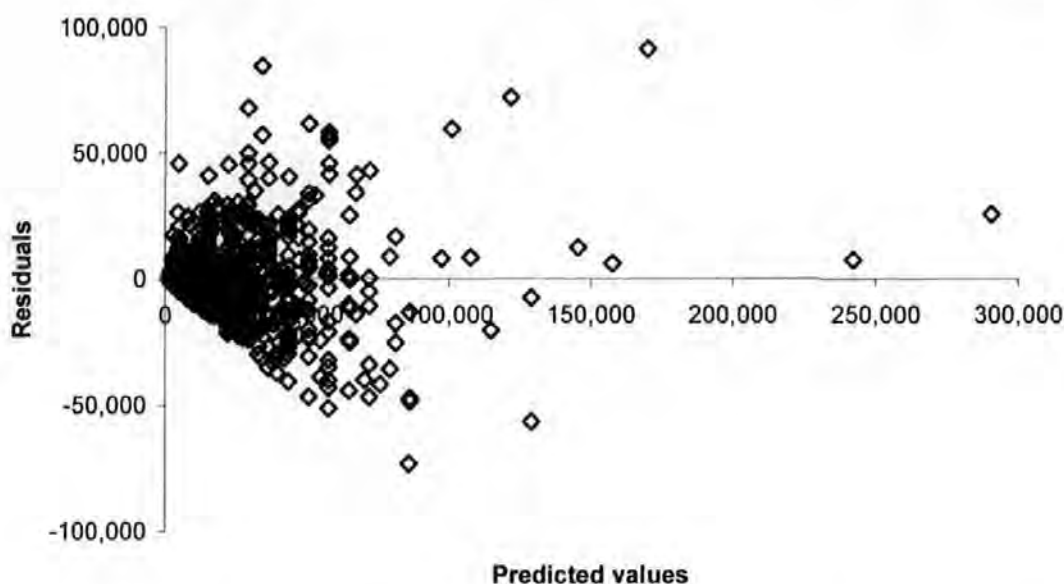


Figure K.8. Residuals of a linear regression against the predicted values $n = 777$.

Although the axes scales of Figure K.4 and Figure K.8 are the same the differences between these two plots are subtle though evident.

K.4 Initial examination: weighted least squares

Two types of transformation were undertaken. As pointed out by Seber, (1977, p178) “...in choosing between linearizing the regression and stabilizing the variance the first usually has preference.” The original data possessed a reasonably strong linear relationship, $R^2 = 0.6934$ so firstly, an alternative regression (weighted least squares) which maintains the original data was tried. While this alternative method of regression using the original data set could have retained the 270 points where $y = 0$ these are left out so that this method can be compared to the other methods employing data transformation.

The weighted least squares regression is appropriate where there is not homogeneity of variances. In this method, a common variance is produced based on each

separate value of the independent variable. SPSS (SPSS, 2003) generated a weight function according to the equation:

$$f(w) = \frac{1}{\text{var}^p}$$

where:

$f(w)$ = weight function.

var = weight variable (the independent variable).

p = power.

The process employed a range of values (-3 to 3, step 0.1) and produced a power value of 1.10. These weights were applied and the regression carried out. Table K.3 shows the regression results and Figure K.9 shows the residual plot.

Table K.3. Weighted least squares regression, see text for details. The regression equation is $\text{lan} = 2228 + 1.06 \text{ haul}$.

| predictor | coefficient | coefficient S.E. | T | P |
|----------------------|-------------|------------------|-------|---------|
| constant | 2227.7 | 379.1 | 5.88 | < 0.001 |
| haul | 1.056 | 0.034 | 30.68 | < 0.001 |
| S | 66.51 | | | |
| r ² | 0.548 | | | |
| r ² (adj) | 0.548 | | | |

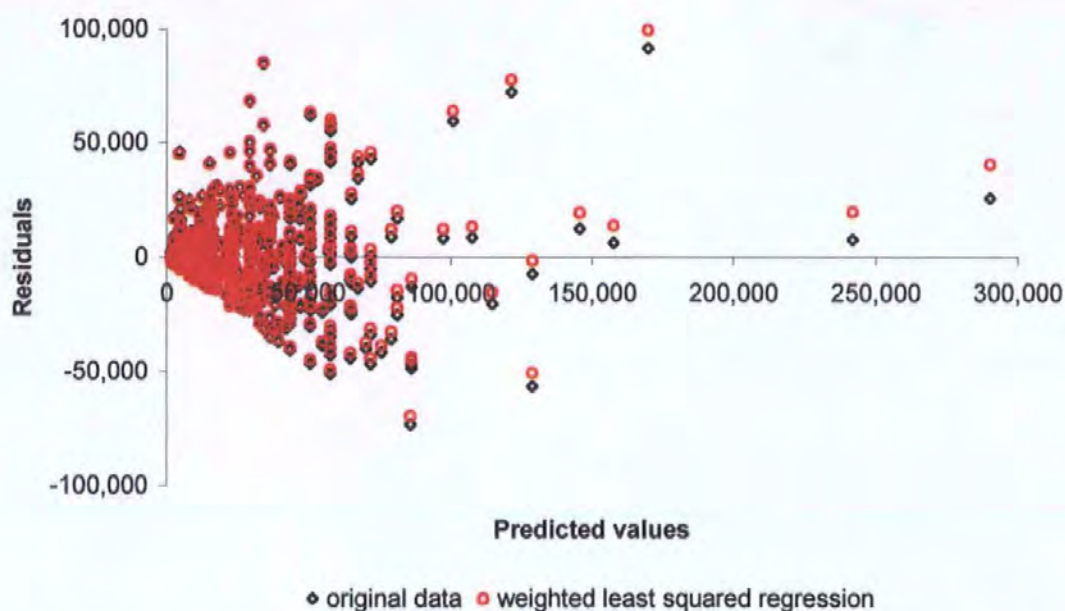


Figure K.9. Residuals against predicted values for original data and weighted least squared regression, $n = 777$ in both series. The data points are shown smaller in this figure than Figure K.4 and Figure K.8 for clarity.

The weighted least squared regression has a less good fit than the original data (according to the adjusted r^2 value in Table K.3) and the residuals plot (Figure K.9) was not greatly better. In fact, the weighted least squared regression has only apparently applied a slight rotation to the residual data.

The inability of the weighted least squares regression to satisfy the assumptions of the linear regression strongly suggest that a transformation must be applied and that for this analysis the data at $y = 0$ must not be included.

K.5 Generation of 'ideal' transformation

The most appropriate transformation for both the portion of the haul to be landed "L" and raised component of the sample "I" were calculated separately by a Box-Cox transformation (Sokal & Rohlf, 1981, p423-426 & 544) in Minitab (Minitab, 2000). Figure K.10 shows the output.

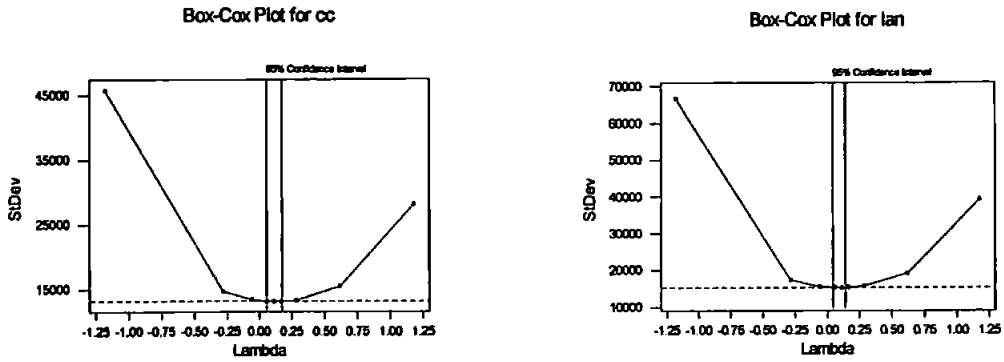


Figure K.10. Box-Cox plot for landed component of haul “L” (cc) [left] and raised landed sample “I” (lan) [right] for all positive values, based on $n = 777$ samples. For ‘cc’ last iteration info (λ then σ) low: 0.056, 13,100; best 0.113, 13,100; high 0.170, 13,100. For ‘lan’ last iteration info (λ then σ) low: 0.055, 15,300; best 0.112, 15,300; high 0.169, 15,300.

Figure K.10 shows that the best fit for lambda (λ) = 0.113 for the haul (cc) and for lan $\lambda = 0.112$. These are both quite close to zero. Choosing zero gives natural logarithms as the best transformation, though zero is outside the 95% confidence interval of the λ values. The data was transformed appropriate to the λ value for each axis according to the equation:

$$Z = \left(\frac{A^\lambda - 1}{\lambda} \right)$$

where:

A = the original data.

Z = transformed output.

λ = Box-Cox function.

The application of the Box-Cox transformation on both axes is not strictly correct, however. The Box-Cox transformation should only be applied to the dependent axis, although in this case it generates a severe deviation from linearity in the model as shown in Figure K.11.

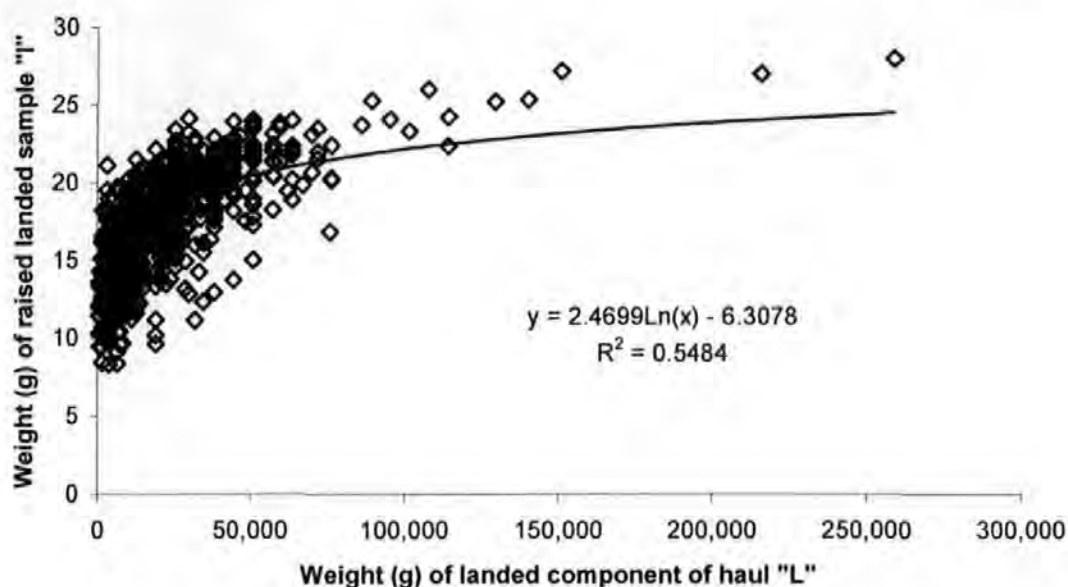


Figure K.11. Accurate depiction of the Box-Cox transformation, $n = 777$. Note that the fitted trend line is logarithmic.

The advantage of this method is that the transformation is correctly fitted according to the equation:

$$y = \left(\frac{x^\lambda - 1}{\lambda} \right)$$

where:

y = the dependent variable.

x = independent variable

λ = Box-Cox function.

However, the important disadvantage was that the comparison of regression lines (ANCOVA, described above on page 273) cannot be undertaken on non-linear regressions. Also, the true application of the Box-Cox transformation does not satisfy the assumption of the variance of the residuals not increasing with the predicted values as shown in Figure K.12.

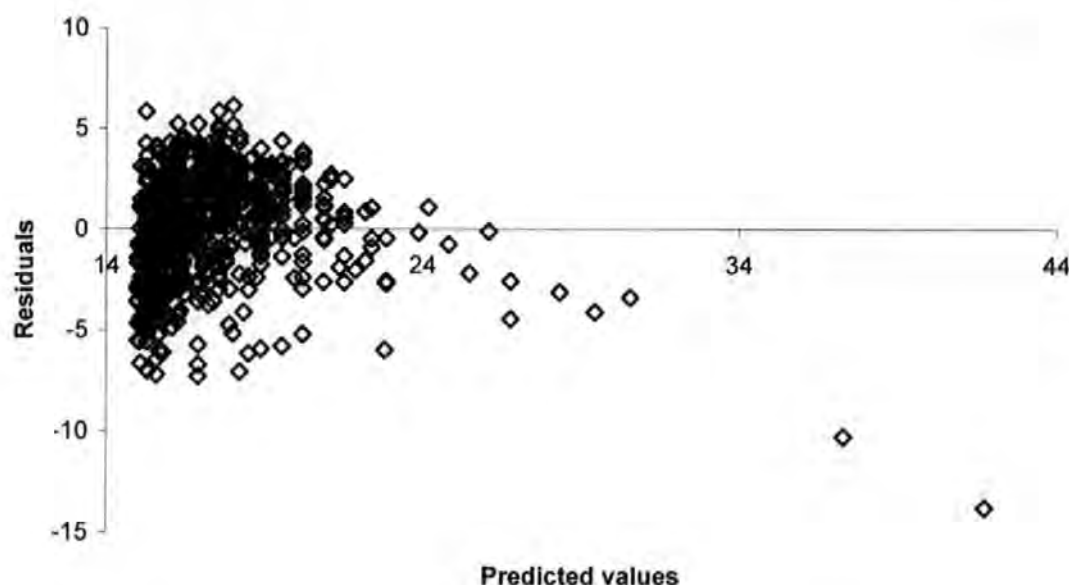


Figure K.12. Residuals against predicted values for the accurate depiction of the Box-Cox derived transformation, $n = 777$. This figure is derived from the regression as shown in Figure K.11.

The residuals plot based on the regression according to the Box-Cox transformation (Figure K.12) while no longer being cone-shaped shows a curvature of the densest part of the plot indicating an inadequate model, (Seber, 1977, p165).

K.6 Comparison of ‘ideal’ and other transformations

This application of the Box-Cox transformation was inappropriate though the double application of the transformation (while not a correct procedure) nevertheless illustrated the ideal transformation. As described above the 95% confidence intervals for λ are outside the value (zero) appropriate for employing the natural logarithm as a transformation function, (Sokal & Rohlf, 1981, p423-426). The alternative was to use

$\log_{10}(+1)$. These two transformations were tested against the ideal as described by the different λ value for each axis. Figure K.13 shows this graphically.

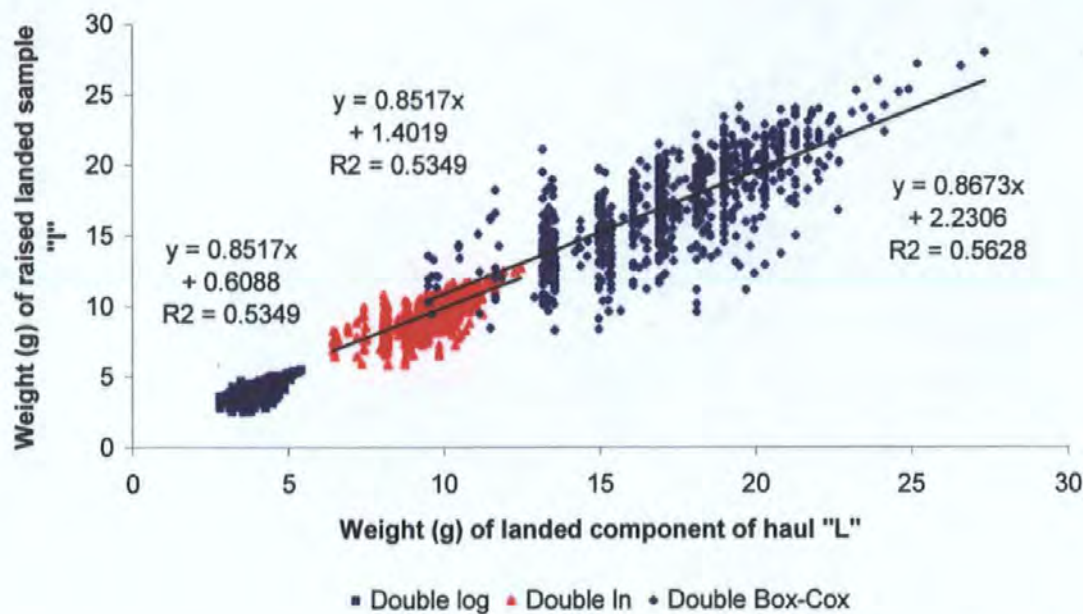


Figure K.13. Comparison of double \log_{10} , double natural log (ln) and double Box-Cox transformation for weight of raised landed sample “I” against weight of landed component of the haul “L”, $n = 777$ for each series.

The data points are shown smaller on this figure than on previous ones (e.g. Figure K.3 and Figure K.7) for clarity only. The slopes and intercept were compared (ANCOVA) to each other and Table K.4 shows the results.

Table K.4. Comparison of regression lines as slope and intercept (as shown in Figure K.3) for double Box-Cox, double \log_{10} and double natural logarithms.

| | comparison type | | |
|-----------|------------------------|---------------|-------------------|
| | Box-Cox to \log_{10} | Box-Cox to ln | \log_{10} to ln |
| P values | | | |
| intercept | < 0.001 | < 0.001 | < 0.001 |
| slope | 0.906 | 0.805 | > 0.999 |

Table K.4 is important in that it shows the best transformation is \log_{10} , as it is closest to the ideal according to the double Box-Cox. Figure K.14 shows the double \log_{10} transformed data.

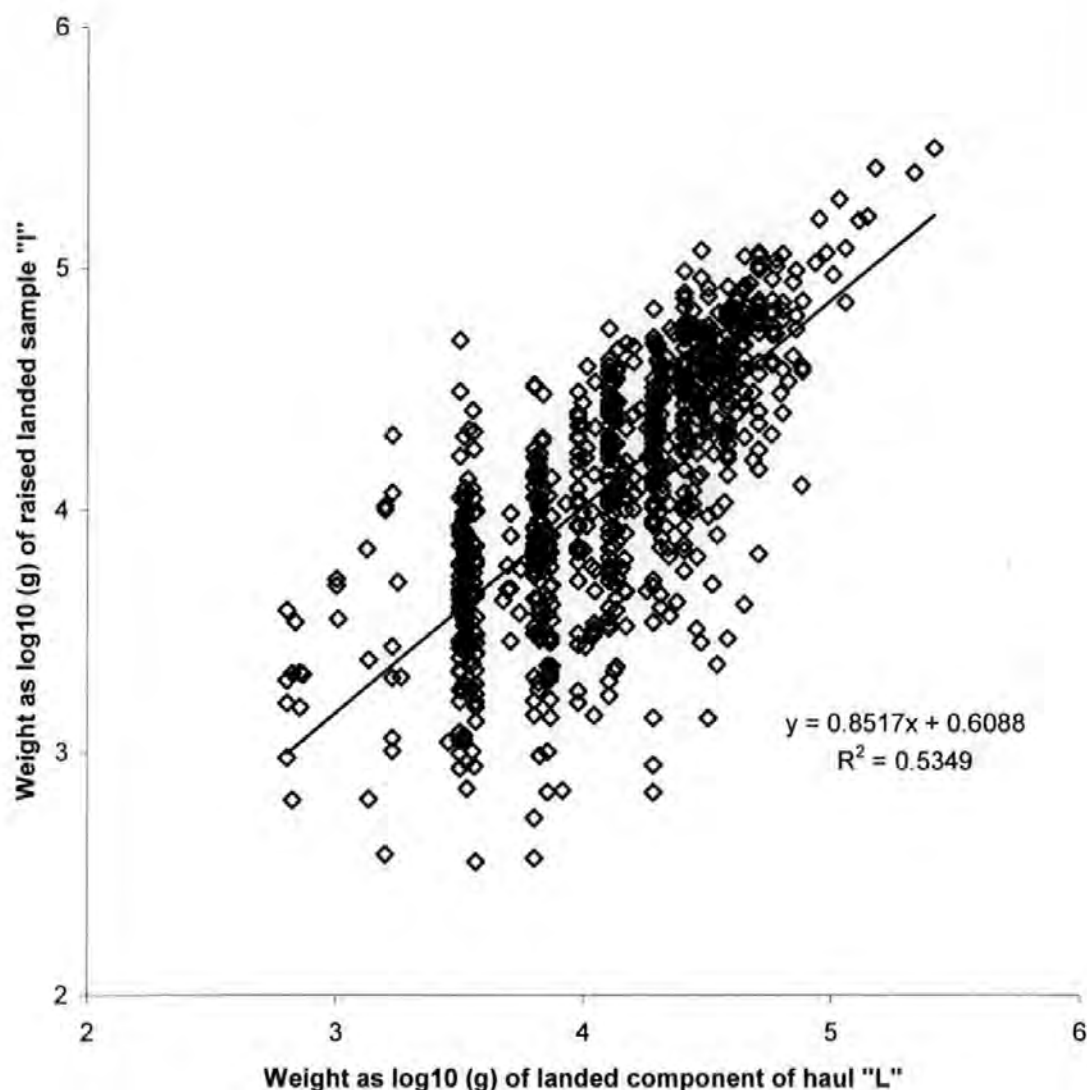


Figure K.14. Weight as log (g) of raised landed sample "I" against weight as log (g) of landed component of haul "L", $n = 777$.

The fit as shown in Figure K.14 was not as good as the untransformed data (Figure K.7, page, 409, above) but the variance problem was now largely resolved, as demonstrated in the plot (Figure K.15) of residuals against predicted values.

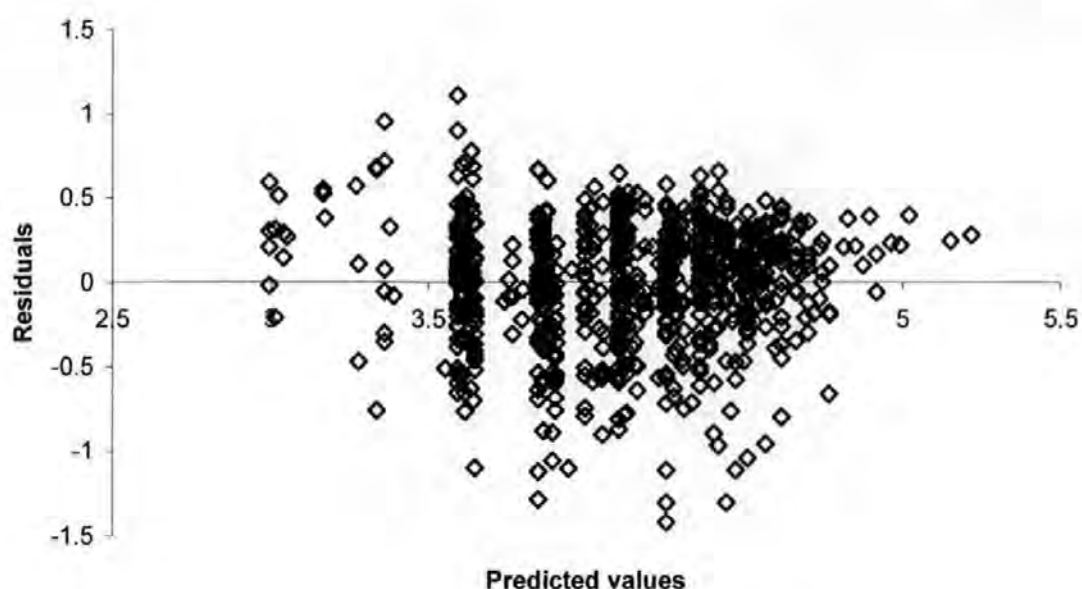


Figure K.15. Residuals against predicted values for the double log transformed regression of weight of raised sample “I” against weight of landed component of haul “L”, $n = 777$.

The majority of the data points in Figure K.15 approximate a band in the centre of the figure. Evident are slight “tails” to the data but these are comprised of relatively few data points.

The conclusion was to use the double $\log_{(10)}$ values, however this was formally assessed by examining the Durbin-Watson test statistic which measures autocorrelation, or assesses how random were the data. A value of 2 is the most ideal and Table K.5 shows the values and the difference from the ideal situation.

Table K.5. Comparison of Durbin-Watson test statistic, and differences from the ideal value of 2 for three data transformations and untransformed data.

| data transformation | Durbin-Watson test statistic | difference from “ideal” value |
|-------------------------|------------------------------|-------------------------------|
| double Box-Cox | 1.974 | 0.026 |
| double $\log_{(10)}$ | 1.969 | 0.031 |
| double natural log (ln) | 1.930 | 0.070 |
| untransformed data | 2.170 | 0.170 |

Table K.5 shows that while the double Box-Cox transformation yielded the best value as described above it was not strictly valid, and the double log transformation is most appropriate.

On both Figure K.14 and Figure K.15 (and other figures which show all or parts of the pooled haul data, such as Figure 9.4 and Figure 9.9 the presence of some of the data in vertical bands is evident. These bands were due to the haul composition “L” data falling into discrete categories according to the raising factor, see Figure K.16.

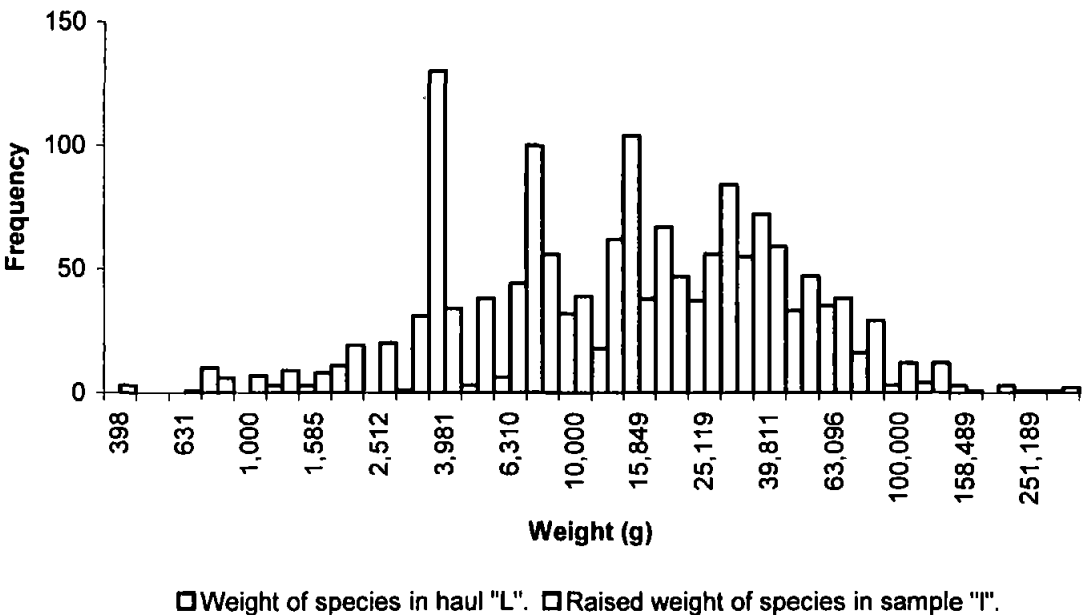


Figure K.16. Frequency histogram of weight in both weight of species in the haul and raised weight of species in the sample. The bin size is weight (g) as $0.1 \log_{(10)}$, converted back as 10^w for clarity in understanding the data. The label on the range is the upper level of each bin.

Both of the distributions in Figure K.16 were reasonably symmetrical, though Figure K.16 shows transformed values, and neither data set approximates a normal distribution; ($A^2 = 1.075$, $n = 30$, $P = 0.007$ for the log raised sample weights, and $A^2 = 3.333$, $n = 30$, $P < 0.001$) for the log weights in the haul according to the Anderson-Darling test. The raised sample weights are right skewed though not very much, $g_1 = 0.246$, though the weight of species in the haul is more so $g_1 = 1.547$. Also, the two raised sample weight is nearly as platykurtic ($\gamma_2 = -1.452$) in distribution as the haul weights are leptokurtic ($\gamma_2 = 1.347$).

The reason for the large steps in Figure K.16 (particularly apparent in “L”) was due to the presence of many similar values in the haul composition. Typically, these weights were half or one stone, which were more likely than a value of 0.49 or 0.51 stones, for example and came about because essentially these weights are estimates generated from the graduated fish basket.

Appendix L

L Raw Graphs

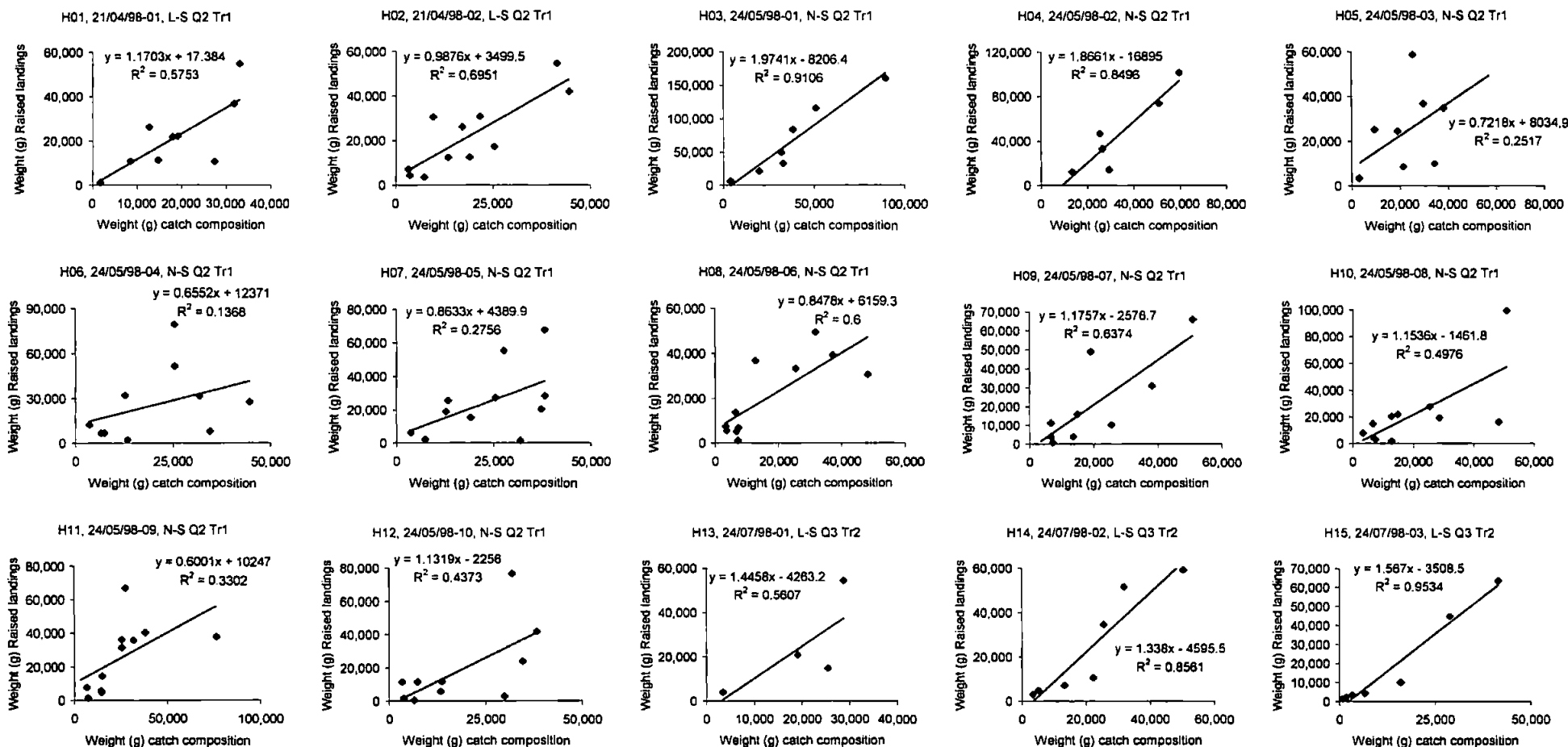


Figure L.1. Sequential plots of weight (g) of raised landed sample "I" against weight (g) of landed component of haul "L" showing all species present in both. Plots also show: date; haul within trip; port and type of trawling, (N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling); quarter of the year, and trip number (of times on particular boat).

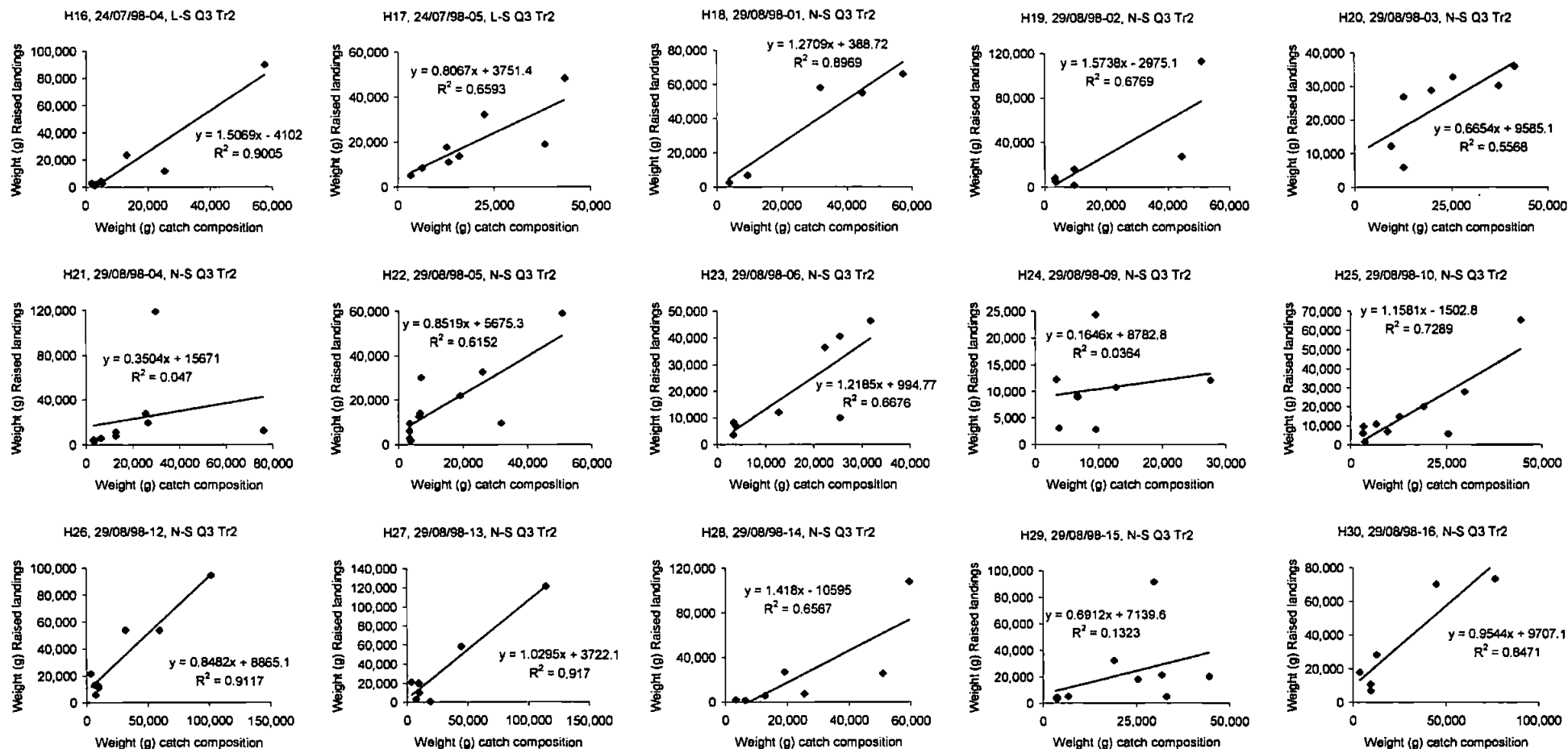


Figure L.2. Sequential plots of weight (g) of raised landed sample "I" against weight (g) of landed component of haul "L" showing all species present in both. Plots also show: date; haul within trip; port and type of trawling, (N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling); quarter of the year; and trip number (of times on particular boat).

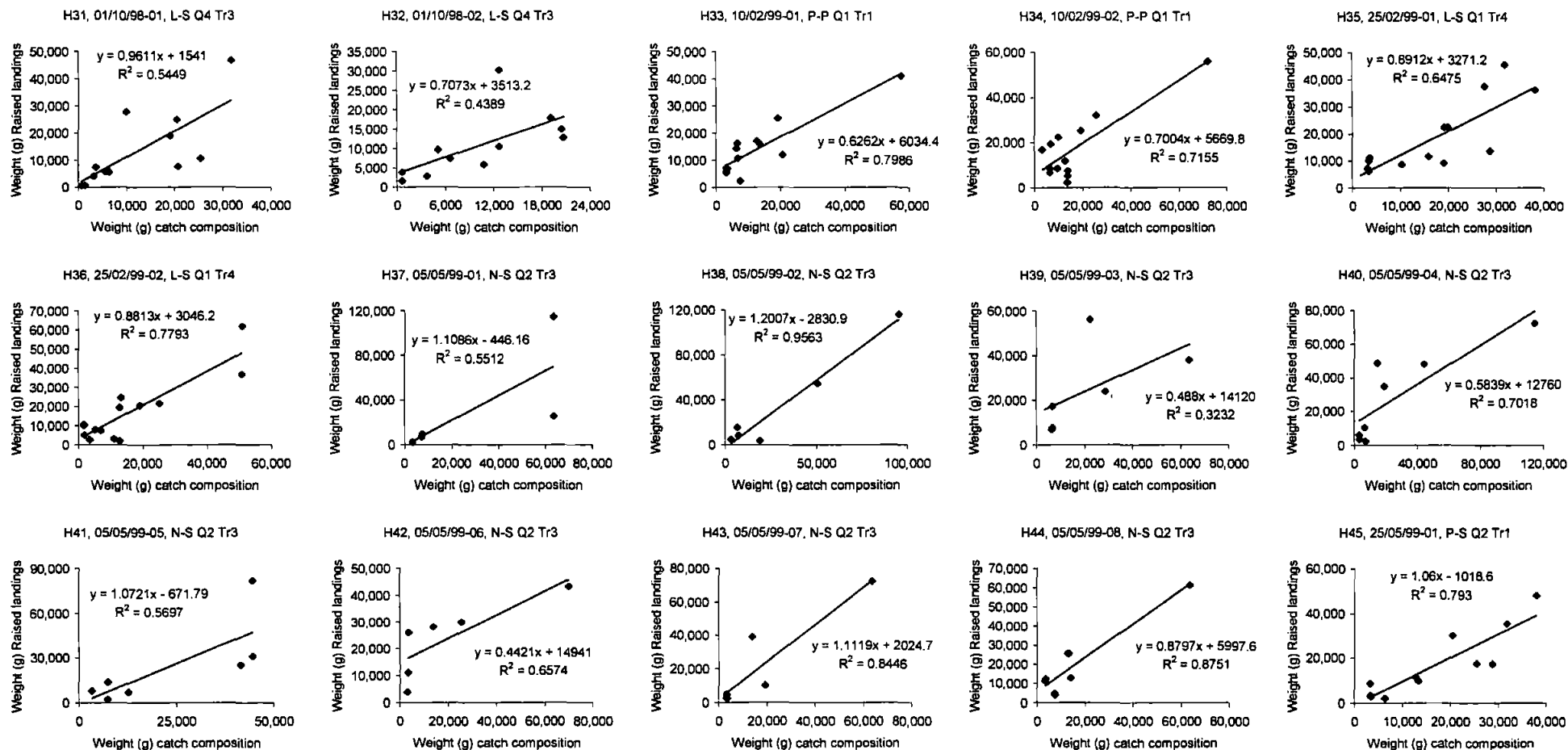


Figure L.3. Sequential plots of weight (g) of raised landed sample “I” against weight (g) of landed component of haul “L” showing all species present in both. Plots also show: date; haul within trip; port and type of trawling, (N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling); quarter of the year; and trip number (of times on particular boat).

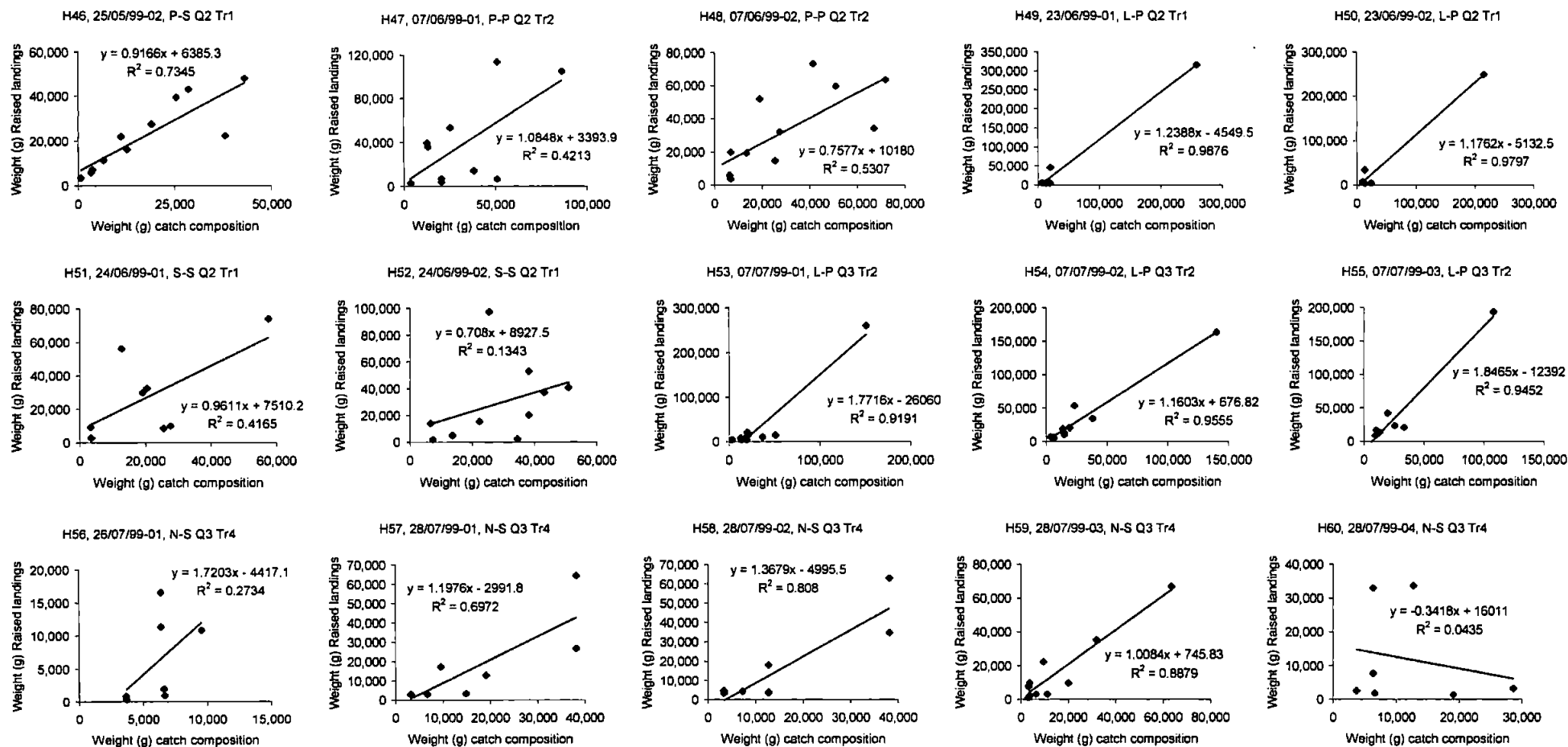


Figure L.4. Sequential plots of weight (g) of raised landed sample "I" against weight (g) of landed component of haul "L" showing all species present in both. Plots also show: date; haul within trip; port and type of trawling, (N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling); quarter of the year; and trip number (of times on particular boat).

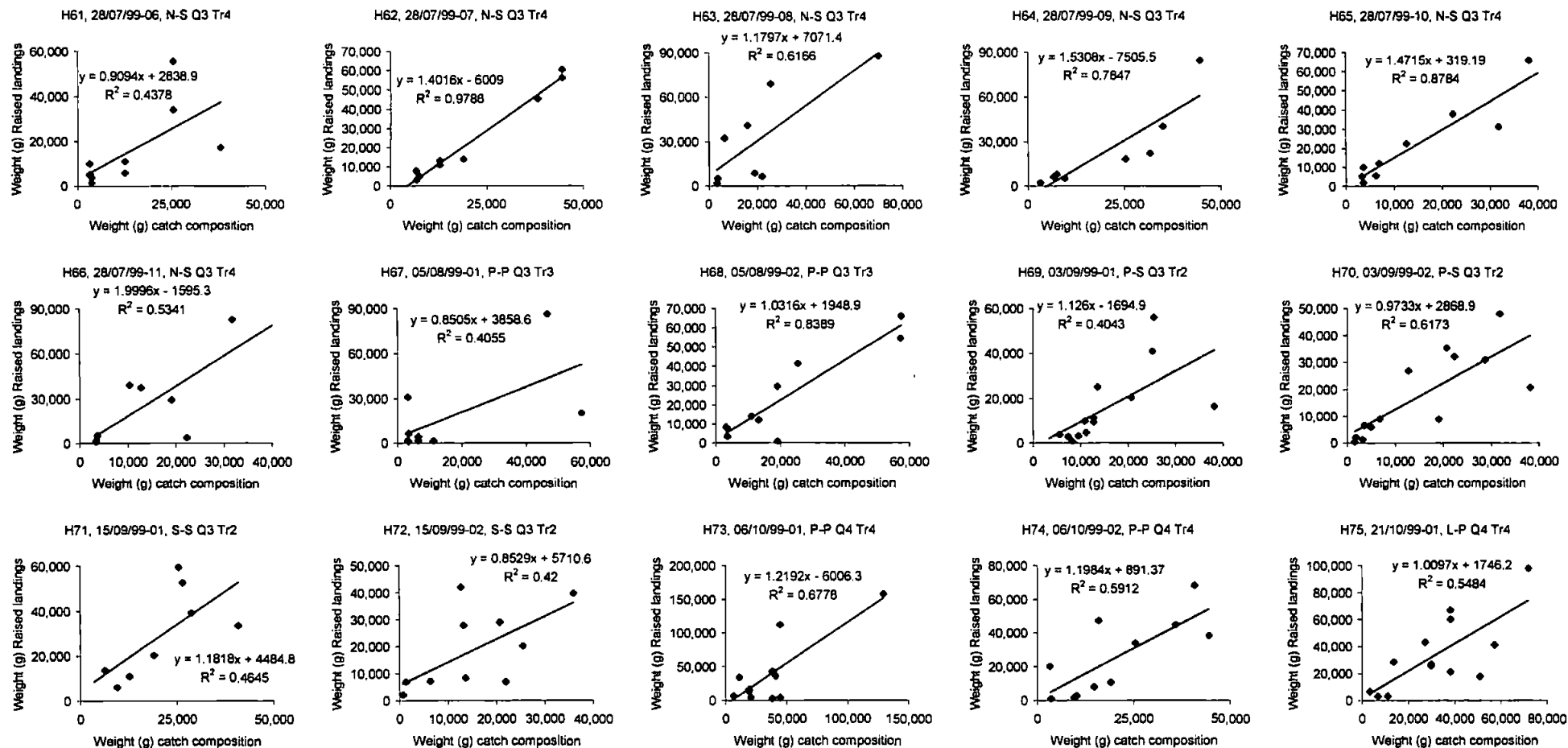


Figure L.5. Sequential plots of weight (g) of raised landed sample "I" against weight (g) of landed component of haul "L" showing all species present in both. Plots also show: date; haul within trip; port and type of trawling, (N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling); quarter of the year; and trip number (of times on particular boat).

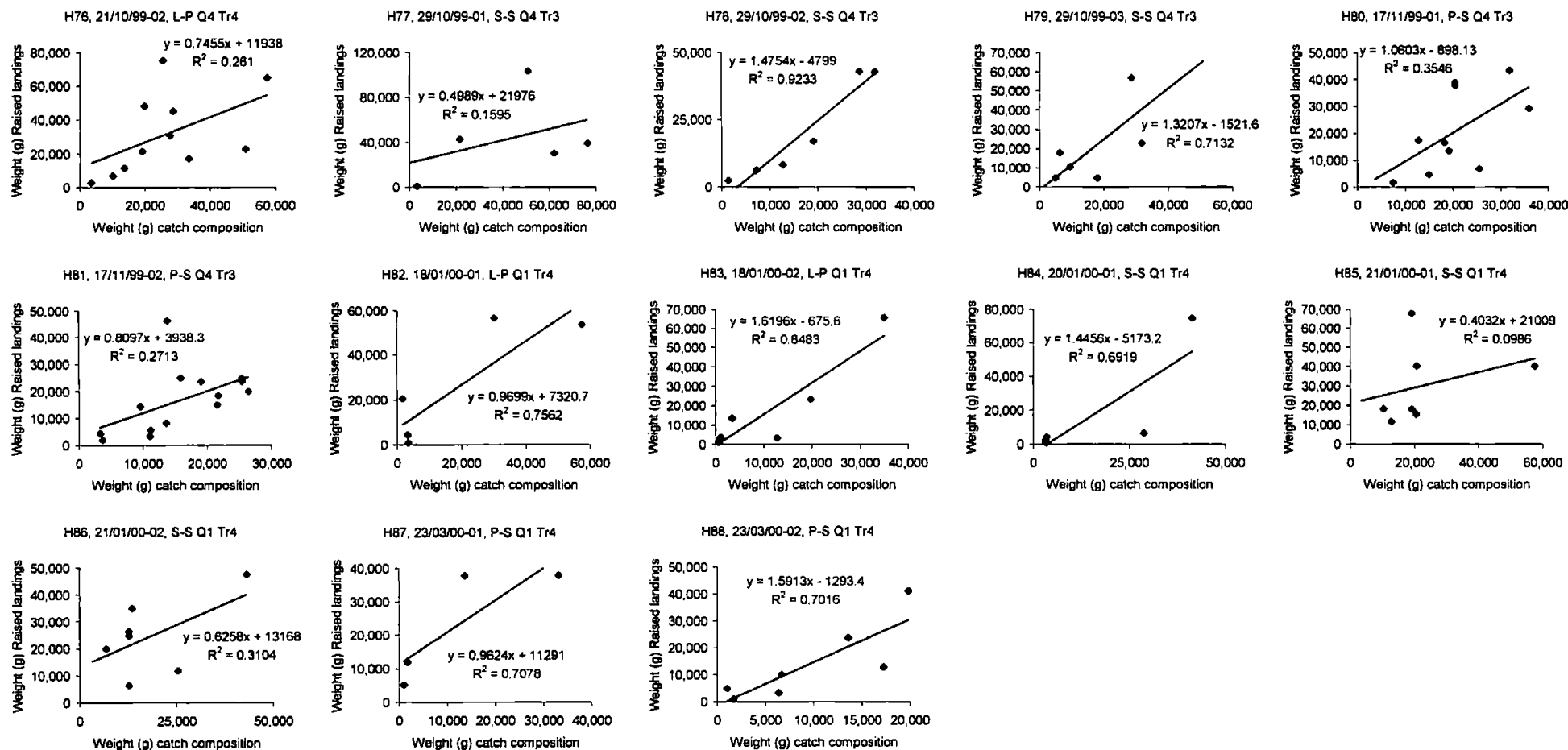


Figure L.6. Sequential plots of weight (g) of raised landed sample "I" against weight (g) of landed component of haul "L" showing all species present in both. Plots also show: date; haul within trip; port and type of trawling, (N- = Newlyn, L- = Looe, P- = Plymouth, S- = Salcombe; -S = single boat trawling, -P = pair boat trawling); quarter of the year; and trip number (of times on particular boat).

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