University of Plymouth

PEARL **https://pearl.plymouth.ac.uk**

04 University of Plymouth Research Theses 01 Research Theses Main Collection

2007

THE ECOLOGY AND CONSERVATION OF THE HARBOUR PORPOISE (PHOCOENA PHOCOENA) ALONG THE WEST COAST OF THE UK

GOODWIN, LISSA

http://hdl.handle.net/10026.1/1117

http://dx.doi.org/10.24382/4175
University of Plymouth

All content in PEARL is protected by copyright law. Author manuscripts are made available in accordance with publisher policies. Please cite only the published version using the details provided on the item record or document. In the absence of an open licence (e.g. Creative Commons), permissions for further reuse of content should be sought from the publisher or author.

store

THE ECOLOGY AND CONSERVATION OF THE HARBOUR PORPOISE (PHOCOENA PHOCOENA) ALONG THE WEST COAST OF THE UK

L. GOODWIN

Ph.D. 2007

90 0762539 0

REFERENCE USE ONLY

THE ECOLOGY AND CONSERVATION OF THE HARBOUR PORPOISE (*PHOCOENA PHOCOENA*) ALONG THE WEST COAST OF THE UK

by

LISSA GOODWIN

A thesis submitted to the University of Plymouth
in partial fulfillment for the degree of

DOCTOR OF PHILOSOPHY

School of Biological Sciences
Faculty of Science

July 2007

University of Plymouth
Library
Item no.
9007625390
Shelfmark
THESIS 639.9795 G00

This copy of the thesis has been supplied on condition that anyone who consults it is understood to recognise that its copyright rests with its author and that no quotation from the thesis and no information derived from it may be published without the author's prior consent.

The Ecology & Conservation of the Harbour Porpoise (*Phocoena phocoena*) along the West coast of the UK

Lissa Goodwin

Abstract

Whilst the harbour porpoise (*Phocoena phocoena*) is the most frequently observed cetacean in the UK, it is at risk from habitat degradation, pollution, incidental capture in fishing nets and anthropogenic disturbance. UK, European and International initiatives have highlighted the conservation need to obtain a better understanding of this species. This research, conducted over 5 years (1999-2004) aimed to further the scientific knowledge of the harbour porpoise in order to influence future conservation initiatives. Studies into the relative abundance, density, distribution, habitat use and behaviour were conducted through combinations of shore- and boat-based research. Technical trials of a towed acoustic device (T-POD) were also conducted from onboard the research vessel. Additional analysis of previously collected acoustic data from bottom-set gillnets was carried out. This research presents some of the first examination of the west coast for the harbour porpoise. Porpoise density was found to be exhibit significant inter-annual differences, with increases noted off West Scotland and a decrease observed for the South West. In the case of Northern Ireland these results are some of the first quantitative analysis of the harbour porpoise within the region. A statistically significant relationship with depth and in particular the 100m depth contour was also observed. The area off north Devon (Morte Point) is considered to offer an important feeding site for the species, where porpoises were found to aggregate in areas of high tidal flow. Site-specific differences in behaviour, group size and distance from shore were observed depending on time of day and tidal cycle. A full description of the ethology of the harbour porpoise is also given and the

potential affects of dolphin watching tourism assessed. Porpoises were observed to regularly engage in cooperative feeding and aerial activity, previously considered rare. The behaviours, as recorded from shore, differed considerably to those recorded from the boat. This highlights the need for precautionary management to increasing numbers of dolphin watching tour operators in UK waters. Acoustic detection of harbour porpoises around bottom-set gillnets revealed that porpoises are present around the nets on a 24 hour basis. This is highly significant in terms of bycatch mitigation as it indicates that porpoises are successfully avoiding entanglement for 99.75% of encounters. In terms of monitoring populations the T-POD was found to present a cheap and quick method which detected an additional 10% of all porpoise encounters which were not detected visually. The results presented here make a significant contribution to the scientific knowledge of the harbour porpoise, which will provide a basis for future research and conservation initiatives.

Contents

1.	Details of Figures	6-10
2.	Details of Tables	11-12
3.	Acknowledgements	13
4.	Author's Declaration and Word Count	14-22
5.	Introduction	23-47
6.	Chapter One: Relative Abundance, Density & Distribution of the Harbour Porpoise (*Phocoena phocoena*) along the West Coast of the UK	48-76
7.	Chapter Two: Diurnal and Tidal variations in Habitat Use of the Harbour Porpoise (*Phocoena phocoena*) in Southwest Britain	77-100
8.	Chapter Three: The behaviour of the harbour porpoise (*Phocoena phocoena*) and the need for precautionary management of cetacean-related tourism in the UK	101-124
9.	Chapter Four: Acoustic Monitoring of the Harbour Porpoise (*Phocoena phocoena*) around Bottom-set Gillnets in the Celtic Sea	125-142
10.	Chapter Five: Acoustic Detection of the Harbour Porpoise (*Phocoena phocoena*): Towing the T-POD	143-162
11.	Discussion	163-174
12.	Literature Cited	175-200

Figures

Chapter One: Relative Abundance, Density & Distribution of the Harbour Porpoise (*Phocoena Phocoena*) along the West Coast of the UK

1. Map of the UK showing the regions surveyed, South-West, Wales, Northern Ireland, West Scotland, North-West Scotland 61
2. Effort related survey tracks completed onboard the research vessel Forever Changes between May and August, 2002, for the west coast of the UK. 62
3. Effort related survey tracks completed onboard the research vessel Forever Changes between May and September, 2003, for the west coast of the UK. 63
4. Effort related survey tracks completed onboard the research vessel Forever Changes between May and September, 2004, for the west coast of the UK. 64
5. Location of observed harbour porpoise (*Phocoena phocoena*) groups during May – August, 2002. 65
6. Location of observed harbour porpoise (*Phocoena phocoena*) groups during May – September, 2003. 66
7. Location of observed harbour porpoise (*Phocoena phocoena*) groups during May – September, 2003. 67
8. Generalised additive model plot for the all years, 2002, 2003 and 2004 combined (Full GAM) for harbour porpoise presence in relation to sea surface temperature. 70
9. Generalised additive model plot for the all years, 2002, 2003 and 2004 combined (Full GAM) for harbour porpoise presence in 71

relation to depth.

Chapter Two: Diurnal and Tidal variations in Habitat Use of the Harbour Porpoise (*Phocoena phocoena*) in Southwest Britain

1. Study site, depicting Morte Point and Lee Bay. Reproduced from Ordnance Survey map data by permission of Ordnance Survey, © Crown copyright. 84

2. Morte Point. Reproduced from Ordnance Survey map data by permission of Ordnance Survey, © Crown copyright. 84

3. Lee Bay. Reproduced from Ordnance Survey map data by permission of Ordnance Survey, © Crown copyright. 85

4. Map, encompassing both sites: Morte Point (51° 11.290'N, o4° 13.559'W) and Lee Bay (51° 11.918'N, 04° 10764'W), North Devon, UK and position of all porpoise sightings. 90

5. Sightings per unit effort for each behavioural category observed (feeding, traveling, resting, social interactions, avoidance and other) during morning and afternoon watch periods in each tidal state at Morte Point. 91

6. Sightings per unit effort for each group size recorded, during morning and afternoon watch periods in each tidal state at Morte Point. 91

7. Sightings per unit effort observed in each band (distance from shore), during morning and afternoon watch periods in each tidal state at Morte Point. 92

8. Sightings per unit effort for each behavioural category observed 93

(feeding, traveling, resting, social interactions, avoidance and other) during morning and afternoon watch periods in each tidal state at Lee Bay.

9. Sightings per unit effort for each group size recorded, during morning and afternoon watch periods in each tidal state at Lee Bay. 94

10. Sightings per unit effort observed in each band (distance from shore), during morning and afternoon watch periods in each tidal state at Lee Bay. 94

11. Percentage time observed within each behavioural category (feeding, traveling, resting, social interactions, avoidance and other) at each of the study sites, Morte Point and Lee Bay. 95

12. Number of times observations of each group size were made for each of the study sites Morte Point and Lee Bay. 96

Chapter Three: The behaviour of the harbour porpoise (*Phocoena phocoena*) and the need for precautionary management of cetacean-related tourism in the UK

1. Map of UK indicating the areas covered by both the shore based surveys from Morte Point (2001) and Lee Bay (2002), highlighted in the inset and line transects covered as part of the boat surveys during 2002-2004. 108

2. Distribution of minimum group size estimates made for all surveys. 114

3. Average group size observed for each behavioural category 114

(feeding, travelling, resting, social interactions, avoidance and other) in relation to each of the study sites (Mort Point, Lee Bay and the Boat).

4. Average percentage of time observed engaged in each behavioural category per hour for records made at both the shore-based and boat-based stations. 115

Chapter Four: Acoustic Monitoring of the Harbour Porpoise (*Phocoena phocoena*) around Bottom-set Gillnets in the Celtic Sea.

1. Number of POD deployments recorded per vessel involved in the study (Ar Bag, Ben Loyal, BMC, CRS, Sharon Corinna, Cork, Excellent, Girl Patricia & Nova Spero relate to vessel names). 134

2. Deployment and fishing effort locations in the Celtic Sea, between October, 1999 and March 2000. 135

3. Average number of minutes with clicks, for each vessel used in deployments (Ar Bag, Ben Loyal, Excellent, Nova Spero, Cork, CKS, BMC, Sharon Corrina, Girl Patricia) across 24 hours. 135

4. Pod deployment/fishing effort in relation to month between October, 1999 and March, 2000, for the Celtic Sea gill netters. 136

5. Average number of minutes with clicks for each month surveyed in deployments from vessels (Ar Bag, Ben Loyal, Excellent, Nova Spero, Cork, CKS, BMC, Sharon Corrina, Girl Patricia). 136

6. POD deployment time in relation to hour, across a 24 hour time period, for the entire study period, October 1999 – March, 2000. 137

7. Average number of click positive minutes for the harbour porpoise throughout the day and night. 137

8. Average click rate per hour for the harbour porpoise throughout the day and night. 138

Chapter Five: Acoustic Detection of the Harbour Porpoise (*Phocoena phocoena*): Towing the T-POD.

1. T-POD software display showing two hours of interval counts from one channel. 148

2. 2002 T-POD showing the buoyancy tube and diving fins as fitted to the outer casing. 152

3. Schematic diagram of T-POD under towing conditions, from a side profile. 152

4. Mean (± s.e.) number of clicks recorded in each category i.e. On(Sonar & Engine), Sonar on(Engine Off), Engine on(Sonar Off), Off(Sonar & Engine), whilst towing the T-POD, during 2002. 155

5. The distance at which boats were recorded for both visual and acoustic surveys, during July & August, 2003. 156

6. The distance at which porpoises were recorded for both visual and acoustic surveys during July & August, 2003. 157

7. The estimated distance for the group size variance recorded in both the visual and acoustic surveys, during 2003. 158

Tables

Chapter One: Relative Abundance, Density & Distribution of the Harbour Porpoise (*Phocoena Phocoena*) along the West Coast of the UK

1. Relative abundance estimates (number of porpoises per 100km) and coefficient of variation (CV) for each sub area sampled during 2002, 2003 and 2004. 68

2. ANOVA testing for annual differences in the number of porpoises per 100km (porpoise density) for each sub area sampled during 2002, 2003 and 2004. 68

3. DISTANCE Analysis for 2004. Estimated population size (N), density (D), with upper (UCI) and lower confidence intervals (LCI) for population size and the coefficient of variation (CV) for each region. 68

4. Results of generalised additive models of presence/absence of harbour porpoises, including model significance and percentage of overall deviance explained. Full: data for 2002, 2003 and 2004 combined. 69

5. Contribution and significance (p) of environmental predictor variables for overall and yearly generalised additive models. Full: data for 2002, 2003 and 2004 combined. 70

Chapter Three: The behaviour of the harbour porpoise (*Phocoena phocoena*) and the need for precautionary management of cetacean-related tourism in the UK

1. Behavioural categories and definitions used in all observational recordings. 112

Chapter Four: Acoustic monitoring of the Harbour Porpoise (*Phocoena phocoena*) around Bottom-set Gillnets in the Celtic Sea.

1. Number of clicks recorded for each of the modal click categories used in classification. 132

Acknowledgements

MER Consultants Ltd, in particular Colin Speedie and Louise Johnson for allowing me to conduct my research from their yacht, for their constant support, advice and much laughter.

Nick Tregenza, for his invaluable support, knowledge and advice throughout.

Dr Graham Pierce, University of Aberdeen for his invaluable advice and comments.

Dr Paul Hewson, University of Plymouth for statistical advice.

Dr Pete Cotton, University of Plymouth, my supervisor.

Dr Simon Northridge, SMRU (Sea Mammal Research Unit) St Andrews, for allowing me access to the Celtic Sea Proto-POD data.

Paul Barbery and Mark of Osprey Charters for their assistance in T-POD deployment and initial towing trials.

Luke Young, Shapes in Plymouth, for his assistance in the design and production of a towing board for the T-POD.

Finally I would like to thank all the volunteers who took part in the boat-based surveys and aided data collection, and to many members of my family and friends for their endless support and love throughout.

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.

Although some chapters have been completed with support from, or in collaboration with Nick Tregenza, Colin Speedie, MER Consultants Ltd (Marine Environmental Research) & Simon Northridge, SMRU (Sea mammal Research Unit), the work presented is principally that of the author.

A postgraduate course in research methods was undertaken during the first year of study, which included research skills, research methods, lab-based teaching methods & practice, ecology & conservation, environmental law & ethics and science & the environment.

Relevant scientific conferences and workshops were regularly attended, at which work was often presented. A variety of talks have been given to the scientific community, marine societies, non-government organisations, schools and members of the public. A list follows which details a) conferences, workshops and meetings attended, b) talks, workshops and courses given and c) publications.

Word count of main body of thesis: 36,147

Signed..... Date..30/07/07.....

Conferences, Workshops & Meetings attended:

- Cetacean Bycatch Meeting with European Fisheries & Maritime Affairs Minister, Joe Borg, European Parliament, Strasbourg, France, July, 2007.
- The 21st European Cetacean Society Conference, San Sebastian, Spain, April, 2007.
- ASCOBANS/ECS Workshop - Selection Criteria for Marine Protected Areas for Cetaceans, San Sebastian, Spain, April, 2007.
- ASCOBANS/ECS Workshop - Wind Farms and Marine Mammals, San Sebastian, Spain, April, 2007.
- The 14th Meeting of the Advisory Committee to ASCOBANS (Agreement on the Conservation of Small Cetaceans of the Baltic and North Sea), San Sebastian, Spain, April, 2007.
- British Divers Marine Life Rescue (BDMLR) Coordinators Meeting, London, November, 2006.
- Cetacean & Fisheries Stakeholder Group, Bristol, October, 2006.
- The 5th Meeting of Parties to ASCOBANS, Egmond aan Zee, The Netherlands, September, 2006.
- DEFRA, The Future of Sea Fisheries Committee's, Meeting, London, August, 2006.
- ASCOBANS MOP Pre-Meet, Bristol, August, 2006.
- Cetacean & Fisheries Stakeholder Group, London, July, 2006.
- DEFRA - Marine Bill Forum, London, May, 2006.

- Wildlife & Countryside Link: Bycatch Group, London, Meeting with Fisheries Minister Ben Bradshaw, May, 2006.
- The 13th Meeting of the Advisory Committee to ASCOBANS (Agreement on the Conservation of Small Cetaceans of the Baltic and North Sea), Tampere, Finland, April, 2006.
- ASCOBANS Pre-Meeting, Bristol, April, 2006.
- The 20th European Cetacean Society Conference, Gydnia, Poland, April, 2006.
- The Wildlife Trusts', Public Understanding of the Marine Environment – Working Group, London, March 2006.
- Invest in Fish, Environmental Group Meeting, Exeter, March 2006.
- Wildlife & Countryside Link: Bycatch Group, London, February 2006.
- Volunteer Strandings Forum, Cornwall Wildlife Trust, Truro, February, 2006.
- DEFRA/Wildlife & Countryside Link Strandings Review Meeting, Bristol, February, 2006.
- Coastal Futures 2006 Conference, London, January 2006.
- Wildlife & Countryside Link, Parliamentary Reception, London, November, 2005.
- Marine Institute, Ireland, Project Evaluation Meeting, November 2005.
- ASCOBANS Strategy Meeting, London, October 2005.
- Marine Bill Conference, London, October 2005.
- Wildlife & Countryside Link: Bycatch Group, London, October 2005
- DEFRA Marine Bill Forum, London, September 2005.

- The 7th Meeting of the Turtle and Cetacean Bio-diversity Action Plan: Fisheries Sub Group, Bristol, September, 2005.
- The Wildlife Trusts', Public Understanding of the Marine Environment – Working Group, London, July 2005.
- Wildlife & Countryside Link: Bycatch Group, London, May 2005.
- The 12th Meeting of the Advisory Committee to ASCOBANS (Agreement on the Conservation of Small Cetaceans of the Baltic and North Sea), Brest, France, April, 2005.
- The 6th Meeting of the Turtle and Cetacean Bio-diversity Action Plan: Fisheries Sub Group, Plymouth, January, 2005.
- The Wildlife Trusts' Conference on Public Understanding of the Marine Environment, London, January, 2005.
- Wildlife & Countryside Link: Bycatch Group, London, November 2004.
- The Marine Workshop of The Wildlife Trusts', July, 2004, Plymouth, UK.
- The Joint Marine Partnership Workshop, The Wildlife Trusts & WWF-UK, July, 2004, Plymouth, UK.
- The 18th European Cetacean Society Conference, Kolmarden, Sweden, March, 2004.
- The European Cetacean Society Workshop: Estimating g(0) in Line Transect Surveys of Cetaceans, Kolmarden, Sweden, March, 2004.
- The 17th European Cetacean Society Conference, Las Palmas, Gran Canaria, March, 2003.
- The European Cetacean Society Workshop: Monitoring Cetacean Acoustics: the TPOD and IFAW Systems, Las Palmas, Gran Canaria, March, 2003.

- The 15th European Cetacean Society Conference, Rome, Italy, May 2001.

Talks, Workshops & Courses given:

- South West Dolphins – Barbican Theatre's Ocean Project Weekend, Plymouth, July, 2007.
- Marine Mammal Observer Course (MMO), University of Plymouth & Westland Geoprojects Ltd, May, 2007.
- Marine Mammal Observer Course (MMO), University of Plymouth & Westland Geoprojects Ltd, January, 2007.
- Cetaceans in Art, Marine - Art Symposium, Public Lecture, University of Plymouth, November 2005.
- Aquariums in Focus: The Argument Against Captivity, presented to National Academy for Gifted and Talented Youth, National Marine Aquarium, Plymouth, July, 2005.
- Dolphins in Close Up, an evening workshop open to members of the public, Saltash, Cornwall, March, 2005.
- Marine Mammal Workshop, given for members of the British Trust for Conservation Volunteers (BTCV) & Marine Conservation Society (MCS), held at the Marine Biological Association, Plymouth, February, 2005.
- Dolphins in Captivity: an ethical debate, Plymouth SCiBar, October, 2004.
- A Summer Sailing: The Harbour Porpoise Exposed. Marine Conservation Society talk, at the Marine Biological Association, Plymouth, April, 2004.
- Cool Water, Hot Wakes: A Summer of Dolphins & Sharks. Exploratory Biology Series, University of Plymouth, November, 2003.

- Porpoises: Distribution, Acoustics and the T-POD. Marine Biology & Ecology Research Group Seminar Series, University of Plymouth, November, 2003.

Publications & Submitted Manuscripts:

Goodwin, L. & Speedie, C., Relative Abundance and Distribution of the Harbour Porpoise (*Phocoena phocoena*) along the West Coast of the UK. *Journal of the Marine Biological Association of the UK* (In Review).

Compton, R.C., Dalebout, M.L., Wimmer, T., Øien, N., **Goodwin, L.** & Whitehead, H., Predicting key habitat and potential distribution of Northern Bottlenose Whales (*Hyperoodon ampullatus*) in the Northwest Atlantic Ocean. *Canadian Journal of Science* (Submitted).

Compton, R., **Goodwin, L.**, & Handy, R., (2007) A critical examination of worldwide guidelines for minimising the disturbance to marine mammals during seismic surveys. *Marine Policy* (In Press).

Goodwin, L. & Edwards, J. (2007) The South West Dolphin Report, A joint publication produced by *Marine Connection & The Wildlife Trusts.*

Goodwin, L. (2007) Response to DEFRA's Consultation on A Sea Change: White Paper Consultation on the Marine Bill. *Marine Connection, London.*

Goodwin, L. (2007) Response to DEFRA's Consultation on implementing the European Liability Directive. *Marine Connection, London.*

Goodwin, L. & Ross, A. (2007) Collection and provision of fishing effort data. *Document for ASCOBANS Meeting of Parties,* San Sebastian, Spain. Presented by Marine Connection & Whale and Dolphin Conservation Society.

Compton, R., Banks, A., **Goodwin, L.** & Hooker, S. (2007), Pilot cruise-ship based trans-Atlantic cetacean survey. *Journal of the Marine Biological Association of the UK,* Vol. 87, pp321-325.

Goodwin, L. (2006) Response to DEFRA's Consultation on Promoting an integrated approach to management of the coastal zone (ICZM) in England. *The Wildlife Trusts, UK.*

Goodwin, L. (2006) Response to DEFRA's Consultation on the Conservation (Natural Habitats, &c.) (Amendment) (England and Wales) Regulations 2006. *Marine Connection, London.*

Goodwin, L. (2006) Response to DEFRA's Consultation on Offshore Marine Conservation (Natural Habitats, &c.) Regulations 2006. *Marine Connection, London.*

Goodwin, L. (2006) Response to DEFRA's Consultation on the Marine Bill. *Marine Connection, London.*

Goodwin, L. (2006) Opportunities to Reduce Cetacean Bycatch in England within the Marine Bill. *Marine Connection, London.*

Goodwin, L. (2006) Marine Protected Areas. Internal Briefing Paper, *The Wildlife Trusts' UK.*

Goodwin, L. & Edwards, J. (2005) The Wildlife Trusts' Marine Conservation Programme. Public Awareness Leaflet, *The Wildlife Trusts', UK.*

Goodwin, L. (2005) Relative Abundance and Distribution of the Harbour Porpoise (*Phocoena phocoena*) along the West Coast of the UK. European Research on Cetaceans – 19. *Proceedings of the 19th Annual Conference of the European Cetacean Society*, La Rochelle. European Cetacean Society, Cambridge.

Goodwin, L. & Cotton, P. (2004) The Effects of Boats on the Behaviour of Bottlenose Dolphins (*Tursiops truncatus*). *Journal of Aquatic Mammals*, Vol 30(2) p279-283.

Goodwin, L. (2003) T-POD: A Self-Contained Cetacean Click Detector. *The Wildlife Trusts', UK.*

Goodwin, L., Tregenza, N., Speedie, C., Dennis, R. (2003) Do Orcas eat Basking Sharks? Occurrence Patterns of Large Marine Organisms off the Coast of Southwest Britain, between 1991 and 2002. European Research on Cetaceans – 17. *Proceedings of the 17th Annual Conference of the European Cetacean Society*, Las Palmas, Gran Canaria (Ed. P.G.H. Evans). European Cetacean Society, Cambridge.

Goodwin, L. (2002) Activity & Habitat Use of the Harbour Porpoise (*Phocoena phocoena*) in South West Britain. European Research on Cetaceans – 16. *Proceedings of the 16th Annual Conference of the European Cetacean Society*, Leige, Belgium (Ed. P.G.H. Evans). European Cetacean Society, Cambridge.

Goodwin, L. (2001) The Bottlenose Dolphins of Teignmouth: a pilot study. European Research on Cetaceans – 15. *Proceedings of the 15th Annual Conference of the European Cetacean Society*, Rome, Italy (Ed. P.G.H. Evans). European Cetacean Society, Cambridge.

Introduction

The phocoenids or porpoises are members of the odontocetes or toothed whales and consist of six species, including the harbour porpoise (*Phocoena phocoena*), vaquita (*Phocoena sinus*), finless porpoise (*Neophocaena phocaenoides*), burmeister's porpoise (*Phocoena spinipinnis*), spectacled porpoise (*Phocoena dioptrica*) and dall's porpoise (*Phocoenides dalli*). As a family group they can be found in many of the world's oceans, although individually they possess quite distinct ranges.

The harbour porpoise, on which this research focuses, may be considered the most widespread of all the Phocoenidae, inhabiting waters of the temperate northern hemisphere. The only other phocoenid species with a similar widespread distribution is the dall's porpoise, which is found throughout the northern Pacific, between the coasts of both eastern Europe and North America (Carwardine, 1995). The dall's porpoise is the largest of the Phocoenidae reaching 1.7-2.2m, 135-220kg, being mostly black, with a striking white patch on its side, whereas the harbour porpoise only reaches lengths of approximately 2m and weighs between 40-60kg (Gill & Gibson, 1997). At birth harbour porpoises are on average 65-70cm in length, weighing approximately 5kg (Lockyer, 1995). The maximum size for adult males is 163cm, 54kg, and for adult females, 189cm, 81kg (Lockyer, 1995). As adults they exhibit sexual dimorphism, with the female being both larger and heavier (Karakosta *et al*, 1999). They generally have a robust shape with small fins, which result in a low body surface area to volume ratio, which minimises heat loss (Kastelein *et al*, 1997; Read, 1999a). They possess a rounded head, and in colour they are a dark brown to dark grey, which lightens to a whitish colour on the belly (Gill & Gibson, 1997). In

addition, a number of tiny bumps or tubercles can be found on the leading edge of the dorsal fins, although their function is unknown (Read, 1999a).

Unlike the bottlenose dolphin (*Tursiops truncatus*), or indeed other small delphinids, photo-identification has not been possible for the harbour porpoise. Through the study of stranded individuals, Koopman & Gaskin, (1994) identified twelve characteristics which may vary individually, but are ultimately unique to each animal. These consist of variations in the pigmentation of each individual porpoise. This may include the presence of a ventral stripe, the shape of the cape, the shape and position of the junction, between the mouth and the line of shading, the colour of the flipper, or in chin patterns or the absence of an eye patch. Any number of these characters, with slight variations within each, makes any porpoise identifiable from another. It is not possible, however, to use these features to identify individuals in any field study. Not only do the animals spend a large proportion of time beneath the surface of the water (Westgate *et al*, 1995), but the majority of characters are found beneath the mid line of the porpoise, and so cannot be observed when the animal is in the water (Koopman & Gaskin, 1994).

Harbour porpoises have been recorded to reach 20 years and in exceptional cases beyond, however the majority of individuals probably fail to reach 10 years of age. Lockyer, (1995) recorded a maximum age of 24 years, whilst Gaskin *et al* (1984) and Read (1990) both failed to find any individuals beyond the age of 13, with few older than 8. Age of sexual maturity occurs at age 3-4 years, however as many young females fail to conceive in their first year or two of sexual maturity, the age at first pregnancy rises to 5-6 years (Read, 1990; Sorensen & Kinze, 1994; Addink *et al*,

1995). The gestation period in this species is approximately 1 year, however most female porpoises will not produce more than a few offspring in their lifetime (Read, 1990; Lockyer, 1995).

The harbour porpoise is usually observed in groups of between 1-3 individuals. On some occasions larger groups may be observed, although these are thought to function as feeding aggregations of many small groups, rather than larger cohesive units, as is observed in many other cetacean species (Hoek, 1992; Reid *et al*, 2003). It is not uncommon to encounter a single porpoise, or conversely in areas where population size is great, larger groups of 5-6 individuals.

The phocoenids share a number of common aspects in both their features and behaviour. All species lack the characteristic beak or rostrum that is observed in the delphinids and they tend to be small in size – among them some of the smallest cetaceans in the world. The acrobatic leap behaviour observed in many cetacean species is considered rare in the phocoenids (Amundin & Amundin, 1974). With the exception of the finless and dall's porpoise most phocoenids are considered shy of boats and have not been observed bow riding (Carwardine, 1995). Often all that is observed of the phocoenids is the dorsal fin (where present) and a small proportion of the back, which often makes them appear even smaller in size. Only the dall's porpoise produces a distinctive spray on surfacing to breath, all others may surface with minimal disturbance to the water surface. The blow of all phocoenids is rarely seen, but can clearly be heard, which has lead to harbour porpoises being referred to as "puffers" in the south west of England (personal communication), as the exhalation sounds like a short, sharp sneeze.

In total there are three major global populations of harbour porpoises, found in the North Pacific, North Atlantic and Black Sea. The Black Sea population, however, is considered completely separate, due to its presumed isolation (Carwardine, 1995). In the Pacific the northerly limit of distribution is thought to be the Mackenzie River Delta, North Alaska and Chukot Peninsula, Russia. Whilst the species is considered rare in Japanese waters, due presumably to historical exploitation, the harbour porpoise is found as far south as Monterey Bay, California (Northridge & Pilleri, 1986). In the Atlantic the northerly limits are the White Sea and the Greenland side of the Davis Strait to 70°N. The southerly limits are dictated by 34 °N to the west and Senegal and Cape Verde to the east (Northridge & Pilleri, 1986). It is generally restricted to temperate and sub-arctic seas of the northern hemisphere (Evans *et al*, 2003). Palka, (1995) found porpoises in waters ranging between 10 – 13.5°C this is however probably an average water temperature where they are found as much of the northern hemisphere waters can range on average from 0.5°C in the winter to 20°C during the summer months, demonstrating that they have a much wider temperature tolerance than is indicated above. Although, given their small body size and high energetic demand it is probably favourable for them to maintain distributions in waters in the upper end of this range.

Additionally, they are generally limited by their foraging and diving capabilities to the continental shelf (Read, 1999b). Westgate & Read (1998) recorded a maximum dive depth of 226m, although the majority of dives ranged from 20-130m. A few sightings have been made of them beyond this in offshore waters, where the water depth is considerably greater than their recorded dive ability. They have been observed in waters reaching a depth of 1502m off the coast of Scotland, on the Rockall and Faroe

Banks (MacLeod *et al*, 2003), although they are sighted only rarely in waters exceeding 200 metres (Evans *et al*, 2003). Despite the obvious limitation to continental shelf waters by their diving capabilities Read & Westgate (1997) found that porpoise home ranges were larger than had previously been thought. It is clear from their results that the harbour porpoises have the potential to utilise large areas of the sea for prey consumption, predator avoidance and social interaction. Researchers found that harbour porpoises from the Gulf of Maine, utilised most of the Gulf (ca. 50,000km^2), an area over 200 times larger than previously estimated. They also identified daily distance travelled, 13.9-28.1 km (with the exception of one, which covered 58.5 km) and a mean rate of travel of 0.6-2.3 kmh^{-1}.

Some porpoises were also found to spend periods from days to weeks in fairly restricted areas which are thought to be related to the distribution of prey (Read & Westgate, 1997). Where habitat heterogeneity, tidal currents, upwelling and subsequently plankton occur there will be high numbers of fish prey species which will subsequently attract numbers of piscivorous predators, such as the harbour porpoise (Zamon, 2003). The species is also known to utilise tidal conditions to aid foraging and prey capture. In 1997, Evans found that porpoises orientated themselves against strong tidal currents in Mousa Sound, Shetland, feeding two hours after high water. In Ramsey Sound, Pembrokeshire, Wales, the harbour porpoise feeds in a similar manner, utilising a benthic trench around a headline, throughout almost the entire ebb of the tide (Pierpoint *et al*, 2004). More recently researchers in the Bay of Fundy, Canada, also noted that porpoises actively forage in regions of enhanced relative velocity, tidal streams or island/headland wakes, in response to an increase in prey densities (Johnston *et al*, 2005). Observations in these areas of high productivity

have typically lead to large group sizes being recorded, as porpoises aggregate to take advantage of the conditions and possible abundance of prey (Pierpoint *et al*, 1994). It is not clear however whether these aggregations simply occur through attraction to the local conditions, or whether there is an element of social and/or co-operative feeding employed once together.

Harbour porpoises have a wide diet, which varies geographically, seasonally and also between sexes and/or age classes (Rae, 1965; Rogan & Berrow, 1996; Santos *et al*, 2004). Some of the very first studies on harbour porpoise diet in the eastern North Atlantic were carried out by Rae (1965, 1973) who found that herring (*Clupea harengus*), sprat (*Sprattus sprattus*) and whiting (*Merlangius merlangus*) were the main prey in Scotland between 1959-1971. Rae noted the inclusion of other species in the diet in other regions, such as the presence of cod (*Gadus callarias*), goby (*Aphya minuta*), sandeel (*Ammodytes sp.*) and crustaceans in a few, though at the time it was not known whether harbour porpoises were directly consuming crustacean species, or whether they represented prey of many of the fish species consumed. Later in 1996, Martin found that gadids (Gadidae), sandeels and gobies (Gobiidae) were the most important prey in UK waters. Rae had concluded that harbour porpoises consumed prey less than 25cm in length, which consisted of pelagic, as opposed to demersal species, though Santos & Pierce (2003) found that porpoises consumed both pelagic and demersal species, noting a dietary shift from clupeid fish to sandeels and gadoids, which was thought to be related to the decline in herring since the 1960's.

Santos *et al* (2004) found regional, seasonal and inter-annual difference in diet, which additionally varied with cause of death (i.e. bycaught, diseased individuals). Sandeels

were found to be the most important prey item during the summer months, with whiting becoming more important during winter months, all other fish species (i.e. herring, sprat, gobies, mackerel (*Scomber scombrus*) etc) were consumed year round. Additionally clupeids were found to be important in medium-sized porpoises whilst gobies were found to be important for the smallest of porpoises (less than 118cm in length, probably less than 1 year old). There is also the suggestion that decapod crustaceans are consumed by porpoise calves as they progress onto solid food, from 3-4 months old (Smith & Read, 1992; Santos *et al*, 2004).

This research would indicate that the porpoise diets have changed over the years. The harbour porpoise has previously been referred to as an opportunistic predator, (Recchia & Read, 1989; Santos & Pierce, 2003). By definition though, to be opportunistic would imply that the harbour porpoise is consuming prey as they are encountered, with the inference that prey availability is influencing diet selection (Santos & Pierce, 2003). Donovan & Bjørge (1995) however, note that the term opportunistic should not be applied to the harbour porpoise, as details concerning prey selection in this species are not known. A detailed analysis of porpoise variation in diet and fishery data would indicate whether or not porpoises are indeed specialist or generalist predators, however much of this type of data is lacking as much of the information on porpoise diet comes from examination of dead animals, found stranded on the beach. More recently however a study by MacLeod *et al* (2006) examined the consumption of sandeels by harbour porpoise in the Scottish North Sea. Results indicated that with a lower proportion of sandeels in the diet the likelihood of starvation was increased as porpoises failed to switch to alternative food sources. These results support a previous study by Evans *et al*, (1997) who found that changes

in harbour porpoise abundance were related to annual variation in sandeel populations. Sandeel spawning stock biomass declined markedly from 1984-92, when coastal summer porpoise populations also apparently declined. During 1993 and 1994, sandeel spawning stock biomass was relatively high and harbour porpoise abundance was also higher. This would indicate the possibility that porpoises are indeed specialist predators that could be seriously affected by either the consequence of climate change and/or over-fishing.

Harbour porpoises are small endotherms, which are suspected to have limited energy stores, losing a large proportion of energy through radiation and conduction (Kastelein *et al*, 1997). Their food consumption will however depend on a number of variables, including: blubber thickness, the insulative properties of the blubber (which may change depending on age, weight or environmental conditions), growth, metabolic rate, activity, diet, digestibility of food, season and reproductive state (Kastelein *et al*, 1997). As they cannot store much energy harbour porpoises are reliant on year-round proximity to food sources and may be more strongly correlated with the presence and distribution of their prey than other cetacean species (Brodie, 1995). Unsurprisingly, many of the areas where harbour porpoises are observed worldwide also support large aggregations of prey (Read & Westgate, 1997; Read, 1999b).

By contrast to diet and examination of stomach contents, relatively little research has been conducted into the behaviour of the harbour porpoise. Attempts to document the behavioural repertoire of the harbour porpoise have been hampered by the difficulty

of studying a small cetacean at sea, which spends little time at the surface, can be difficult to observe due to their small size and is inherently shy of boats.

The first dedicated study on harbour porpoise behaviour was conducted in 1974, by Amundin & Amundin, who made behavioural observations from a shore-based station. Their research details mother-calf interaction, meeting behaviour and leaping, fright reactions and resting. Although all notes are purely descriptive, it was the first study to consider the ethology of the harbour porpoise in any detail. In mother-infant interactions the pair were observed to regularly traverse the bay, where interactions ensued when other individuals approached the pair. Fright reactions were observed when vessels approached to within 100-200m, with speed boats producing a more pronounced and rapid response. A number of different leap behaviours were also noted, including high leaps, clean out of the water. This was considered of interest as the harbour porpoise was not normally considered to exhibit this behaviour except in captivity, under training. Amundin & Amundin (1974) were unable to state the purpose of these high leaps and concluded that further research was required. Pierpoint *et al* (1994) also describe leaping behaviour in harbour porpoises off west Wales in the UK. Here leaping seemed to occur during both foraging behaviour and in an apparent social context amongst individuals. Pierpoint *et al*, (1994) also described tail flip dives, where the porpoise rolls forward quickly, lifting the flukes and exposing the ventral surface on diving. In 1997, Evans made an ecological assessment of harbour porpoises in Shetland, North Scotland. This, once again produced little quantitative assessment, but described observed behaviours, which included transiting, foraging, milling, tail slapping, sexual behaviour, leaping and reaction to boats. Leaping was again, considered rare and no individual was observed to

completely exit the water, instead only the first two thirds were observed out of the water. Despite these studies into the behavioural categories utilised by the harbour porpoise, little focused behavioural research on wild populations has been published since.

With increasing interest in cetaceans the UK is facing a boom in eco-holidays and wildlife watching pursuits, as the nation becomes more environmentally aware. In west Scotland alone, cetacean-related activities were estimated to account for £7.8 million (Parsons *et al*, 2003) as people visit the area to see the whales and dolphins and subsequently spend additional money during their stay. Whilst this income and environmental awareness is perceived by many as a good thing, few take the time to consider the potential impact on small, elusive species such as the harbour porpoise, which is known to be shy of boats.

Whale and dolphin watching is one of the most rapidly growing forms of nature-based tourism in the world. The most recent estimate of the industry worldwide, found that tours are offered in 87 countries, worth an estimated US$ 1 billion (Constantine *et al*, 2004), yet researchers and conservationists alike have highlighted the possible detrimental effects of boat disturbance to cetaceans. Indeed studies on both spinner dolphin (*Stenella longirostris)* and spotted dolphin (*S. attenuata)* groups showed that in all cases the dolphins' response to boats were to move away from an approaching ship; responding even when the vessel was still on the horizon (Au & Perryman, 1982). Early responses to avoid an oncoming vessel have also been noted in many other species, including Arctic beluga whales, (*Delphinapterus leucas)* (Blane & Jackson, 1994; Richardson, 1995) and killer whales (*Orcinus orca)* (Kruse, 1991),

whilst fin whales (*Balaenoptera physalus)*, humpback whales (*Megaptera novaengeliae)* and sperm whales (*Physeter macrocephalus)*. Additionally, all demonstrated shorter surface periods and fewer blows in response to whale-watching craft (Notarbartolo di Sciara *et al*, 1996). Wells (1993) also reported a significant increase in the number of bottlenose dolphins using deep water channels when there were high levels of boat traffic. This habitat displacement was also found by Allen and Read (2000) who found differing habitat preference between two populations of bottlenose dolphin depending of levels of boat use throughout the week. A study by Evans *et al* (1994), conducted off the coast of Scotland has also shown the early avoidance response of harbour porpoises (*Phocoena phocoena)* in relation to approaching motor vessels.

There are locations however where cetaceans appear to tolerate, or are unaffected by, the presence of boats, which suggests that they have habituated to their presence. This has occurred in areas of relatively light boating traffic, or where particular vessels maintain a predictable course, such as passenger ferries (Shane, 1990; Janik & Thompson, 1996; Gregory & Rowden, 2001).

As dolphin watching trips proliferate many conservation groups and non-governmental organisations (NGOs) have now been forced to make the distinction between "responsible" and "irresponsible" operations. However, in the UK where no specific marine mammal legislation exists the difficulty lies in not only limiting the increasing number of operators but in educating them in responsible boat handling and managing the industry effectively. Whilst harbour porpoises are not necessarily ever going to be the focus of dolphin watching activities, due to their shy and elusive

nature, their coastal habituation places them at risk from anthropogenic disturbance as the number of recreational boats offering dolphin watching trips increase.

Within the UK, the harbour porpoise is the most frequently sighted (and stranded) cetacean, although sightings vary seasonally with region (Evans *et al*, 2003). The harbour porpoise is frequently observed around northwest and northeast Scotland, western Ireland, Wales and the southwest of England. Groups also occur in the North Sea and adjacent waters (Hammond *et al*, 2002; Evans *et al*, 2003; Evans & Wang, 2002; Reid *et al*, 2003) although numbers have decreased in the last thirty years (Evans *et al*, 2003). The results of the SCANS (Small Cetacean Abundance of the North Sea) survey, conducted in 1994 estimated a population of 341,366 porpoises (95% CI: 260,000-449,000) for the North Sea, Channel, and Baltic. Whereas within the Celtic Sea, the corresponding estimate was 36,280 (CV = 0.57). During this survey no porpoises were observed within the Channel. More recently, with SCANS II, a repeat (and extension to include the west coast of the UK) of the previous study, there appears to have been a distributional shift from the northern North Sea to the south (SCANS II), although reasons for this movement remain unknown (Hammond, & MacLeod, 2006). The total estimate for the whole survey area was 385,600 (CV = 0.20). Around the southwest of England collation of anecdotal recording would indicate that sighting numbers of the species have declined in the last 50 years (Tregenza, 1992). Yet since 1994, results of the SCANS II survey (conducted in July 2005) demonstrate that the summer harbour porpoise population in this region remains relatively constant (Hammond & MacLeod, 2006). It may be that harbour porpoises which previously were seen from shore have moved further off onto the

continental shelf as development of the coastal zone has increased in recent years, leading to a decrease in shore-based sightings for this region.

For both the North Sea and southwest England sighting rates peak between January and March, and peak again in late autumn (October – December) for the southwest. For the southeast of England sighting rates peak during April, whereas eastern England demonstrates peaks during August and September (Evans *et al*, 2003). In Scotland sightings peak between May to October, with peaks in August for the North, July or August for the East and July-September for the West of the region. In Wales there is little seasonal variation as porpoises are observed year round, a slight decrease in numbers during the winter months may be a result of reduced observation (Evans *et al*, 2003). As seasonal variations in sightings and numbers of individuals within and beyond 12 nm were similar with peak numbers occurring off the shelf in May and June - two months earlier than on the shelf, there has been some speculation that this offshore movement is related to calving (Evans *et al*, 2003). In UK waters calves are seen between February – September, with a peak in June (Evans, 1992). This would be indicative of a calving period from June to July as has been observed in other scientific studies (Sorensen & Kinze, 1994; Lockyer, 1995).

Whilst discussion of harbour porpoises around the UK have so far dealt with a single North Atlantic population there is some evidence to suggest that subpopulations may exist in the North Sea and adjacent waters, with possible separate populations occurring on the Celtic shelf and in both the northern and southern North Sea. Indeed morphological studies from stranded animals have demonstrated that harbour porpoises in the southwest of England posses a larger skull size and overall body size

to porpoises elsewhere in the UK. Genetic analyses of skeletal and dental samples also found significant differences between porpoises found in the North Sea and Celtic Shelf, as well as sub-divisions within the North Sea itself. Additionally the North Sea porpoises are different again from porpoises found in the Skagerrak, Kattegat, Inner Danish waters and the Baltic (Walton, 1997; Lockyer, 1999). These studies also demonstrate that females are more philopatric than males (Walton, 1997; Tolley *et al*, 1999). It is not only here in the UK that these subpopulations have been discovered, in North American waters haplotype differences have been found between Bay of Fundy, Gulf of Maine, Eastern North America and Newfoundland & Gulf of St Lawrence populations (Wang *et al*, 1996). Once again males were found to disperse more widely than females (Wang *et al*, 1996). The existence of subpopulations may have serious implications for the conservation of the species as it indicates that regional threats can have potentially devastating effects on the population as a whole.

Current research has seen advancements made in monitoring of cetacean populations, through the development of passive acoustic monitoring (PAM) devices. One such device, known as the Proto-POD (POrpoise Detector) has recently been superseded by the production of the T-POD (Jefferson *et al*, 2002; Tougaard *et al*, 2003). This is a submersible hydrophone and computer, which listens for and logs cetacean echolocation click trains. It was originally designed for the harbour porpoise however it has since been developed to monitor other cetacean species as well. Harbour porpoise echolocation pulses are different from those of other species. They have a high frequency component in the bandwidth 120-150kHz, with sound source levels around 150-160 dB re 1μPa at 1m (Mann *et al*, 2000). These pulses tend to be longer

in duration (hundreds vs. tens of microseconds) and have a lower level and narrower bandwidth than the bottlenose dolphin, (Mann *et al*, 2000). Although harbour porpoises do not produce characteristic whistles, their click trains have been proposed to function both as a searching tool and as a communication aid (Goodson & Sturtivant, 1996; Mann *et al*, 2000).

Jefferson *et al* (2002) towed the early version of the device, the Proto-POD to assess trackline detection probability, g(0), in line transect surveys of the finless porpoise. The Proto-POD was found to detect the majority of visual sightings recorded, permitting the researchers to define a detection range of 250-350m for the device. Later use of the T-POD during both 2002 and 2003 saw both static and towed deployments made to assess the short-term effects of the construction of wind turbines on harbour porpoises, at Horns Reef, Danish North Sea (Tougaard *et al*, 2003). Despite difficulties encountered with the T-PODs a full assessment of the effects of construction on the resident harbour porpoise population was made. In addition to the T-POD other acoustic listening devices on the market include the traditional hydrophone and IFAW's (International Fund for Animal Welfare) Porpoise Logger, a towed array which logs porpoise clicks directly onto a computer onboard the research vessel. With this system it is possible to view the echolocation activity in real time, whereas with the T-POD system all acoustic activity may only be viewed once the towed device has been retrieved from the water. All three systems have been used in a number of research studies (McDonald & Fox, 1999; Akamatsu *et al*, 2001; Cox *et al*, 2001; Culik *et al*, 2001; Northridge *et al*, 2001; Tougaard *et al*, 2003) where one system may demonstrate benefits over the others depending on the circumstances

(types of survey, vessel, towed speed, weather conditions) and species (echolocation characteristics) for which they are used.

Acoustic monitoring of cetacean populations is however in the early stages of development and trial, though the advancements being made are adding important information to the current knowledge base, permitting a greater understanding of this species. The data gained using these devices, combined with more traditional research methods should allow policymakers in the UK and elsewhere to make informed management decisions about the conservation and protection of the harbour porpoise.

There are a number of pieces of legislation across the world which aim to conserve and protect cetacean species. Some are general and cover all marine mammals, whereas others specify species which are endangered, threatened or at risk. In the UK, the harbour porpoise, along with other cetacean species, is currently protected under section five of the Wildlife & Countryside Act 1981, which states that they cannot be intentionally killed, injured, captured or harassed. Despite the apparent all-encompassing terminology used in this piece of legislation the emphasis is placed on the word "intentionally", which means that any injury, stress or death caused has to have been "intentional" on the part of the accused. This means that it is almost impossible to prosecute under this piece of legislation, as it would be impossible to prove intent over ignorance of their actions. In 2000 however, the Countryside and Rights of Way (CROW) Bill, was passed by Government, which provides species protection from "reckless disturbance". This was a ground-breaking piece of legislation which gave added weight to the legal protection afforded to cetacean species in the UK. In Scotland the flaws in the Wildlife & Countryside Act were

remedied by the introduction, in 2004, of the Nature Conservation (Scotland) Act. This, like the CROW Bill made "reckless" disturbance or injury an offence (Scott & Parsons, 2004). Even with this piece of legislation however, very few cases have ever been brought to court. Probably one of the greatest threats to cetacean species in UK waters aside from incidental capture in fishing nets (bycatch) and prey depletion is boat disturbance and harassment. Every year incidences are reported to Police Wildlife Crime Liaison Officers, yet very few of the perpetrators are ever identified, let alone taken to court for reckless disturbance. In Scotland a recent amendment to the Nature Conservation Act requires the introduction of a Scottish Marine Wildlife Watching Code, which outlines advice to operators in order to reduce disturbance around marine wildlife. As with any piece of protective legislation the degree of compliance or rather the amount of illegal activity arises through a combination of factors – the likelihood of getting caught and the penalty enforced if caught and prosecuted. Unless there is adequate monitoring and enforcement of legislation the piece of legislation is worthless as it will not be viewed as an adequate deterrent to irresponsible behaviour.

The harbour porpoise, which is characterized as "vulnerable" by the IUCN (The World Conservation Union) (ICES, 2005) is listed as a priority species of conservation concern in the UK Biodiversity Steering Group Report (HMSO, 1995), is listed in Appendix II of CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora), Appendix II of the Bonn Convention, Appendix II of the Berne Convention, Annexes II and IV of the EC Habitats Directive and on a list of threatened and declining species by OSPAR. The species is also covered by the terms of ASCOBANS (Agreement on the Conservation of Small Cetaceans of the

Baltic and North Sea), through the Jastarnia Plan (Recovery Plan for Harbour Porpoises in the Baltic Sea), the North Sea Conservation Plan and by Resolution 5, on the Incidental Take of Small Cetaceans. Yet despite all of these unilateral, European and International conventions, the UK does not at present have specific cetacean protective legislation as is the case with the Marine Mammal Protect Acts of the USA and New Zealand. Current legislation in the UK is very general, has used terrestrial legislation as a basis and is notoriously difficult to enforce.

More than fifteen years on after the discovery of a significant problem of cetacean bycatch in many of the UK's inshore fishing fleets, little action has been taken to reduce the number of cetacean deaths. A study conducted in 1997, by Kirkwood *et al*, demonstrated that bycatch figures have risen from 22% of all deaths in 1990 to 65% in 1995. Results published in 2000 indicate that as many as 2300 animals are being taken by UK and Irish offshore netters, whilst 4500 are being caught by Danish gill-netters (Tregenza, 2000). The numbers of porpoises being caught in UK waters is currently unsustainable. The Celtic Sea population is estimated at approximately 35,000 individuals (Hammond *et al*, 2002). Bycatch levels within the Celtic Sea represent 6.2% of the total estimated population (Tregenza *et al*, 1997); other studies have demonstrated that even a 4% reduction is unsustainable at a population level (Woodley & Read, 1991). In the 2006 meeting of parties to ASCOBANS (Agreement on the Conservation of Small Cetaceans of the Baltic and North Sea), parties regretted that bycatch had not yet been reduced to less than 1.7% of the best available population estimate and reiterated the recommendations of Resolution 3 which stated the general aim to minimise bycatch ultimately to zero. Conservation groups are

increasingly frustrated by the lack of action taking place in the UK and are now highlighting the same recommendations for change originally identified 15 years ago.

In order to mitigate the problem of bycatch in inshore set-net fisheries, an acoustic alarm, commonly know as the "pinger" was developed. These, now manufactured by four companies, are cylindrical or banana shaped devices, 20cm or less in length. They are attached to the net at regular spacings of 100 to 200m and emit a 'ping' or high frequency sound approximately every four seconds in an attempt to alert the porpoise or marine mammal to the presence of the net (Dawson *et al*, 1998; Culik *et al*, 2001).

Pingers have been tested in a number of scientific studies, to establish their effect on bycatch levels, the cetacean species and the target species of the fishery concerned (Kastelein *et al*, 1997; Kraus *et al*, 1997; Dawson *et al*, 1998; Trippel *et al*, 1998; Westgate & Read, 1998; Newborough *et al*, 2000; Culik *et al*, 2001; Northridge *et al*, 2001). Whilst many studies have demonstrated a reduction in bycatch numbers, there is a degree of uncertainty about the resultant behaviour caused by the pinger (Dawson *et al*, 1998). Concern has also been expressed over the aversive nature of the ping and the possible consequences of habitat displacement (Trippel *et al*, 1998).

Despite these concerns the European Commission Regulation (No. 812/2004), was brought into force during April 2004, making the use of pingers mandatory across both bottom-set gill and tanglenet fisheries, for vessels over 12m in length. The regulation has been phased in across ICES sea divisions since June 2005. For the UK pingers became mandatory in the North Sea from June 2005 (however no fishermen

were prosecuting the fishery so no pingers have been fitted), the South West from January 2006 and more recently in the South East from January 2007. Despite offering the best means of bycatch reduction in these fisheries (Kastelein *et al*, 1997; Kraus *et al*, 1997; Dawson *et al*, 1998; Trippel *et al*, 1998; Westgate & Read, 1998; Newborough *et al*, 2000; Culik *et al*, 2001; Northridge *et al*, 2001) to date, no pingers have been implemented within the UK. Sea trials by the Sea Fish Industry Authority have additionally identified a number of health and safety concerns with pingers when the fishing gear is shot and hauled onboard, making fishermen and their producer organisations understandably reluctant to use them. There have also been problems with the battery life and longevity of the devices themselves (Seafish, 2005). As these problems are yet to be solved, to date no pingers have been attached to nets and the fishery is continuing to operate as normal.

Additional protection to cetaceans, including the harbour porpoise may be sort under the EC Habitats and Birds Directive, through which there is an obligation on member states to implement an ecologically coherent network of Special Areas of Conservation (SACs), to "*enable the natural habitat types and the species' habitats concerned to be maintained or, where appropriate, restored at a favourable conservation status over their natural range*". These sites, together with the Special Protection Areas (SPAs) established by the 1979 Birds Directive (79/409/EEC), constitute the Natura 2000 network across the European Union. In 1999, UK courts ruled that the Habitats Directive applies to Member States' EEZ (Exclusive Economic Zone) or equivalent (Bull & Laffoley, 2003, Kelleher & Phillips, 1999). SACs are designed to protect natural habitats and species considered important at the EU level. A site may be recommended for designation as an SAC if it has a significant or

nationally important presence of one or more of the species or habitats listed within the Annexes of the Habitats Directive (i.e. the harbour porpoise). The focus on a relatively restricted list of habitats and species provides only limited opportunity for achieving the broader objective of conserving and allowing recovery of ecosystem processes and functions. Moreover, the criteria for designating Natura 2000 sites mean that only those sites considered to be of European importance can be protected.

Given the high mobility of the harbour porpoise, it is recognised that it may not be possible to achieve a high level of representation of this species within the Natura 2000 network (Evans & Wang, 2002). Indeed further study of the SAC designation for the Moray Firth has since found that in the time taken to designate the area as protected there has been a distributional shift in bottlenose dolphin occurrence, such that they are now frequently observed outside of the designated area (Wilson *et al*, 2004). Even after designation of a site as a marine SAC, it can be very difficult to prevent damage to that site, or stop an activity from having an adverse affect on the habitats and species that the SAC designation is there to protect. Whilst conservation agencies can advise on the management of SACs, they have no executive role in the management process, and often rely on voluntary compliance by the various sectoral relevant authorities with no one group taking the lead. In the UK there is currently no mechanism to enforce marine SAC management schemes.

The UK is further obliged to designate Marine Protected Areas (MPAs) under the OSPAR Convention, World Summit on Sustainable Development, Convention on Biological Diversity, the UN Convention on the Law of the Sea, the Bonn

Convention, and the Ministerial Declaration of the 5th International Conference on the Protection of the North Sea (Bull & Laffoley, 2003, Kelleher & Phillips, 1999).

Over the past 20 years, government reviews have continually identified the need to address shortfalls in marine nature conservation legislation (Review of Marine Nature Conservation (RMNC), 2004). It has been accepted that Marine Nature Reserves established under the Wildlife and Countryside Act (1981) had not been as successful as had been hoped, with only three having been designated (presenting a total area of less than 0.001% of the UK's seas).

The RMNC endorsed a new framework for marine nature conservation in the UK, based on a hierarchy of spatial scales: the wider sea, the regional sea, marine landscapes, important marine areas and priority marine features. It noted that important marine areas, a fundamental component of the marine nature conservation framework, should be viewed not in isolation but as part of an ecologically coherent network. Indeed Evans & Wang (2002) had previously stated that cetacean focused areas should be identifiable on the basis of: continuous or regular presence of the species, good population density and a high ratio of young to adults during certain periods of the year. Other factors such as observed social and sexual behaviour should also be deemed important to site classification.

Following the RMNC, the UK government made a commitment to provide a Marine Bill in 2004, which was subsequently followed by a public consultation during 2006. Now, in 2007 the government are working on draft legislation which promises to provide a marine planning system, streamlined regulatory regimes for licensing, new

mechanisms for marine nature conservation, a marine management organisation (MMO) and new arrangements for inshore fisheries and related environmental enforcement. It will only be in the coming implementation and enforcement that the true conservation potential of this piece of legislation for cetacean species may be realised.

It is clear from the current wealth of scientific literature and anecdotal reporting that many aspects of harbour porpoise life history and ecology have been extensively studied, yet gaps in the knowledge base for the species remain. There are many areas which require further investigation where current knowledge has just begun to answer questions, raising more in the process. Given the current and substantial threat to harbour porpoises, through incidental capture in fishing nets, prey depletion and disturbance, it is imperative to further our understanding of this species, in order to inform adequate conservation measures.

Despite the level of knowledge which already exists a number of important questions remain unanswered. Firstly, whilst population estimates have been made following the SCANS survey in 1994, at the time of study no complete quantitative survey had been conducted along the west coast of the UK. It is acknowledged that quantitative data exists through the European Seabirds at Sea (ESAS) data, and dedicated shore-based watches, however the ESAS data fails to go beyond 1997 and shore-based surveys are limited to the coastal zone alone. SCANS II, conducted during the summer of 2005, did surveyed the west coast of the UK, with an extension into additional previously un-surveyed areas, however the research presented here is the first systematic survey of the entire west coast of the UK since 1997. This large scale,

boat-based study was supported by a small scale shore-based study, off the coast of North Devon which enabled investigation of habitat use, behaviour and localised movements for the harbour porpoise. As both studies recorded harbour porpoise behaviour it has been possible to make a detailed assessment not only of the research platforms utilised but also of the additional risks to the harbour porpoise of the increasing public interest in eco-holiday and dolphin watching experiences.

In order to avoid or mitigate the adverse effects of human activities, baseline research is urgently required, supported by a greater understanding of the threats which this species faces. In terms of mitigating against cetacean bycatch it is of crucial importance to understand why and how cetaceans get caught in fishing nets. Acoustic research carried out as part of this work presents new information about harbour porpoise behaviour around bottom-set gillnets.

In addition to understanding harbour porpoise behaviour and movements it is also important to be able to adequately monitor and record sightings from a boat-based platform. Any observational, boat-based study is however based on a number of assumptions, in addition to the limitations inherent in this type of work, as observation may only be conducted during daylight hours and even then may miss sightings due to animals surfacing when the researcher is looking elsewhere or perhaps after the vessel has passed. The findings presented here consider the difficulties in developing an acoustic monitoring device for towing, but also demonstrate the potential in using such methods to enhance cetacean research.

The information provided in the following chapters will facilitate future conservation strategies and support existing UK data. With marine legislation currently going through parliament it is hoped that lead agency's and partners will be provided with a streamlined, ecosystem-based management structure which will provide adequate conservation for the harbour porpoise, amongst other marine species and habitats.

Relative Abundance, Density and Distribution of the Harbour Porpoise (*Phocoena phocoena*) along the West Coast of the UK

Chapter One

Relative Abundance, Density & Distribution of the Harbour Porpoise (*Phocoena phocoena*) along the West Coast of the UK

Abstract

The harbour porpoise (*Phocoena phcoena*) is the most frequently sighted cetacean in the UK, yet there is a conservation need to assess both abundance and distribution for this species. During May-August, 2002-2004 a boat-based visual survey, employing effort-related line transect methodology was conducted for the west coast of the UK. Estimates of relative abundance were made, with full DISTANCE analysis being carried out during 2004. A generalised additive model (GAM) was constructed examining month, position (latitude, longitude), depth and sea surface temperature for all years and for each year of the study individually. Harbour porpoise density estimates between years demonstrated a significant decrease in the South West, with an increase for West Scotland, whilst 2003 produced greater numbers for both Northern Ireland and the Firth of Clyde. Population size was estimated for each region, the South West of England was estimated to have 163 (67_{LCI}-400_{UCI}) individuals during the months of May and June, Northern Ireland had 387 (170_{LCI}-877_{UCI}) individuals, during July, with 1645 (823_{LCI}-3289_{UCI}) individuals around the Firth of Clyde in July and 3105 (2032_{LCI}-4745_{UCI}) in West Scotland during August and September. The GAM demonstrated that porpoise presence increased around the 100m depth contour, thought to be related to the distribution of prey species. Whilst further research is required in each of the areas throughout the year, this study provides important information on the distribution and habitat use of the harbour porpoise within UK waters.

Introduction

The harbour porpoise (*Phocoena phocoena*) is a continental shelf species found throughout temperate waters of the northern hemisphere, (Carwardine, 1995; Read, 1999a; Reid *et al*, 2003). As such this species is the most frequently sighted cetacean in UK waters (Evans *et al*, 2003).

A number of studies have been carried out to examine harbour porpoise abundance around the UK coastline, including the waters of South West Ireland (Leopold *et al*, 1992), the North Sea (Heide-Jørgensen *et al*, 1993) and around South East Shetland (Evans *et al*, 1994). More recently the Whale and Dolphin Conservation Society, in collaboration with Greenpeace carried out a winter survey off the South Western approaches to the UK, which considered all cetacean species encountered, including the harbour porpoise (WDCS, 2004). Additionally both the Sea Mammal Research Unit (SMRU) and the Hebridean Whale and Dolphin Trust (HWDT) have conducted research on the harbour porpoise from the Scottish coast (Stockin *et al*, 2001; Gordon & Northridge, 2003; Grellier & Wilson, 2003; Parsons *et al*, 2003; MacLeod, 2004).

Whilst these published studies have provided data on specified areas, none were sufficiently large or extensive enough to allow assessment of overall UK population status, though they have provided important regional information. Covering a larger area, data has also been collated through the Seabirds at Sea Team (now Seabirds and Cetaceans Branch) of the UK Joint Nature Conservation Committee (JNCC). Between November 1979 and January 1997 surveys for seabirds were conducted from the North Sea, Danish waters, North and West coast of Scotland, Irish Sea, South West Ireland and the English Channel (Evans & Wang, 2002). These surveys, whilst

primarily interested in distribution of seabirds, also collected information on cetaceans encountered at the time.

By far the most extensive survey however, in terms of area covered, is that of the SCANS (Small Cetacean Abundance in the North Sea) survey, first conducted in 1994. This provided the first large-scale survey of the area, addressing the status of small cetaceans, including the harbour porpoise (Hammond *et al*, 2002). Researchers carried out both shipboard and aerial line transects in order to gather data to inform future conservation initiatives in European waters. The harbour porpoise was found throughout most of the North Sea, Skagerrak and Kattegat and the Celtic Sea. With population estimates of 280,000 for the North Sea, 36,000 for the Celtic Shelf and another 36,000 for the Skagerrak and Belt Seas (Hammond *et al*, 2002). No porpoises were recorded for either the English Channel or the southern North Sea and only small numbers were recorded in the Baltic (Hammond *et al*, 2002). In addition to this, studies were also carried out in Norway and the inner Danish waters, where abundance figures were: 11,000 porpoises in waters north of 66°N and the Barents Sea, 82,000 for the northern North Sea and southern Norwegian waters (1995), 500-580 to the North of Fyn, 500 in the Great Belt, 100 in the Little Belt, 90-200 in Kiel Bight and finally 1-500 around the Island of Sylt (1991-2) (Hammond *et al*, 2002). More recently SCANS II carried out in 2005 extended the survey area to include the west of the UK, Ireland and the inshore waters of Spain. Whilst for the study area as a whole harbour porpoise numbers were not found to vary significantly, with a total of 341,000 (CV = 0.14) in 1994 and 386,000 (CV = 0.20) in 2005, clear distributional shifts in abundance were observed from the north to the south of the entire study area. This was particularly notable in the North Sea and Channel where abundance figures

were seen to decrease in the North (239,000 (1994) – 120,000 (2005)) and increase in the South (102,000 (1994) – 215,000 (2005)) (Hammond & MacLeod, 2006). The reasons for this distributional shift remain unknown, although it is likely that distributional and abundance changes in prey species could account for the relocation of the harbour porpoise.

The remaining existing information on number and distribution within the UK arises from volunteer observer schemes, such as Seaquest Southwest (Cornwall & Devon Wildlife Trusts) and a National Whale & Dolphin watching week, hosted by the Sea Watch Foundation. Within both schemes, members of the public are encouraged to report sightings with as much additional environmental detail as possible. Despite the possible errors (misidentification, group size estimates, behaviour etc.) in both schemes, the volunteer observer programs are extensive and provide almost complete coverage of UK waters. As such they provide broad-based evidence of changes in relative abundance and distribution (Evans, 1992).

In addition to assessing abundance it is also important to consider distribution and any key areas for habitat conservation and wildlife protection. The UK is obliged under national, European and International agreements to investigate and monitor cetacean distribution and abundance (e.g. National Biodiversity Action Plans; EU Habitats Directive, 1992; EU Regulation No. 812/2004; OSPAR Convention, 1992 etc). Accurately describing and understanding the distribution of cetaceans is a fundamental problem with important conservation and management implications (Redfern *et al*, 2006). If conservation of wild cetacean populations is to be effective then relationships between species and their habitats need to be understood (Cañadas

et al, 2005). This should include examination of environmental variables to enable an ecosystem-based approach to be taken to management.

Previous research has demonstrated that cetacean species favour particular habitat areas (Gaskin, 1968; Hui, 1979; Au & Perryman, 1982; Cockcroft *et al*, 1990; Palka, 1995; Johnston *et al*, 2005). However investigations into the harbour porpoise have demonstrated seasonal and temporal variations in distribution, with further changes dependent on the area examined (Palka, 1995; Weir *et al*, 2001; Hamazaki, 2002; Tynan *et al*, 2005; Ballance *et al*, 2006). A study by Hamazaki (2002) conducted in the mid-western North Atlantic demonstrated seasonal shifts in harbour porpoise habitat use during June and August. Researchers also found the animals in water less than 500m, in nearshore regions, which is in accordance with their known ecology as a continental shelf species.

Gaskin (1968) indicated a relationship between bottlenose dolphins and water temperature, which has additionally been demonstrated for the harbour porpoise by both Tynan *et al*, (2005) and Palka, (1995). The latter study found harbour porpoises in waters ranging between 10 – 13.5°C. This is however probably an average water temperature where they are found, as much of the northern hemisphere waters can range on average from 0.5°C in the winter to 20°C during the summer months, demonstrating that they have a much wider temperature tolerance than is indicated above. Given their small body size and high energetic demand it is probably favourable for them to maintain distribution in waters in the upper end of this range.

Tynan *et al* (2005) found that in addition to latitude, temperature and depth the harbour porpoise was associated with the presence of frontal systems and areas of high surface abundance of chlorophyll, which is indicative of their reliance and subsequent spatial distribution in relation to prey hotspots (Borges & Evans, 1996). Harbour porpoises cannot store much energy and are therefore reliant on year-round proximity to food sources. As such they may be more strongly correlated with the presence and distribution of their prey than other cetacean species (Brodie, 1995). Unsurprisingly, many of the areas where harbour porpoises are observed worldwide also support large aggregations of prey (Read & Westgate, 1997; Read, 1999b).

In the UK, few published reports relate specifically to harbour porpoise distribution and environmental variables, yet Weir *et al* (2001) note an increase in numbers during June-September around Shetland and the Orkney islands, when larger groups may form after calving (Evans, 1992). The authors also note that the species is found occasionally off the continental shelf in deeper waters. Indeed they have been observed in waters as deep as 1502m off the coast of Scotland, on the Rockall and Faroe Banks (MacLeod *et al*, 2003). Bannon (2006) also noted an increase in relative abundance during May – September in the Sea of the Hebrides. Bannon's study observed distributional changes in harbour porpoises which may reflect spatial and temporal variations in the biological, hydrographical and topographical features of the study site.

The primary aim of this study is to further our knowledge of abundance, density and distribution of the harbour porpoise in western UK waters. As the harbour porpoise is a highly mobile species, the spatial scale at which they experience the marine

environment is also large (Balance *et al*, 2006). Therefore it is important to conduct analysis of the environment on an equally large spatial scale. The hypotheses that harbour porpoises show regional variation in distribution and preference for specific environmental conditions will be tested via consideration of a number of parameters including: year, month, latitude, longitude, sea temperature and depth. This study will also provide yearly population density estimates and an estimate of population size for each of the regions studied.

Methods

A boat-based survey of the west coast of the UK was undertaken between May and September, for three consecutive years, 2002, 2003 and 2004.

The UK seas are typically characterized by a complex coastal zone, which leads down to the continental shelf at a depth of approximately 200m, before descending further into the deep sea, where canyons and sea mounts preside (Connor *et al*, 2006). Within the South West few subtidal sediment banks exist. Where they do these are characterized by slopes of >2% rising from the shelf plain, usually consisting of coarse sands and gravels. There is a single shelf mound or pinnacle off Lands End, marked by a slope >2% on three or more sides consisting of rock. The seabed around the South West is otherwise largely coarse sediment interspersed with sandy and muddy sand. Moving up the west coast of the UK, Wales and Northern Ireland consist of coarse sediment and mud/sandy mud, but are otherwise relatively uniform at a large scale. The seabed off the coast of Scotland is interspersed with shelf troughs - elongated depressions carved in the seafloor by glacial processes which have a considerably greater depth than the surrounding seafloor. The sediment is

heterogeneous with rock, coarse sediment and mud/sandy mud in between. There are patches of sand in inshore, coastal waters. The sea surface temperature of the UK is on average 6-10°C during the winter, rising to 14-16°C during the summer months. There are of course isolated areas which either experience colder temperatures during the winter months, or see localised elevations during the summer months (Connor *et al*, 2006).

The research vessel, SRV Forever Changes, is an 11.7m Dufour sailing yacht, with a Perkins 4.108 auxiliary diesel engine, fitted with a Variprop feathering propeller. It is primarily involved in basking shark (*Cetorhinus maximus*) research, although cetacean, turtle, and marine wildlife surveys also take place onboard. The standard observation height from the platform is 3m.

The survey, onboard what is effectively a platform of opportunity, began in May from Falmouth, where it remained surveying the South West peninsula and the Isles of Scilly before leaving for the north coast, Wales and Northern Ireland in July. In the middle of July the vessel sailed from Northern Ireland to the Clyde Sea, Scotland, for two weeks, before continuing onto the Sea of the Hebrides, returning to Cornwall at the end August. The same route was undertaken in all years however during 2003 and 2004, the survey of the Welsh coast was omitted due to adverse weather conditions at the time of the survey. A larger proportion of time was given to studying the waters off Northern Ireland, by adding an extra week of dedicated survey time during the journey south from Scotland to Cornwall towards the end of the season. As a result, the survey vessel did not return to Falmouth until the end of September in both the latter years.

Line transect surveys were carried out between fixed positions both inshore and offshore, using a standardised methodology. Transects were selected daily, taking into consideration the weather and sea state. The following assumptions were made whilst on survey: a) that all porpoises on the track line were recorded, b) that porpoises did not respond to the approach of the vessel before detection by an observer; c) sightings are independent of each other. It is widely acknowledged however that the assumption a) that all animals on the trackline are detected (g(0)=1) is rarely true. It is accepted that cetaceans by their very nature will be missed by the survey vessel as they may be submerged at the time of passing or indeed dive in response to the vessel itself. Whilst other studies have been able to estimate the probability of detection and hence g(0), this has not been possible as this survey did not have available an additional platform or the ability to separate observers teams. As such g(0) is assumed to be equal to 0.769, calculated by Barlow (1987) for harbour porpoises, following ship-board surveys.

Two observers were employed at all times, each scanning one side of the vessel, with a third crew member recording the vessels' position every half hour via a Furuno GP-32 GPS/WAAS Navigator interfaced with a DELL notebook computer operating SeaPro Pro navigational software and ARCS electronic charts. Observers were rotated every three hours to prevent misidentification or missed animals due to fatigue. Additional navigational and environmental data were recorded each half hour included the vessels' heading, wind direction and speed, sea state, weather, cloud cover, depth and sea temperature. A litter and marker buoy survey was also conducted onboard, as part of another research project. Distance estimation was always required in recording the location of all marker buoys and litter encountered. Following initial

training, volunteer observers soon adapted to distance estimation and their recording was frequently calibrated by estimation of distance to known land marks (using information from the ship's radar or plotter) and checked by more experienced members of the crew. When harbour porpoises were encountered the following data were recorded: time, GPS location, vessel heading, distance, radial angle to cetaceans, depth and sea temperature. A hand-held sighting compass was used to measure the angle to the harbour porpoise, whilst distance was estimated by eye. A minimum estimate of group size was also made; this was defined as the maximum number of animals seen on surface at any one time. A group was defined as two or more individuals in close contact, <20m from each other and closer to one another than individuals belonging to another group (Slooten, 1994). Unfortunately despite training, observers did not always record radial angle and distance to sightings during 2002 and 2003. This rendered the data insufficient to complete DISTANCE analysis for abundance estimates in those years. Therefore only abundance estimates for the most recent year, 2004 are presented.

Surveys in all years encompassed the summer season, ranging from May-September. The time at which a transect was begun on any given day varied due to a number of factors, primarily weather and tides however when conditions permitted, transects were completed during daylight hours on almost all days. The Friday of every week was a crew changeover day, this also allowed for the vessel to be restocked and any minor technical problems to be addressed. Whilst all hours were covered, the majority of data were collected between 10:00 – 18:00. A greater number of hours in all categories were spent on survey during 2003, compared with 2002 and 2004, largely because of unfavourable weather conditions in those years. It may also be assumed

that a greater proportion of harbour porpoises are seen and therefore recorded in smooth or slight sea states, compared to an increase in chop or inclement weather conditions. Therefore, in line with previous studies (Jefferson, 1996; Hammond *et al*, 2002), only data points recorded in a sea state ≤ 3 were included in the subsequent analyses.

Relative abundance estimates were calculated for all years, expressed as number of porpoises per 100km. Data were divided into the following regions: South West England (49°30-50°30N; 04°-06°W), Wales (52°-53°N; 04°-05°W), Northern Ireland (54°30-55°30; 05°-06°W), Firth of Clyde (55°30-56°30N; 04°30-06°W) and West Scotland (56°30-58°N; 05°30-07°W) (here Kintyre was used as a dividing landmark, which also serves to delineate the two surveys legs that were completed there) (Figure 1). Regions were chosen through a combination of time and effort constraints and also served to delineate the whole coast into temporally independent blocks. As the same northward movement of the survey vessel through the course of the year occurred each time, each survey area was examined separately to avoid temporally confounding the results through either seasonal variation in abundance and/or calving periods. The coefficient of variation has been calculated for all density estimates. A one-way ANOVA has been carried out on harbour porpoise density for each region sampled to examine variation across years. A density estimate and approximate number of individuals has been calculated using DISTANCE 4.1 software for 2004. The effective search width has been calculated for the survey as a whole after pooling all observations during 2004.

Whilst the harbour porpoise is tolerant of a wide temperature gradient, being found through the northern temperate waters, the variable, sea surface temperature was selected for analysis as it will vary in regions of tidal fronts and upwelling, where Gaskin, (1985) hypothesised that large numbers of prey would aggregate. Additionally as bathymetry is known to influence cetacean distribution (MacLeod *et al*, 2003), depth was included in the analysis in an attempt to explain the observed distribution with varying topographic features. Generalised additive modeling (GAM) is an exploratory data analysis tool for elucidating functional forms of relationships between observations and predictor variables (Hastie & Tibshirani, 1990). GAMs are very useful for interpreting ecological interactions as they are able to fit non-parametric functions to estimate the relationship between response and predictor variables without imposing limitations of any underlying relationships (Hastie *et al*, 2005). They can be used to assess how each environmental variable relates to presence or absence of the harbour porpoise. Using a binomial logistic function with the 'mgcv' package within the statistical program 'R' (Wood, 2004), GAM has been used to model the effects of month, position (latitude, longitude), sea surface temperature (temp) and depth on the presence/absence of harbour porpoises for the entire west coast of the UK. The significance of the p-value of each term was based on the chi-squared test of comparing the full model and the model omitting the respective predictor. A GAM was run on the entire data set to assess the relationship between environmental variable and porpoise presence. To assess within year variability the GAM was then run using individual years of data: 2002, 2003, 2004.

Results

During 2002, a total of 20 weeks were spent at sea, with approximately 333.5 hours on survey. During this time, a total of 3137 km were surveyed (Figure 2). In 2003, the survey was repeated but with increased coverage of Northern Ireland and almost no coverage of Wales (Figure 3). A total of 22 weeks were spent on survey, comprising of 501 hours, over 3736 km. In 2004, again 22 weeks were spent at sea, with 385 hours over 3892 km (Figure 4).

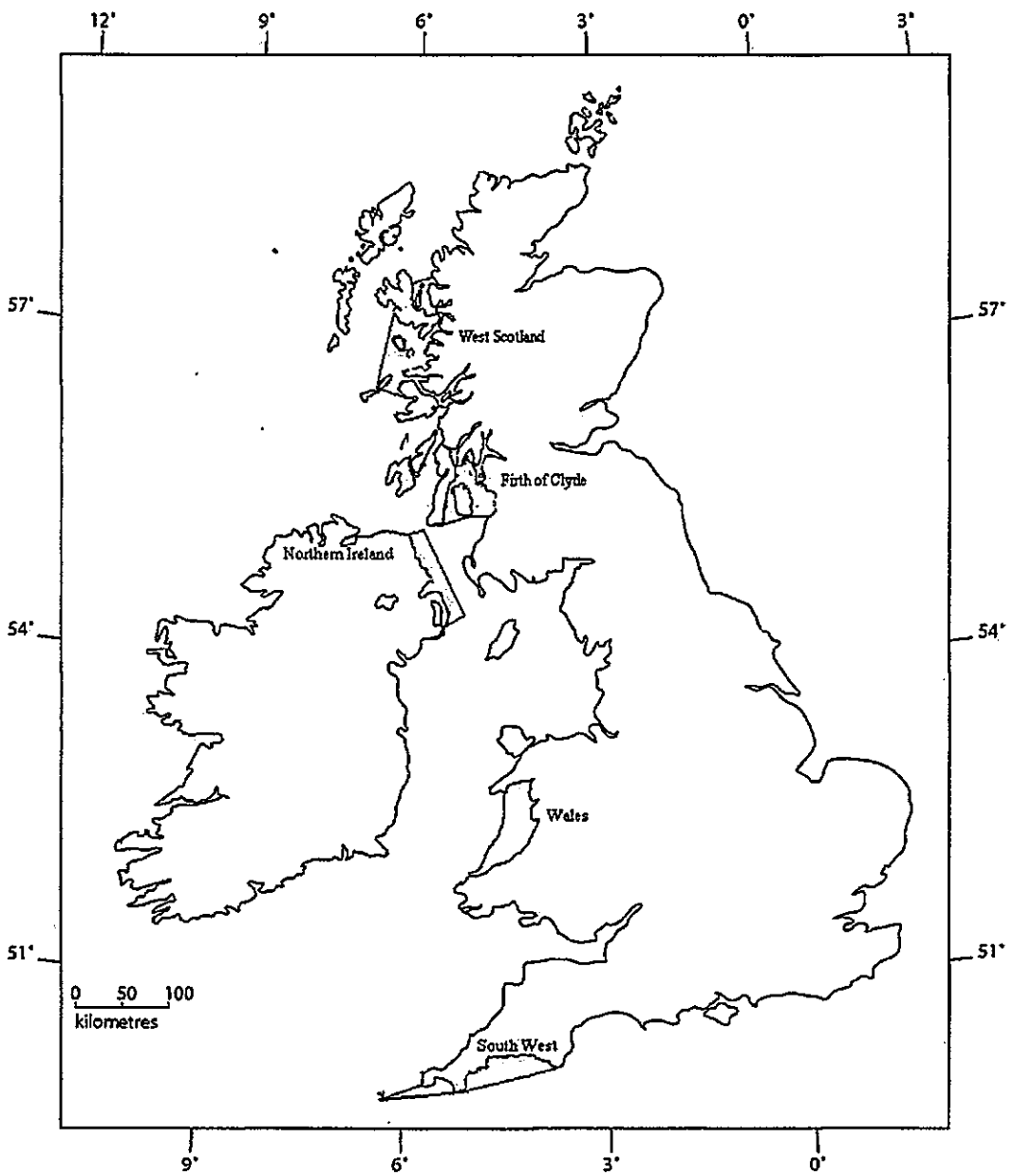


Figure 1: Map of the UK showing the regions surveyed, South West, Wales, Northern Ireland, Firth of Clyde, West Scotland.

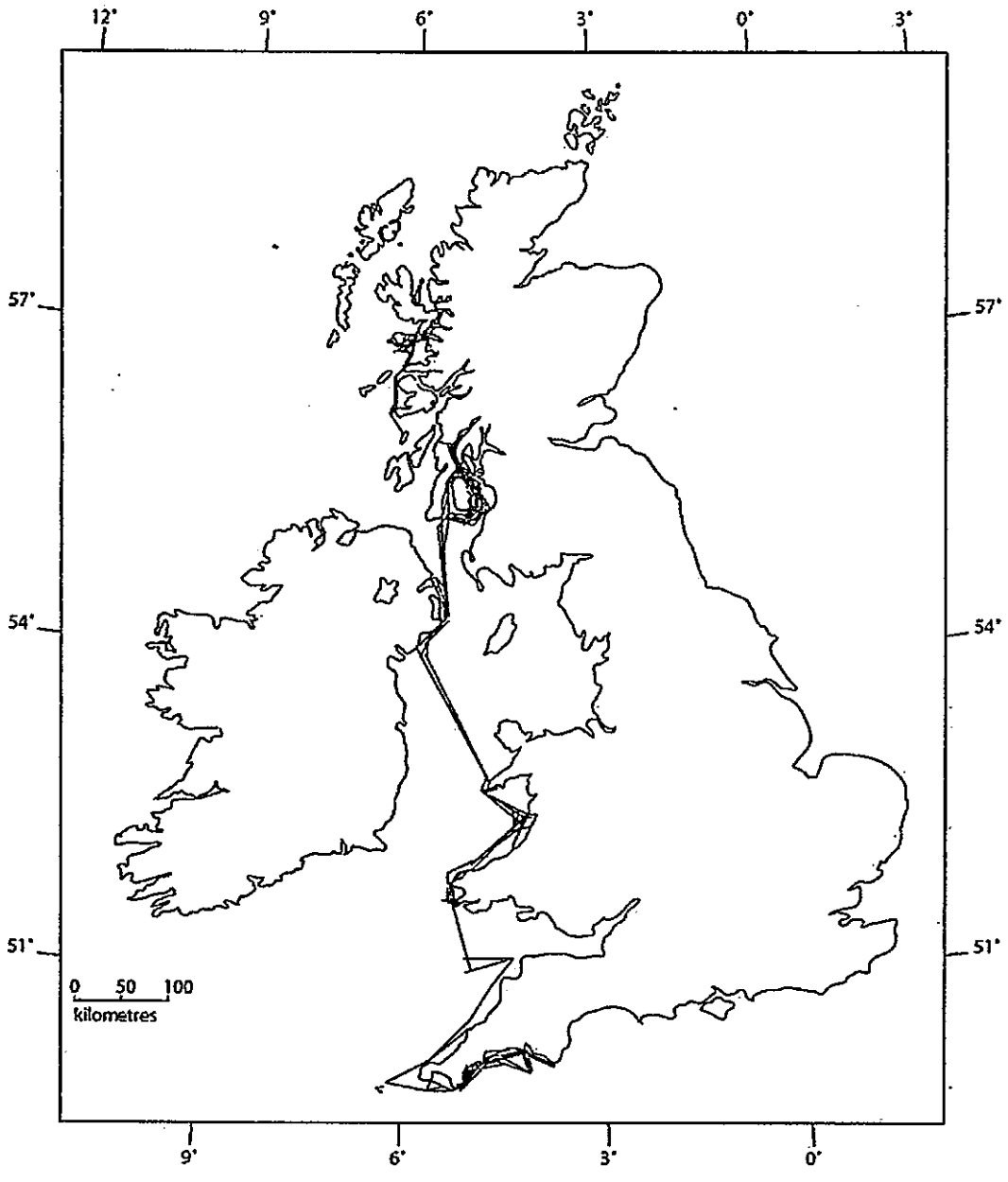
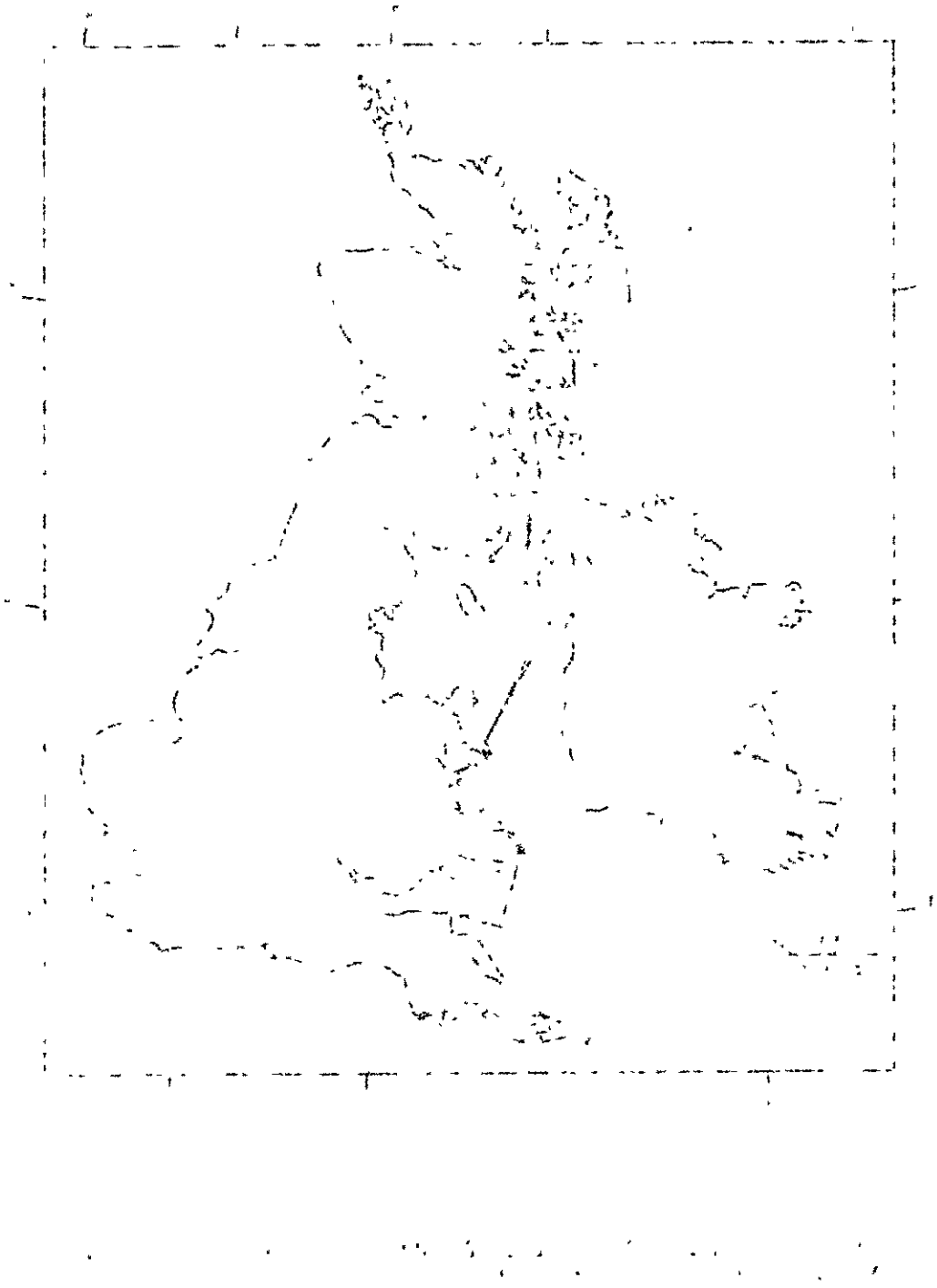


Figure 2: Effort related survey tracks completed onboard the research vessel Forever Changes between May and August, 2002, for the west coast of the UK.



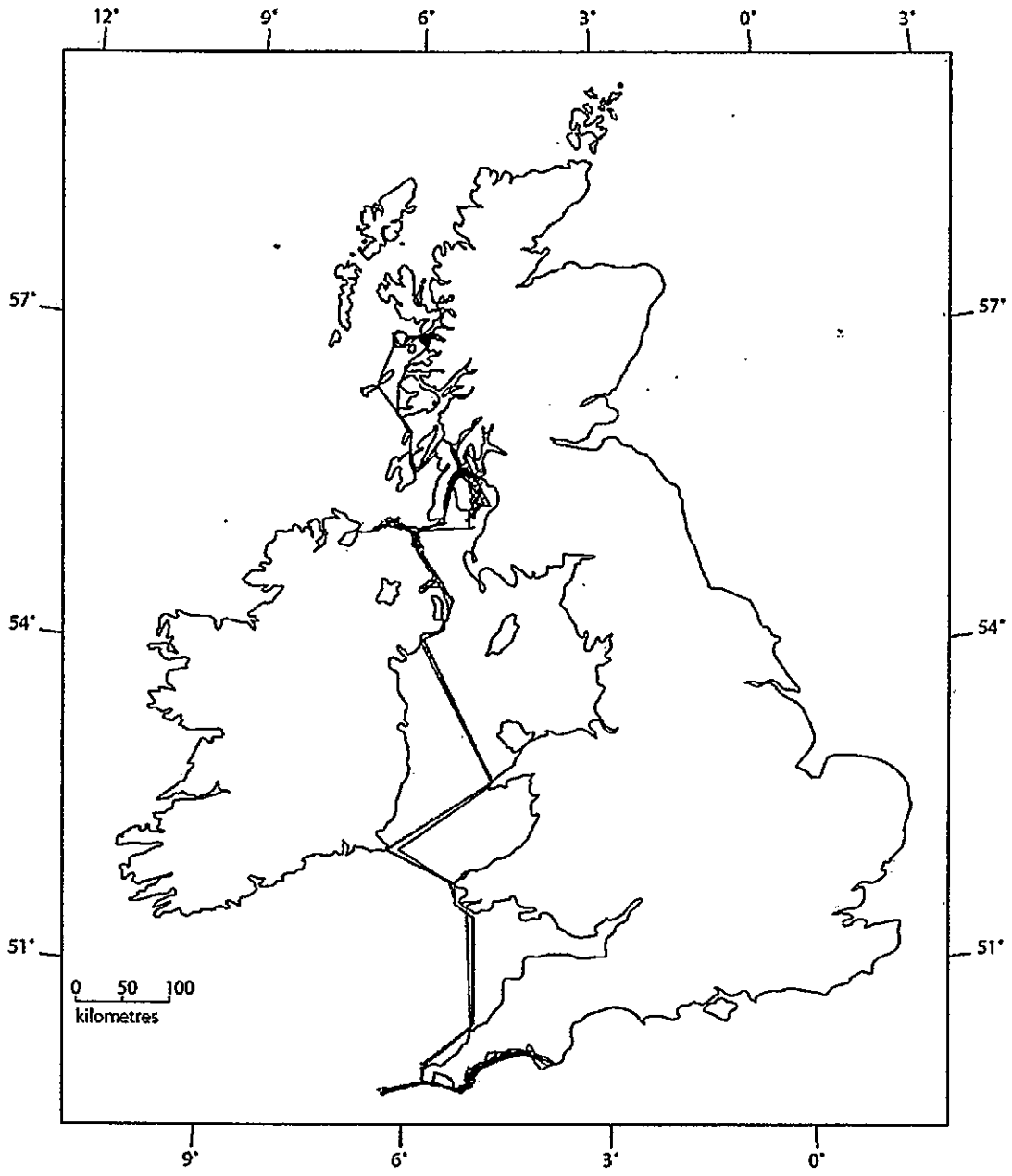


Figure 3: Effort related survey tracks completed onboard the research vessel Forever Changes between May and September, 2003, for the west coast of the UK

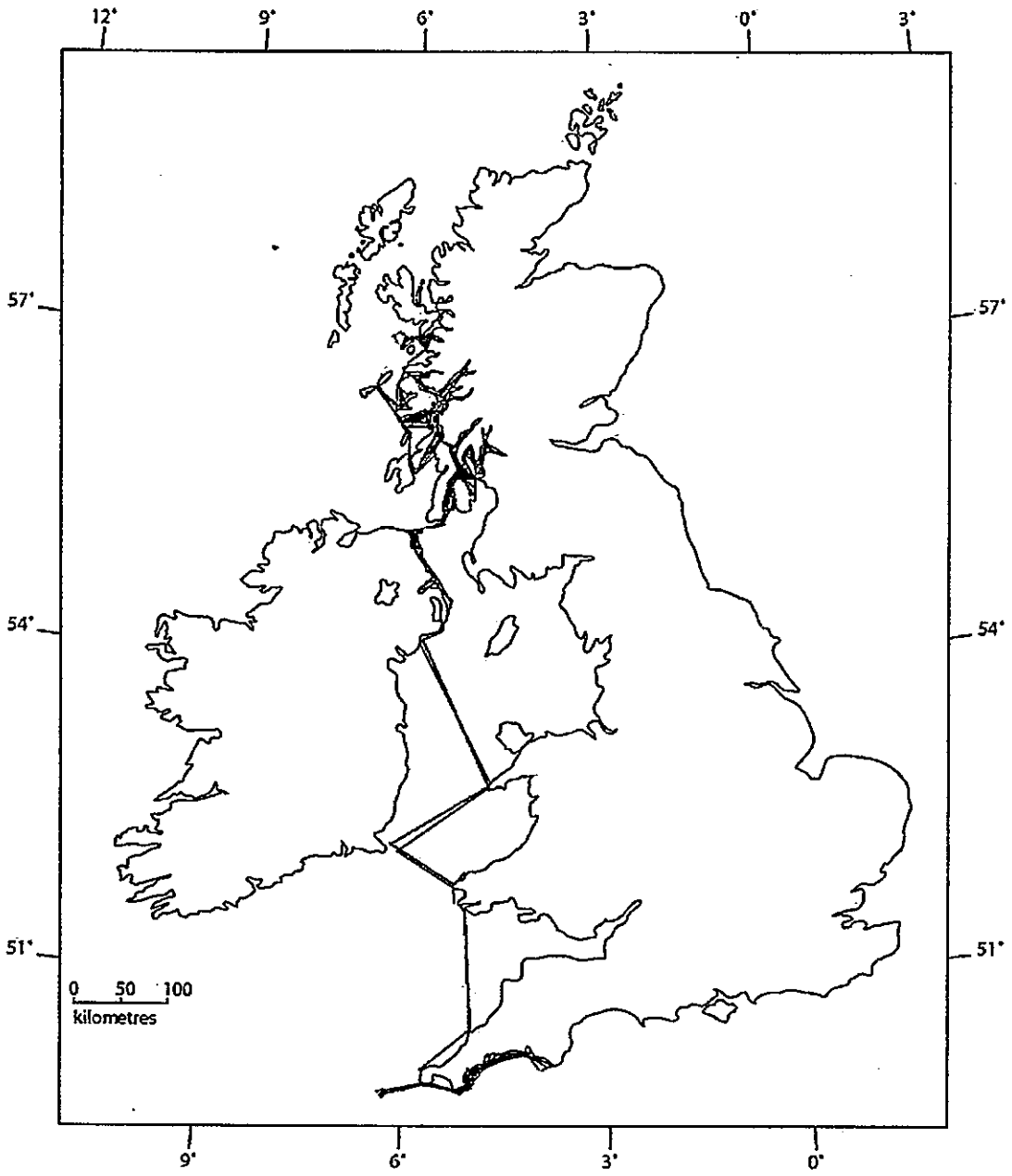
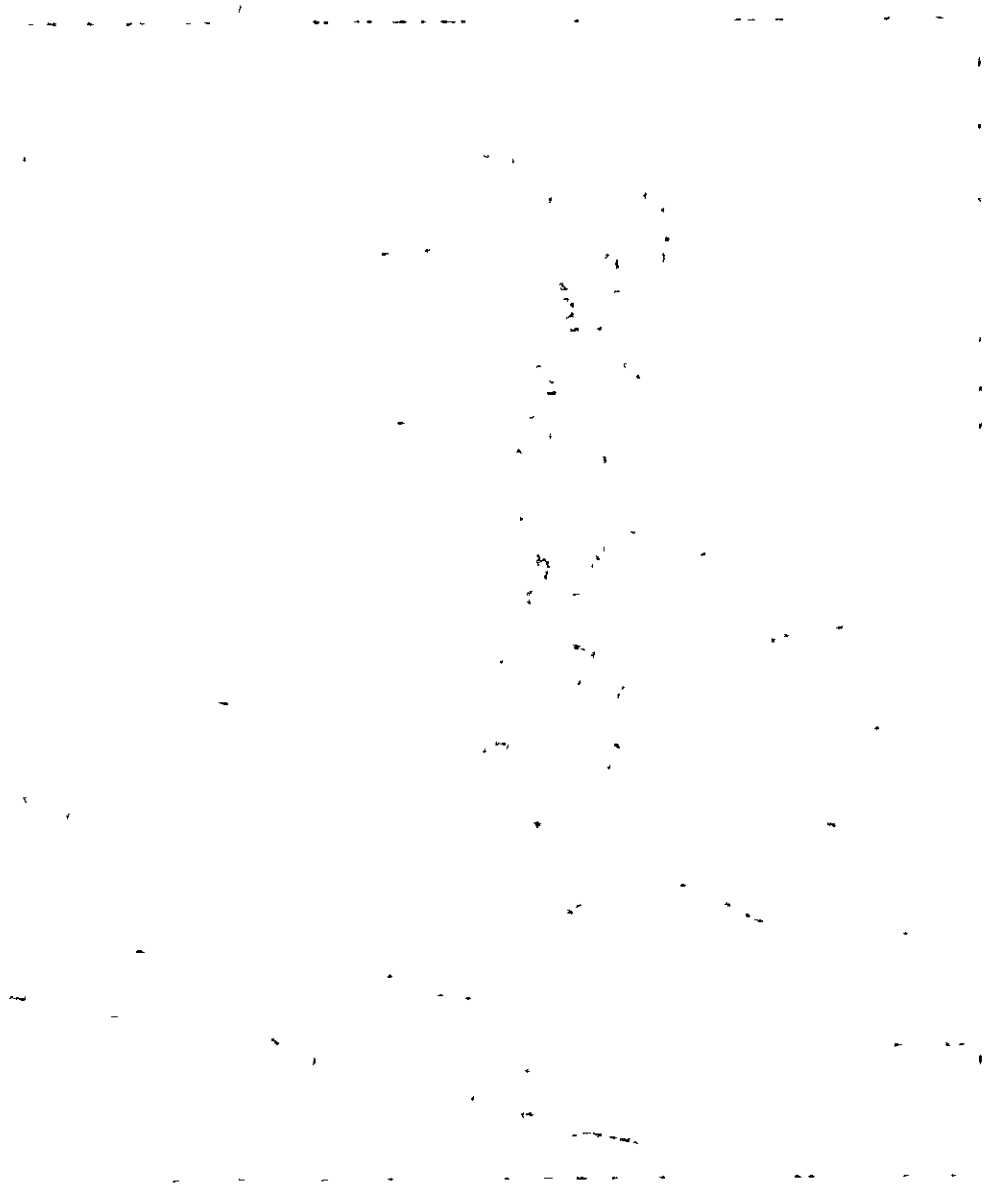


Figure 4: Effort related survey tracks completed onboard the research vessel Forever Changes between May and September, 2004, for the west coast of the UK



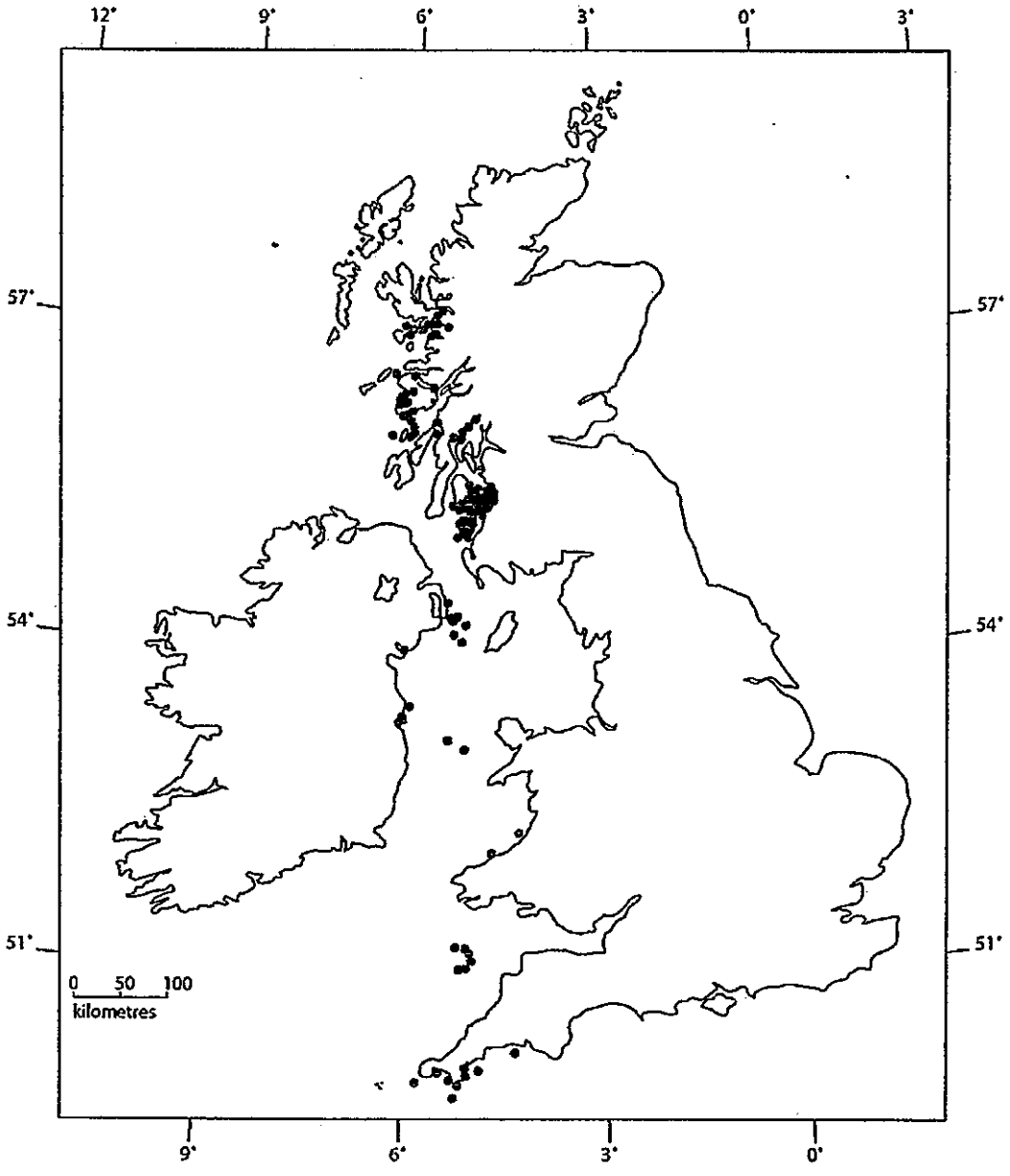
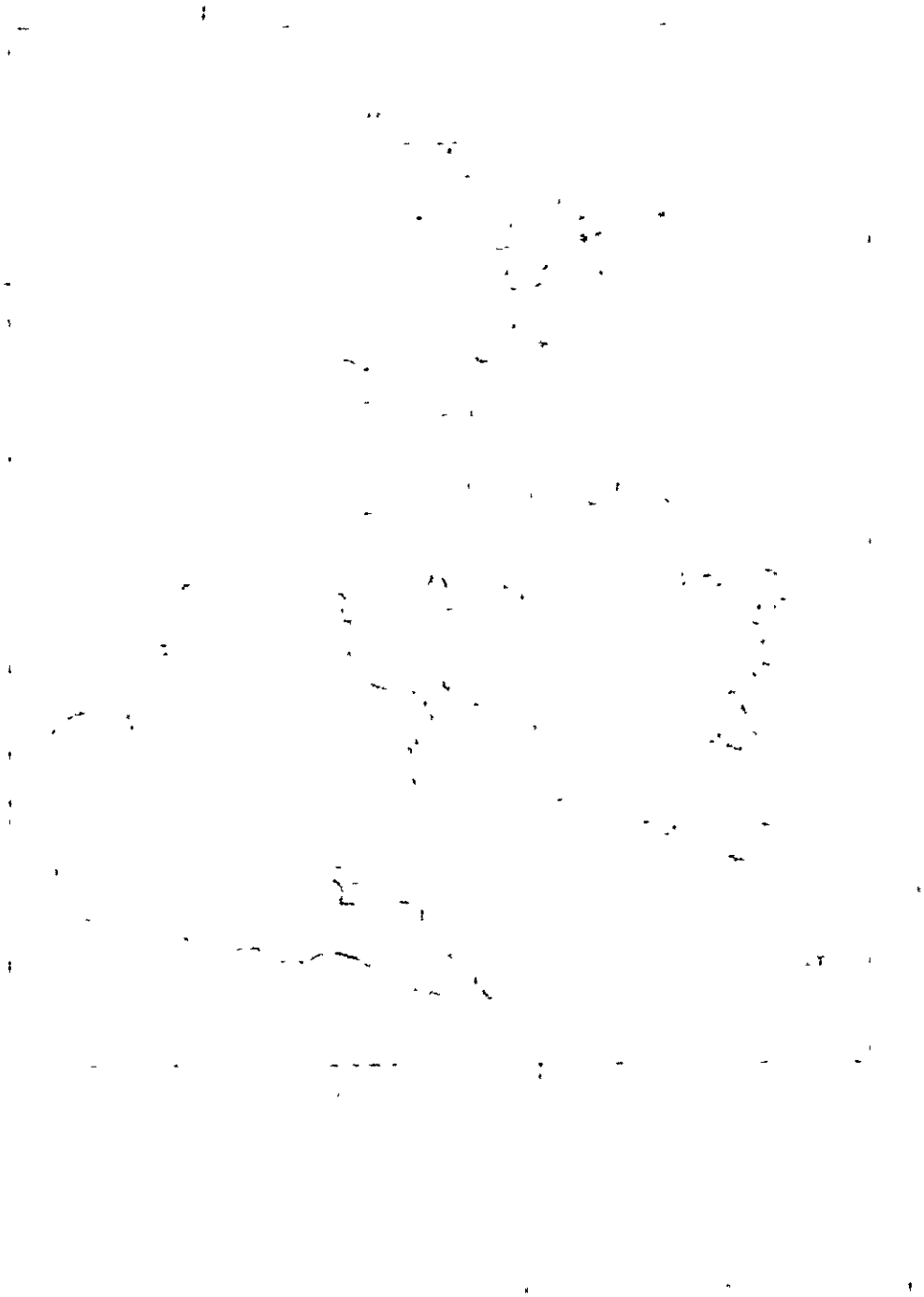


Figure 5: Location of observed harbour porpoise (*Phocoena phocoena*) groups during May – August, 2002.



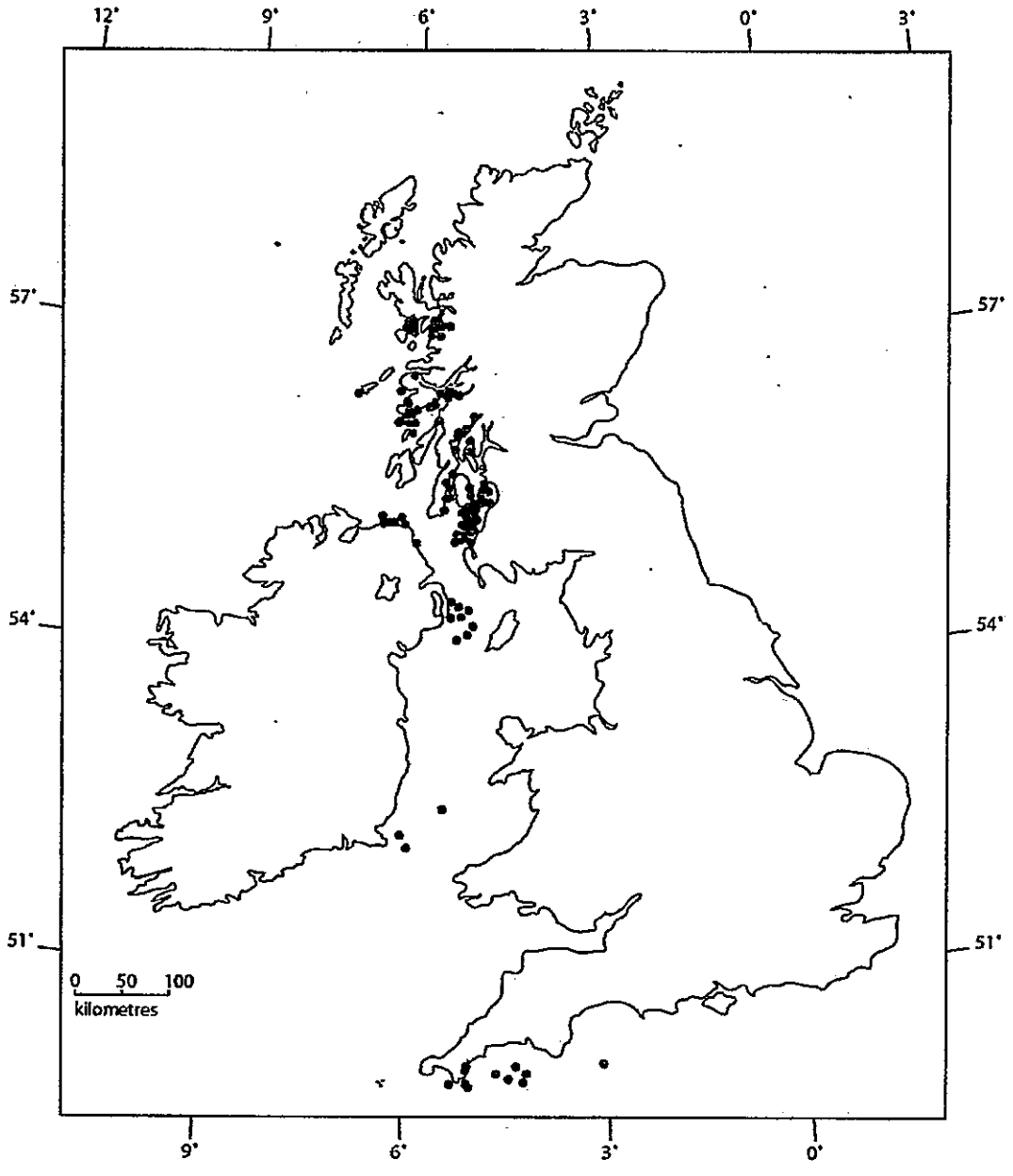
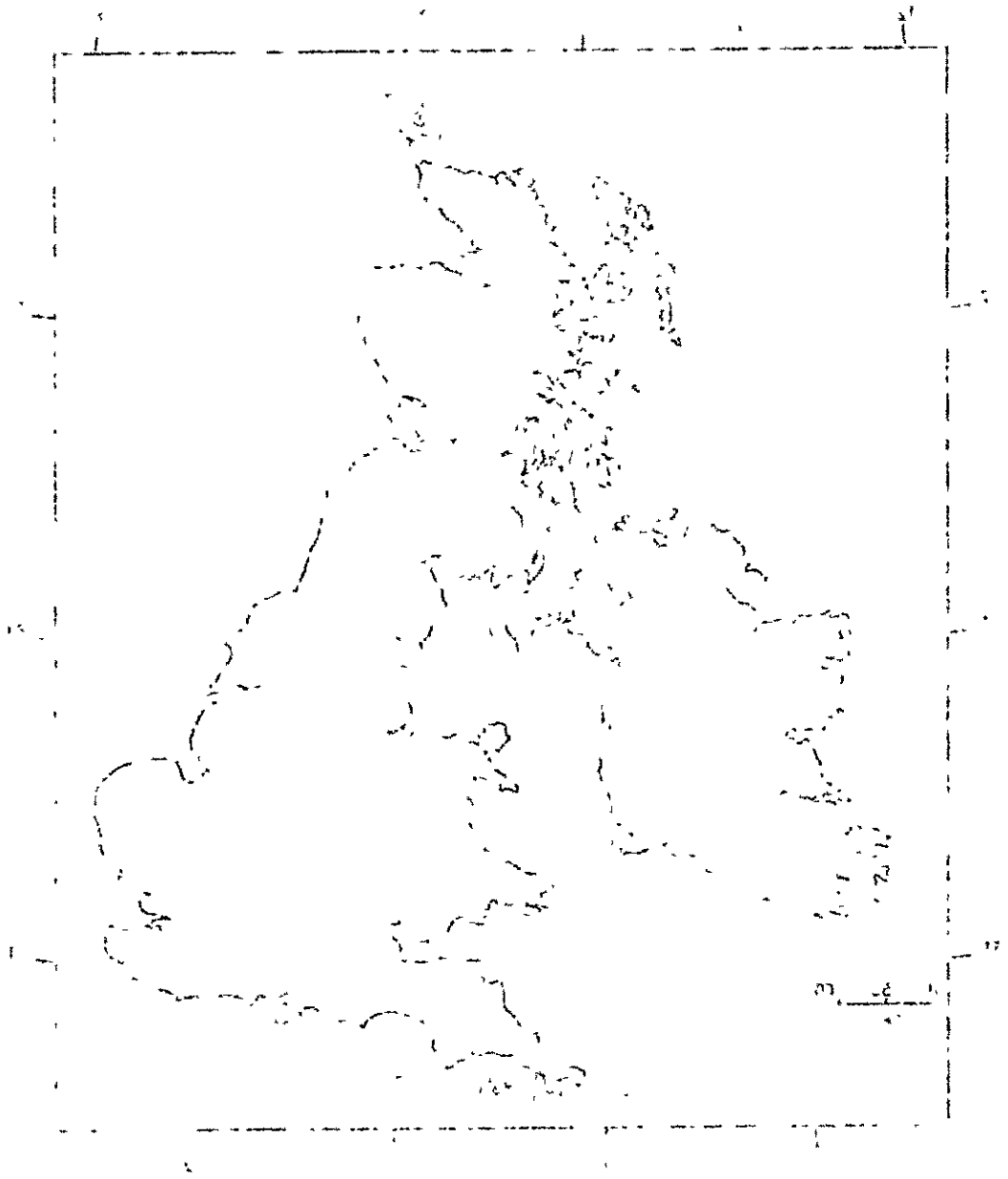


Figure 6: Location of observed harbour porpoise (*Phocoena phocoena*) groups during May – September, 2003.



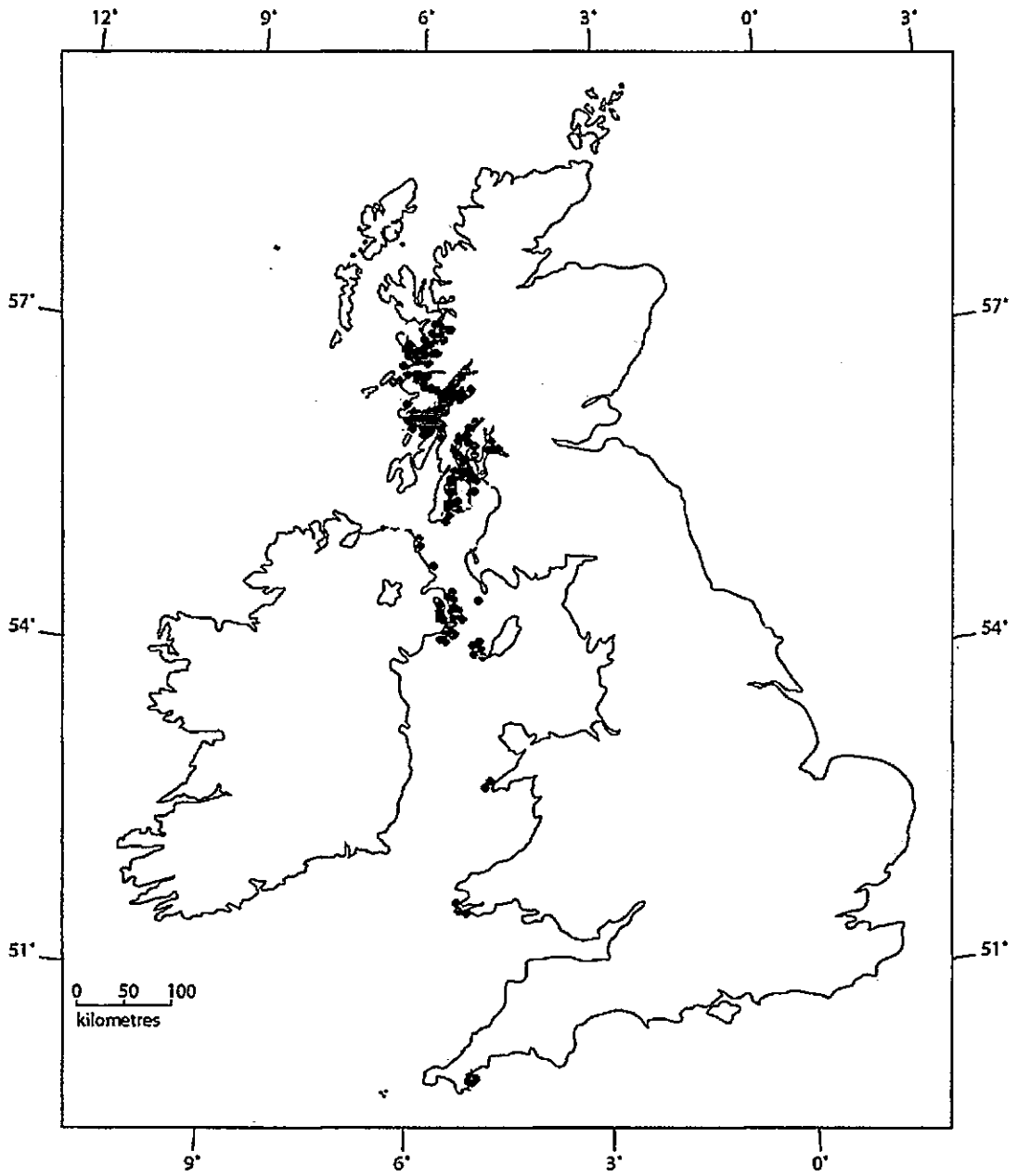
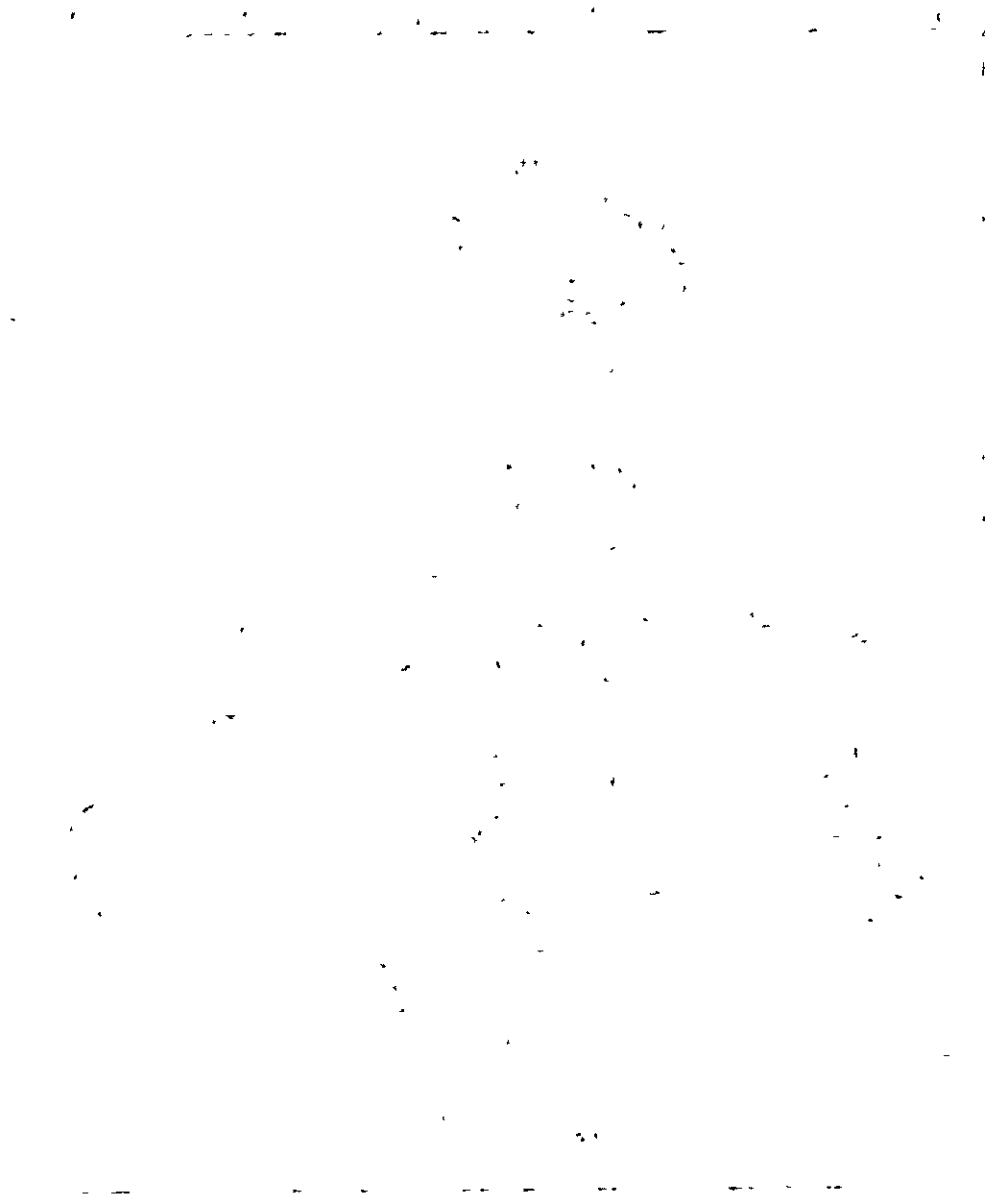


Figure 7: Location of observed harbour porpoise (*Phocoena phocoena*) groups during May – September, 2004.

Comparison of relative abundance estimates has only been made between years, as opposed to between regions due to the seasonal differences relating to when each region was surveyed. Whilst there does not appear to have been much change across the years (Table1), in each region, an ANOVA has demonstrated statistically significant differences in porpoise density for all regions across the three years



surveyed (Table 2). It is clear that relative abundance estimates over the course of the three years have declined in the South West (Table 1), whilst there has been a slight increase in numbers for the West of Scotland. Interestingly 2003 observed greater density of harbour porpoises for both Northern Ireland and the Firth of Clyde. Pooling the data over all years provided estimates of relative abundance for each area study.

Table 1: Relative abundance estimates (number of porpoises per 100km) and coefficient of variation (CV) for each sub area sampled during 2002, 2003 and 2004.

Area	2002	CV	2003	CV	2004	CV	All Years	CV
South West	**1.8**	0.388	**0.58**	0.524	**0.41**	0.500	**0.81**	0.439
Wales	**2.5**	0.503	-	-	-	-	**2.5**	0.503
Northern Ireland	**5.8**	0.508	**8.75**	0.659	**6.04**	0.783	**6.91**	0.775
Firth of Clyde	**10.6**	0.834	**15.25**	0.579	**10.76**	0.639	**12.19**	0.662
West Scotland	**24**	0.521	**23.65**	0.629	**29.75**	0.624	**26.67**	0.603

Table 2: ANOVA testing for annual differences in the number of porpoises per 100km (porpoise density) for each sub area sampled during 2002, 2003 and 2004.

Area	F	df	p
South West	5.203	44	<0.05
Wales	-	-	-
Northern Ireland	7.206	29	<0.05
Firth of Clyde	12.279	239	<0.05
West Scotland	12.984	380	<0.05

Analysis of the most recent data (2004) using DISTANCE 4.1, provided the following estimates in population size (Table 3, Figure 9).

Table 3: DISTANCE Analysis for 2004. Estimated population size (N), density (D), with upper (UCI) and lower confidence intervals (LCI) for population size and the coefficient of variation (CV) for each region.

Area	N	D	LCI	UCI	CV
South West	163	0.148	67	400	0.443
Northern Ireland	387	0.387	170	877	0.406
Firth of Clyde	1645	0.823	823	3289	0.351
West Scotland	3105	1.071	2032	4745	0.208

The effective search width was calculated for the survey as a whole after pooling the data, (ESW ± s.e.) 190.28 ± 13.42m.

Generalised Additive Modelling (GAM)

The results of the GAM suggest that position (latitude, longitude), temperature and depth were significantly related ($p<0.05$) to the presence of harbour porpoises during the combined 2002, 2003 and 2004 surveys (Table 4). The overall GAM explained 45.1% of the deviance in the porpoises presence/absence. The model was significant ($p<0.05$) and explained a greater amount of deviance (64.7%) when run using data from 2004 only, whereas only 30.2% of deviance was explained using data from 2002 (n.s.) and 59.7% ($p<0.05$) during 2003.

Table 4: Results of generalised additive models of presence/absence of harbour porpoises, including model significance and percentage of overall deviance explained. Full: data for 2002, 2003 and 2004 combined.

GAM Model	Pr(>|z|)	R^2	Deviance Explained (%)
Full	0.002	0.461	45.1
2002	0.802	0.246	30.2
2003	0.044	0.606	59.7
2004	0.037	0.656	64.7

For the combined GAM all variables had a significant relationship with harbour porpoise presence (Table 5). Of these, position (latitude, longitude) and ($p<0.01$), temperature ($p<0.001$) were significant, with an increasing number of porpoises with increasing temperature (Figure 9). Depth ($p<0.05$) depicted an increase in porpoises around the 100m depth contour (Figure 10). The number of porpoises observed during the month of June was also highlighted as being significant over the months of May, July, August and September ($Pr(>|z|)<0.01$).

Table 5: Contribution and significance (p) of environmental predictor variables for overall and yearly generalised additive models. Full: data for 2002, 2003 and 2004 combined.

Variable	Est. df	χ^2	p
Full GAM			
Long, Lat	9.630	43.74	0.00163
Temp	1.00	14.74	0.000124
Depth	3.348	14.71	0.03993
2002			
Long, Lat	8.27	28.089	0.0439
Temp	1.00	3.701	0.0544
Depth	1.00	0.195	0.6586
2003			
Long, Lat	6.279	17.82	0.1643
Temp	1.454	6.465	0.0911
Depth	3.441	13.47	0.0615
2004			
Long, Lat	1.546	11.290	0.0235
Temp	1.297	8.530	0.0362
Depth	1.000	6.621	0.0101

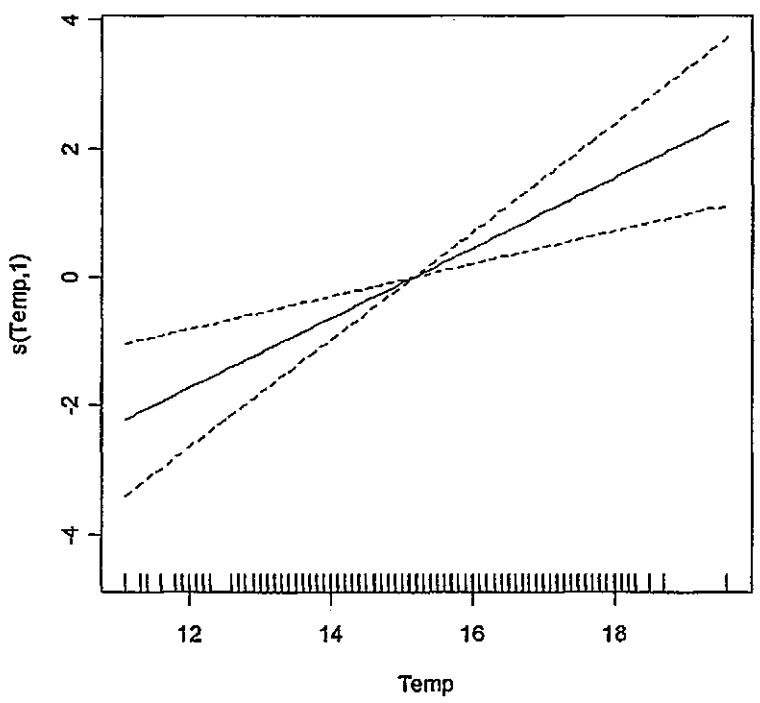


Figure 8: Generalised additive model plot for the all years, 2002, 2003 and 2004 combined (Full GAM) for harbour porpoise presence in relation to sea surface temperature.

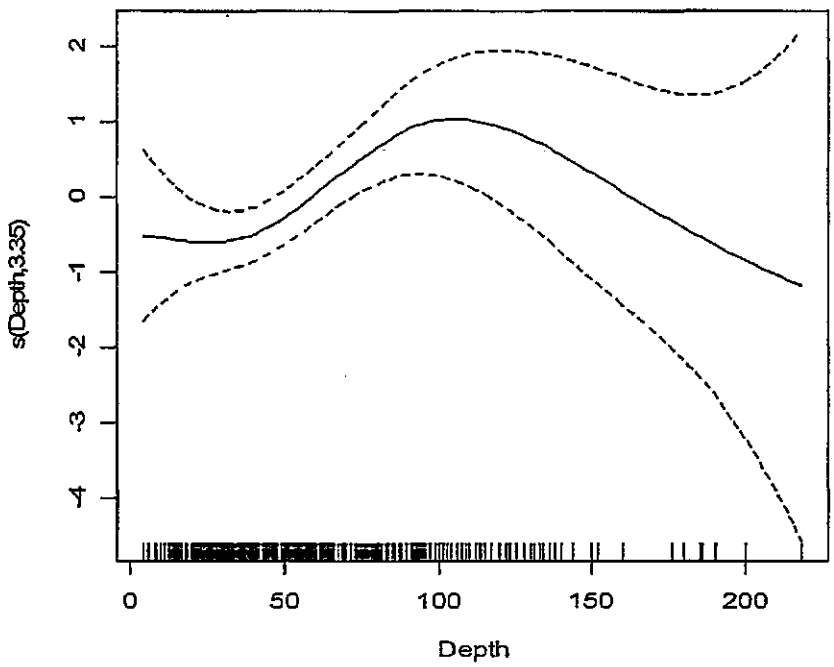


Figure 9: Generalised additive model plot for the all years, 2002, 2003 and 2004 combined (Full GAM) for harbour porpoise presence in relation to depth.

Discussion

It is clear from this data that the west coast of the UK represents an important area for the harbour porpoise during the summer months. Harbour porpoises may be observed throughout the entire west coast of the UK, being seen around the South West in May and June, throughout waters in Northern Ireland and Wales in July and around the Firth of Clyde and the West of Scotland during July, August and September.

Population estimates have been given for each region studied during 2004, however these should be examined with caution, as each estimate is seasonally dependent on the time of survey. Only through repeat surveys in additional years or through year round monitoring of the sites can accurate estimates of the population within these areas be given. The South West was found to have an estimated group of 163 (67_{LCI}-400_{UCI}) individuals during the months of May and June. This estimate is undoubtedly

smaller than the actual population for the entire region, as survey observations have only been made on the south coast. Nevertheless, as no porpoises were observed within the Channel on the SCANS survey during 1994 and only a small number of observations made in this region in 2005 it may be assumed that this is a small population, or one which is dispersed over a large area. The other alternative suggestion is that the South West population exists largely offshore. The findings of the joint WDCS (Whale and Dolphin Conservation Society) and Greenpeace 2004 winter survey demonstrated a number of sightings of harbour porpoises in offshore waters in the South Western approaches to the UK (WDCS, 2004). Indeed research has demonstrated their presence in waters as deep as 1502m off the shelf waters off the coast of Scotland, on the Rockall and Faroe Banks (MacLeod *et al*, 2003). This highlights the importance of research into new or as yet un-surveyed waters. A lack of research does not indicate a lack of animals, just as high effort in some areas does not necessarily indicate an area of critical importance for the species (Kenney & Winn, 1986).

Whilst the SCANS II survey in 2005 only identified a small number of porpoises for the South West, there has been a noticeable north to south movement of animals since the original survey conducted in 1994 (Hammond & MacLeod, 2006). The South West population therefore may have the potential to increase further, however as the region is also known to have high levels of cetacean bycatch (Goodwin & Edwards, 2007), this population may only increase if adequately protected.

Harbour porpoises also utilise coastal waters off Wales (Weir *et al*, 2001), however as data collection beyond the first year of study was not possible, no estimate of

population size for this region has been given. It is noted however that the region has been classified by Evans & Wang (2002) as a Category 1, (locations where porpoises have been recorded over several years, with a presence in every month of the year and concentrations in at least four months during April-September) warranting further attention as a protected area. At present this area is designated as an SAC for bottlenose dolphins, however there is a good case that the site should additionally be recognised for the harbour porpoise.

To date the coast of Northern Ireland has received little, if any, quantitative attention in terms of the harbour porpoise. This research identifies the presence of porpoises in the region and estimates the population to be approximately 387 (170_{LCI}-877_{UCI}) individuals, during the month of July. Whilst time spent on survey within the region is less than that required for a Category 3 classification, under the site classification criteria produced by Evans & Wang (2002) (locations where porpoises have been recorded over several years, with a presence in at least three months and concentrations in at least two months), personal communication with both local people, fishermen and Ulster Wildlife Trust would indicate that this may be a key area for the species, where they are sighted on a regular basis.

The coast of Scotland is renowned for its sightings of cetacean species (Evans *et al*, 2003; Scott & Parsons, 2004), with both the Sea Mammal Research Unit (SMRU) and the Hebridean Whale and Dolphin Trust conducting research from the coast (Stockin *et al*, 2001; Gordon & Northridge, 2003; Grellier & Wilson, 2003; Parsons *et al*, 2003; MacLeod, 2004). Despite this however, few detailed assessments of harbour porpoise population or distribution in this region have been published. This study

indicates that a population of 1645 (823_{LCI}-3289_{UCI}) exists around the Firth of Clyde and its associated waters in July, with approximately 3105 (2032_{LCI}-4745_{UCI}) further north around the Western Isles, and potentially out into Hebrides during August and September. The area from Mallaig up to the far north of Scotland has received a Category 1 classification (Evans & Wang, 2002) however no classification has been made for the region around the Firth of Clyde, where the numbers recorded in this study would indicate an area of high use by porpoises.

It must be remembered that each of these areas is seasonally restricted by the nature of the survey undertaken. The areas surveyed from June onwards are likely to have an increased sighting rate due to calving within this period. Indeed Bannon (2006) and Weir *et al* (2001) found similar increasing numbers of harbour porpoises during these months due to calving of young. Additionally, Hamazaki (2002) notes a seasonal shift in habitat use during the months of June and August, indicating that the increasing numbers observed further north, as the survey progresses up the coast may be additionally confounded by seasonal variation in habitat use.

The results of this study found a statistically significant relationship between harbour porpoise presence and temperature, however this is seasonally dependent. As the survey progressed through the summer so the sea surface temperature will have increased. Due to the time of the year and possible calving periods, as temperature was seen to increase so the numbers of porpoises will also have increased. It is not surprising therefore that the generalised additive modelling extracted temperature as being significant in porpoise distribution. What has been interesting however is the relationship with depth, observing an increasing number of porpoise sightings around

the 100m depth contour. Previous research has demonstrated significant relationships with depth for the harbour porpoise thought to be related to the distribution of prey species (MacLeod *et al*, 2003; Hastie *et al*, 2005; Molina-Schiller *et al*, 2005; Tynan *et al*, 2005;). Indeed Johnston *et al* (2005) note that distribution patterns of harbour porpoises are usually the result of foraging decisions made at a meso (10s to 100km) and fine (1-10km) scale, based on the assumption that these animals, requiring a high energy consumption, will remain near a prey patch until it becomes energetically profitable to move on (Molina-Schiller *et al*, 2005). Given their small size, energetics requirements and reliance on prey availability their patterns of movement are likely to be highly correlated with prey distribution (Johnston *et al*, 2005), which this study demonstrates is around the 100m depth contour.

Comparing the estimated porpoise density in each region for each year of the survey highlights inter-annual variation, which for the South West of the UK is potentially concerning. Whilst the SCANS surveys indicate a general increase in the last 10 years, the results of this survey from 2002-2004 indicate a decline in porpoise density for the region. Are porpoises spending more time offshore, or are the porpoises which make up the larger population size being subjected to greater amounts of cetacean bycatch in the region? The results also indicated an increase in density for Northern Ireland and the Firth of Clyde, during 2003 which then returned to 2002 figures in 2004, whilst for the West coast of Scotland the density of harbour porpoises continued increasing. This increase could represent movement of the animals from Northern Ireland and the Firth of Clyde observed in 2003 to the West coast in 2004.

These data provide a three year analysis of density and distribution of the harbour porpoise for sites along the west coast of the UK. This provides some of the first examination of the west coast for the harbour porpoise. Whilst the study is limited by the seasonal nature of the survey course, considering different areas, at different times of the year, it does provides inter-annual comparison of sites from 2002-2004. In the case of Northern Ireland these results are some of the first quantitative analysis of the harbour porpoise within the region. The GAM depicts a statistically significant relationship with depth and in particular the 100m depth contour, which is interesting to note in relation to further understanding habitat use by this species.

Although each site examined was seasonally limited this study enhances our understanding of the distribution and habitat use of this biodiversity action plan species on a wide scale.

Diurnal and Tidal variations in Habitat Use of the Harbour Porpoise (*Phocoena phocoena*) in Southwest Britain

Chapter Two

Diurnal and Tidal variations in Habitat Use of the Harbour Porpoise (*Phocoena phocoena*) in Southwest Britain

Abstract

With the UK required to designate special areas of conservation (SACs), under Nature 2000 by 2010, it is important to understand site-specific activity and habitat use in order to identify potential sites. Shore-based observations were carried out from two sites in North Devon, UK. Morte Point was surveyed during August and September, 2001 and Lee Bay was observed during August and September, 2002. Focal group follows were conducted, monitoring porpoise behaviour and movement over tidal and diurnal cycles. At Morte Point porpoises were found to aggregate in an area of high tidal flow, where prey items are likely to be abundant. Whilst no differences were observed in occurrence during diurnal and tidal cycles, group size and distance from shore were found to be statistically significant with time of day at Morte Point. Porpoises were observed feeding here 59.9% of the time, with 78% of feeding taking place in multi-species associations, with larger group sizes being observed at this site. At Lee Bay, porpoises were found to utilise an area of high heterogeneity, where rocky outcrops divide an otherwise sandy bay. In contrast to Morte Point porpoises were observed feeding at this site 27.6% of the time, spending 34.7% of the time engaged in travelling, in smaller groups. Despite these differences, behaviour and group size between the two sites were not found to be significantly different. At Lee Bay tidal variation was observed in behaviour, group size and distance from shore. It is thought that Morte Point represents an important feeding area, whilst Lee Bay provides a corridor between more productive sites. This study highlights the site-

specific nature of diurnal and tidal trends as differences in habitat use were observed for two sites geographically close together.

Introduction

The harbour porpoise (*Phocoena phocoena*) is perhaps one of the most widespread and the best studied of all the phocoenids, however significant gaps in ecological research still remain. It is found throughout coastal waters of the northern hemisphere, and in parts of the North Atlantic, North Pacific and Black Sea (Read, 1999a). Whilst some surveys have recorded the harbour porpoise in offshore waters, reaching a depth of 1502m off the coast of Scotland, on the Rockall and Faroe Banks (MacLeod *et al*, 2003), the species is generally limited by its foraging and diving capabilities to waters less than 200m in depth (Westgate *et al*, 1995; Read, 1999a ; Weir *et al*, 2001).

Around the British Isles the harbour porpoise has been recorded throughout the east coast, northwest Scotland, on the Celtic shelf and into the Channel, though sightings previously found to be few in the southern North Sea and eastern Channel (Reid *et al*, 2003), have since increased in numbers, demonstrating a north to south redistribution of individuals over the last 10 years (Hammond & MacLeod, 2006). Whilst some large-scale, effort-related and opportunistic studies have been carried out, small-scale research has primarily focused on resident groups in Scotland and Wales (Northridge *et al*, 1995; Borges & Evans, 1996; Weir *et al*, 2001; MacLeod *et al*, 2003;). Historically, porpoises were also observed regularly along the south coast of England and further offshore into the Channel, where fifty years ago their appearance was considered frequent (Tregenza, 1992), now however they are considered a rare sight. In order to adequately conserve the harbour porpoise it is important to accurately

describe and understand the processes that determine distribution on both a small and large scale (Johnston *et al*, 2005; Redfern *et al*, 2006).

Being small in size, with a high energetic demand on fitness, availability to prey is an important consideration for the harbour porpoise and so their distribution is often correlated with that of their prey (Johnston *et al*, 2005). Previous research has identified diurnal trends in both movement, behaviour and feeding for many species (Saaymann *et al*, 1973; Shane *et al*, 1986; Brager, 1993). In particular, the Tucuxi (*Sotalia fluviatilis*) move from open water into lakes and bays in the morning, only to return again in the afternoon (DaSilva & Best, 1994). Humpback dolphins (*Sousa chinensis*), Dall's porpoises (*Phocoenoides dalli*), Hector's dolphins (*Cephalorhynchus hectori*) and bottlenose dolphins (*Tursiops truncatus*) have also been shown to demonstrate diurnal variation in both behaviour and movements (Amano *et al*, 1998; Karczmarski & Cockcroft, 1999; Bejder & Dawson, 2001). Dall's porpoises demonstrate diurnal feeding patterns in relation to the migrations made by their prey species (Amano *et al*, 1998). They have also demonstrated a degree of behavioural plasticity, similar to that observed in the bottlenose dolphin (Shane *et al*, 1986), altering feeding times in relation to prey availability (Amano *et al*, 1998). A review of diurnal rhythms in Cetacea (Klinowska, 1986) indicates that for most species, where data are available, some form of diurnal pattern in feeding has been identified. What is not clear is whether such patterns are a result of internal clocks, external cues or a result of diurnal rhythms in prey species.

Further research has concentrated on behavioural and distributional patterns linked to tidal cycles, although these are generally less common in cetacean species (Stevick *et*

al, 2002). In the UK, Gregory & Rowden (2001) studied bottlenose dolphins at two sites in Wales. They analysed sightings information with respect to tidal state, time of day and boat traffic. While no pattern was observed with time of day, dolphin movement was correlated with tidal state, with dolphins moving with tidal flow, or during slack water. Although Shane (1980) found that bottlenose dolphin movements in Texas were also correlated with tidal movement, dolphins were found to move against the tidal flow. Humpback dolphins have also been found to move into near shore areas, including mangroves and rivers, with the tide (Ross *et al*, 1994). This clearly demonstrates an increase in spatial utilisation of the area, in search of prey. More recently, Mendes *et al* (2002) found that bottlenose dolphins were more abundant on the flood tide than during slack water, which is thought to be due to increased foraging efficiency due to the resultant accumulation of prey.

The activity and habitat use of the harbour porpoise however, has not been extensively studied. Knowledge of this species is limited due to the difficulties associated with studying them at sea. They are relatively small in size, do not possess individual markings (Koopman & Gaskin, 1994) and spend only 5% of their time on the surface (Westgate *et al*, 1995). Previous research which has monitored porpoise movements with satellite telemetry (Read & Westgate, 1997), indicate that porpoises in the Bay of Fundy may spend periods of time, ranging from days to weeks, in rather restricted areas. It is believed that their movements relate to aggregations of herring (*Clupea harengus*), a primary prey item for harbour porpoises in Canada (Borjesson *et al*, 2003). Data published by Neave & Wright (1968) suggest that individual porpoises make discrete migrations into a wider geographic area. It is not thought that

these movements are temporally co-ordinated, but they suggest that these may be as a result of fluctuating prey densities.

In the UK harbour porpoises have been found to be distributed in relation to their prey, which largely consists of pelagic and demersal species, including sandeels (*Ammodytes sp.*) and gadoids during the summer months, with whiting (*Merlangius merlangus*) being consumed during the winter and herring (*Clupea harengus*), sprat (*Sprattus sprattus*), gobies (Gobiidae) and mackerel (*Scomber scombrus*) consumed year round (Santos *et al*, 2004). Off the coast of west Wales, Pierpoint *et al* (1994) have described leaping behaviour in the harbour porpoise, which seemed to occur during foraging behaviour. In southeast Shetland, Scotland, porpoise distribution was also found to be correlated with prey items (Borges and Evans, 1996). In Mousa Sound, Scotland, porpoises were found to generally move in the opposite direction to tidal flow, though they were observed at all states of the tide (Evans, 1997).

The objective of this research is to provide data on the activity and habitat use of the harbour porpoise on a small scale, examining two sites, which are oceanographically quite different, but are in relative close proximity along the coast. The current UK Biodiversity Action Plan for the harbour porpoise highlights the need to expand research into areas frequented by harbour porpoises. This will enable the identification of waters that may qualify for further protection as Special Areas of Conservation (SACs). Whilst no such areas have yet been designated, despite an analysis of the UK coastline by Evans & Wang (2002), this has subsequently become of key importance as the UK Government has committed to establish a coherent network of marine protected areas, which will support Natura 2000, by 2012 (Bull &

Laffoley, 2003, Kelleher & Phillips, 1999). Evans & Wang (2002) identified sites based on levels of presence throughout the year. Both the sites selected in this study qualified for category 1 classification by Evans & Wang (2002) which states that "*porpoises have been recorded over several years, with a presence in every month of the year and concentrations in at least four months during the period April-September*". This study will test the hypothesis that porpoises differentially use the sites through the examination of shore-based observational data. It will consider diurnal and tidal variation with comparison of the activity budget between the sites.

Methods

Study Site: Morte Point, Mortehoe, North Devon

Morte Point (51° 11.290'N, 04° 13.559'W) is a large headland of National Trust land, which protrudes out between Woolacombe Bay and Rockham Bay, North Devon. From the study site an area of approximately 3.83 km^2 can be viewed, which includes the Morte Stone channel buoy (51° 11.02'N, 04° 15.00'W) and the area just beyond it, and stretches as far east as Bull Point (51° 11.934'N, 04° 12.123'W). Although the area up to Bull Point may be observed, not all of this was included in the study site as sighting efficiency decreases with distance (Findlay & Best, 1996). A total study area of 0.80 km^2 was surveyed, from a height above sea level of approximately 65m.

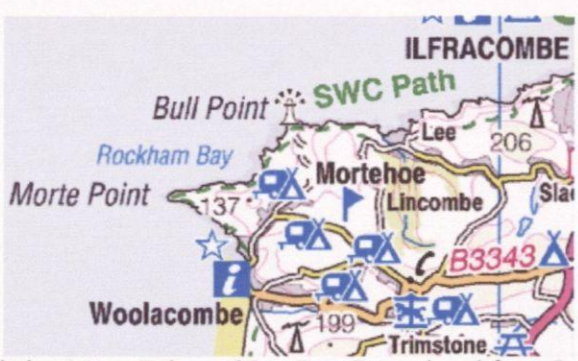


Figure 1: Study site, depicting Morte Point and Lee Bay. Reproduced from Ordnance Survey map data by permission of Ordnance Survey, © Crown copyright.

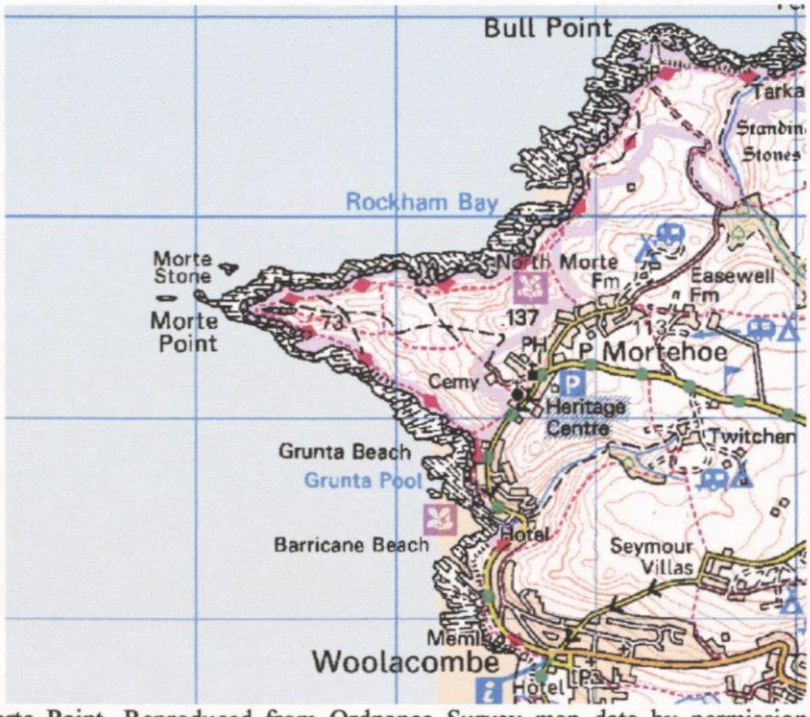


Figure 2: Morte Point. Reproduced from Ordnance Survey map data by permission of Ordnance Survey, © Crown copyright.

The seabed surrounding Morte Point consists mainly of sand, shingle and gravel, alternating between gravel and fine sand further out. The Morte Stone buoy not only marks the large rock formations, which protrude out into the sea, but also marks an area of tidal rapids, which form due to the prominent nature of the point. These rapids vary from 0.1 – 1.5 knots during neap tides and 0.3 – 3.2 knots during spring cycles.

The levels of boating traffic were recorded continuously throughout the study. Although small fishing boats utilise the area close inshore, their numbers are few (1-2 vessels per watch). The area is generally quiet in terms of marine traffic, with only one boat offering coastal tours and all large cargo ships remaining on the horizon (approximately 4.6 km offshore). Therefore all porpoise behaviour recorded is presumed to be that of undisturbed individuals.

Study Site: Lee Bay, Lee, North Devon

Lee Bay (51° 11.918'N, 04° 10.764'W) is a relatively small inlet, situated further east around from Bull Point. The cliffs however on the western side of Lee provide good views over the area. Two cliff formations on either side delimited the study area, although sighting efficiency with distance was once again taken into consideration, a total area of 0.68 km^2 was studied, from an elevation of approximately 30m above sea level.

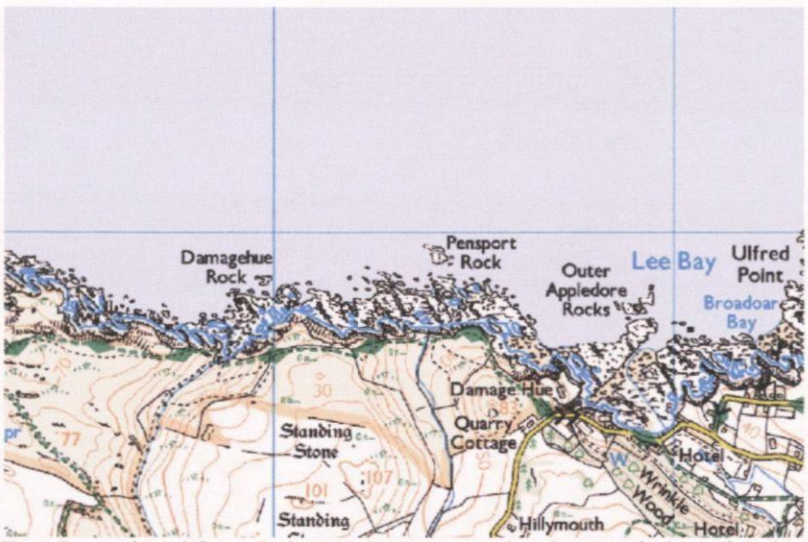


Figure 3: Lee Bay. Reproduced from Ordnance Survey map data by permission of Ordnance Survey, © Crown copyright.

The seabed in Lee Bay is largely homogeneous, consisting of fine sand, with gravel patchily distributed. A number of submerged rock formations are present at the base of the cliffs on either side of the bay. Although no strong tidal rapids exist within the study area, those that form off Bull Point may be viewed on the far western side of the area.

As with Morte Point, Lee Bay receives little marine traffic, despite its proximity to the port of Ilfracombe. Here small fishing boats set and check lobster pots and pass

through the area (1-2 fishing vessels per watch). All other traffic remains on the horizon.

Shore-based observations

At both sites, a number of shore-based observations were conducted. At Morte Point these were carried out between August and September 2001, and consisted of watches centered on either high or low tide, with watches conducted over 4 hour periods ensuring that all times of day were observed. Similarly, Lee Bay was surveyed during August and September 2002, when once again shore-based observations were conducted over a 4 hour period. After this time it was assumed that observer effort and sighting efficiency would decrease (Findlay & Best, 1996).

During a watch the area was scanned every fifteen minutes, using a telescope and a pair of binoculars. When a group of porpoises entered the area they were surveyed using a focal group follow (Mann, 2000), which lasted either until the watch ended or until the porpoises left the study area. The porpoise's behaviours were monitored continuously with the aid of a dictaphone and positional data were logged using a sighting compass and local landmarks. The area was subdivided into bands with the aid of headlands, cliffs and rock formations to facilitate distance estimation and to provide a second fix on the porpoise's position. Given the site, distance of the porpoises from the shore and the size of the species involved, this was deemed to be the most appropriate method of position fixing. Minimum group size was also recorded which was defined as the total number of animals observed at the surface at any one time. Porpoise behaviour was classified using an ethogram of 6 categories:

feeding, travelling, resting, social interactions, avoidance, other (Shane *et al*, 1986). In this study they were classified as follows:

- Feeding, recorded when porpoises were observed chasing or in association with fish. Due to the distance and speed of the fish it was impossible to state with any accuracy the species of fish involved. Communication with local fishermen indicated that mackerel and herring were the most frequently caught species within the area. When groups of porpoises were observed in association with feeding seabirds, usually northern gannets (*Morus bassanus*), it was assumed that the porpoises were engaged in feeding behaviour (Camphuysen & Webb, 1999).
- Travelling was defined as a constant movement in a particular direction.
- Resting was categorised as surfacing and slow or undirectional movement within a given area.
- Social interactions were classified when more than one porpoise engaged in leap, chase, or surface rushing behaviour when there was no evidence of feeding or directed travel.
- Avoidance was recorded when the animals were observed, in association with another animal, object or marine vessel, to change direction, dive (>5minutes), or leave the area entirely.
- Other, this category was established for when behaviour could not be classified into one of the above.

Any other interactions either with marine traffic, other wildlife (e.g. seals or birds) were also recorded.

During watch periods conducted over the course of eight weeks, porpoises were observed for a total of 22.25 hours at Morte Point. Similarly, over eight weeks at Lee Bay, a total of 18 hours were spent observing the porpoises. Although positional data were recorded continuously, preliminary analysis revealed that a time interval of fifteen minutes was required to ensure that the data were temporally independent (Swihart & Slade, 1985). This was completed by plotting all positions for two watch periods on a chart of the area. The chart was divided into sections, dictated by 5 degrees vertical sections and horizontal banding as indicated by landmarks. The mean time for the porpoises to cross a boundary line was calculated. This ensures that results are not skewed by porpoises repeatedly resurfacing in an area, unless they are utilising this area for greater than fifteen minutes. It is recognised that this could represent either the same group resurfacing in the same area, a new group or the addition of new individuals to the group already recorded. Compass bearings were used to divide the study site into sectors. The size of the bands increased with distance offshore, up to a cut off point, at which sighting individual porpoises was unreliable. Therefore the final band is smaller than the one preceding it; this is also amplified by the utilisation of natural landmark as boundaries. This means that sections in band 1 (closest to the shore) at Morte Point were $0.004km^2$, band 2 = $0.007km^2$, band 3 = $0.03km^2$, band 4 = $0.01km^2$. For Lee bay, band 1 = $0.004km^2$, band 2 = $0.02km^2$ and band 3 = $0.007km^2$. At Lee Bay only 3 bands were allocated. The site was not as elevated as that of Morte Point and so a smaller study area was viewed. If the null hypothesis that porpoises show no habitat differences is correct, then counts per unit area (porpoise densities) should be proportional to area across both study sites. Dividing the total number of sightings (in any one watch) by the total area of the site resulted in an expected density of 1 porpoise sighting per $10,000m^2$ at Morte Point and

1 porpoise sighting per 25,000m^2 at Lee Bay. A chi-squared test was used to determine whether these expected values are correct or whether the distribution of porpoises varied from this.

The hypothesis that harbour porpoise sightings show variation with respect to tidal and diurnal variation was also tested using a G test to compare number of sightings per unit effort in respect of flood tide, high tide, ebbing tide and low tide for both morning (10:00 – 14:00) and afternoon (14:00 – 16:00) watch periods. Harbour porpoise behaviour (feeding, travelling, resting, socialising, avoidance, other), group size (1-6(+)) and distance from shore (bands 1-4) were also tested assuming the hypothesis that variation in the above mentioned factors occurs with respect to time of day (morning, afternoon) and tidal state (flood, high, ebb, low). A three level, nested analysis of variance (ANOVA) was conducted for each factor and time of day and tide simultaneously at each of the study sites (Morte Point & Lee Bay). Total duration spent engaged in each behavioural category and minimum group size for each site was also calculated and plotted. Behavioural observations (activity budget) and the group sizes observed at each site were compared using a Mann-Whitney U test.

Results

Morte Point

After assessment to ensure temporal independence, a total of 68 sightings were used from 8 weeks of data collation. Porpoise sightings were found to be tightly clustered in one area of the bay ($\chi^2_{(6)} = 14.19$, $p<0.01$), where 29 of the 68 sightings were observed (Figure 4).

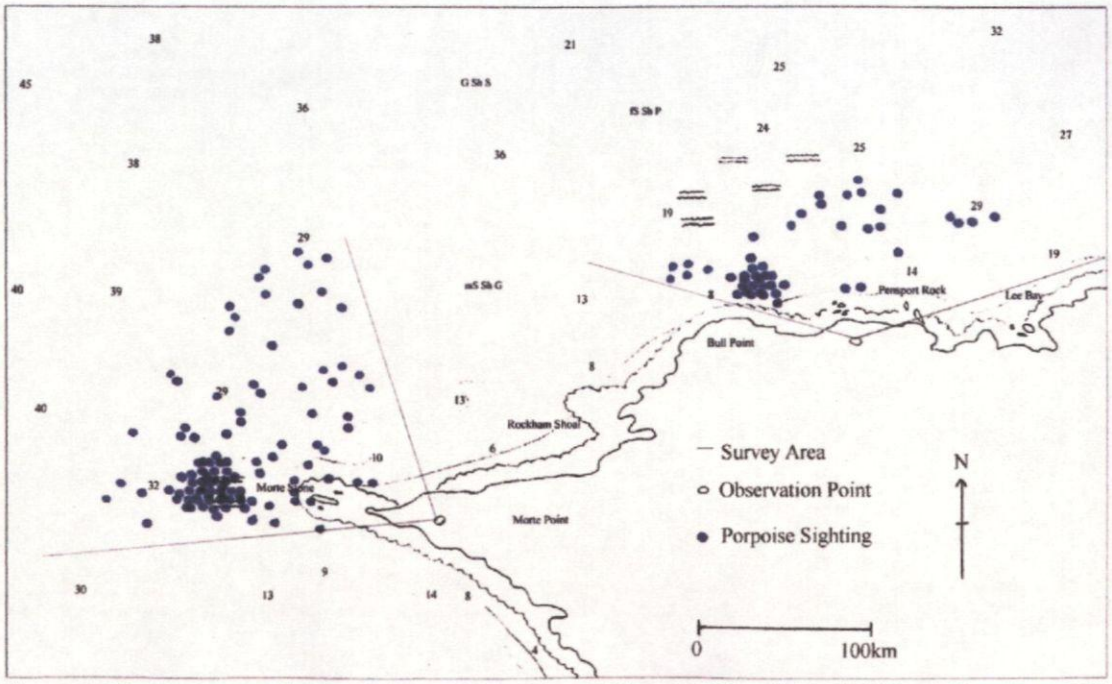


Figure 4: Map, encompassing both sites: Morte Point (51° 11.290'N, o4° 13.559'W) and Lee Bay (51° 11.918'N, 04° 10764'W), North Devon, UK and position of all porpoise sightings.

Porpoises were observed throughout the majority of both diurnal and tidal cycles with no statistically significant difference between sightings (G_{adj} = 3.559, df = 3, p=0.469). Equally when behaviour was examined (Figure 5) no significant difference between tidal or diurnal states was observed (F_{47} = 2.251, p = 0.184 (time of day); F_{47} = 2.091, p = 0.076 (tidal state)). However when the data were analysed for group size (F_{47} = 8.338, p<0.05 (time of day); F_{47} = 1.346, p = 0.260 (tidal state)) and distance from shore (F_{31} = 14.587, p<0.05 (time of day); F_{31} = 0.507, p = 0.797), statistically significant differences were observed with time of day (Figures 6 and 7).

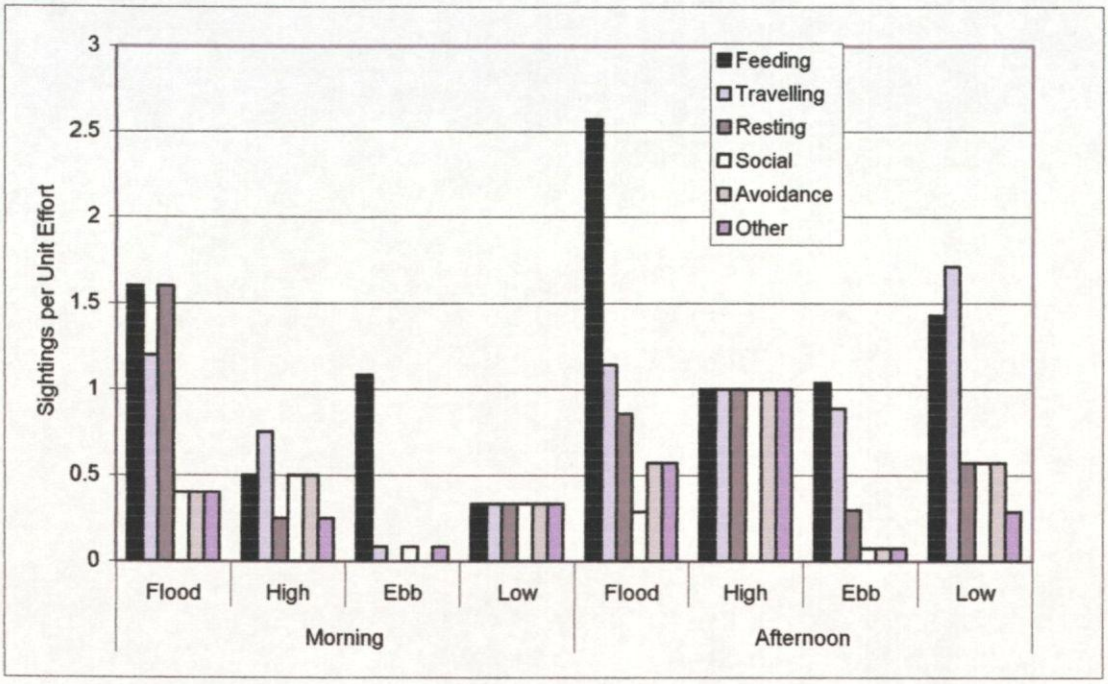


Figure 5: Sightings per unit effort for each behavioural category observed (feeding, traveling, resting, social interactions, avoidance and other) during morning and afternoon watch periods in each tidal state at Morte Point.

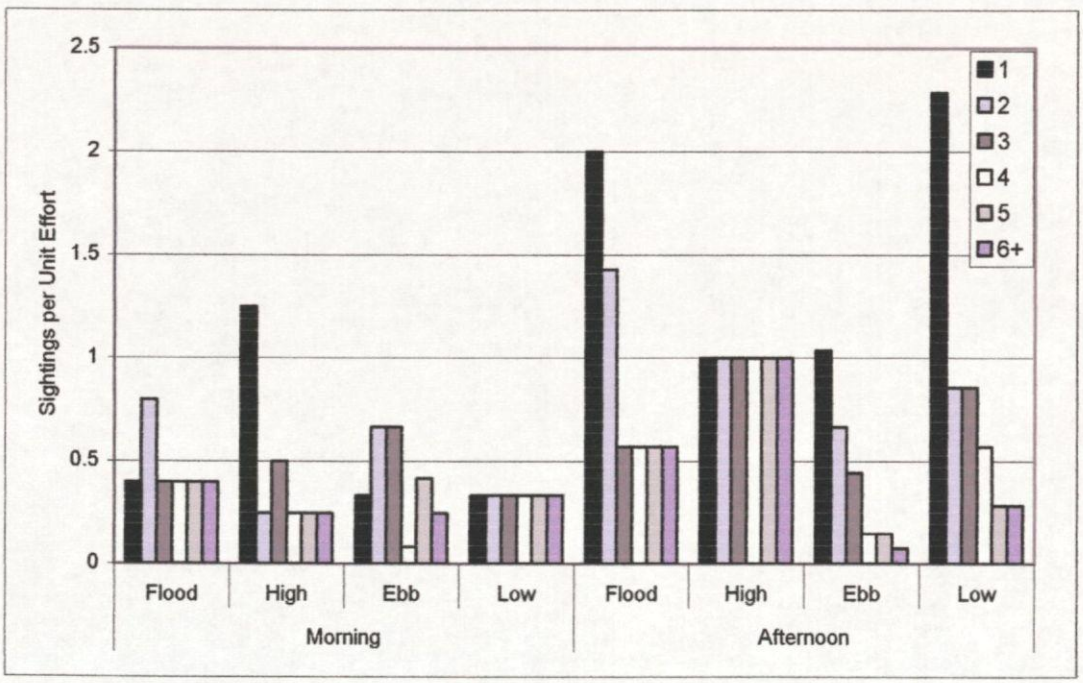


Figure 6: Sightings per unit effort for each group size recorded, during morning and afternoon watch periods in each tidal state at Morte Point.

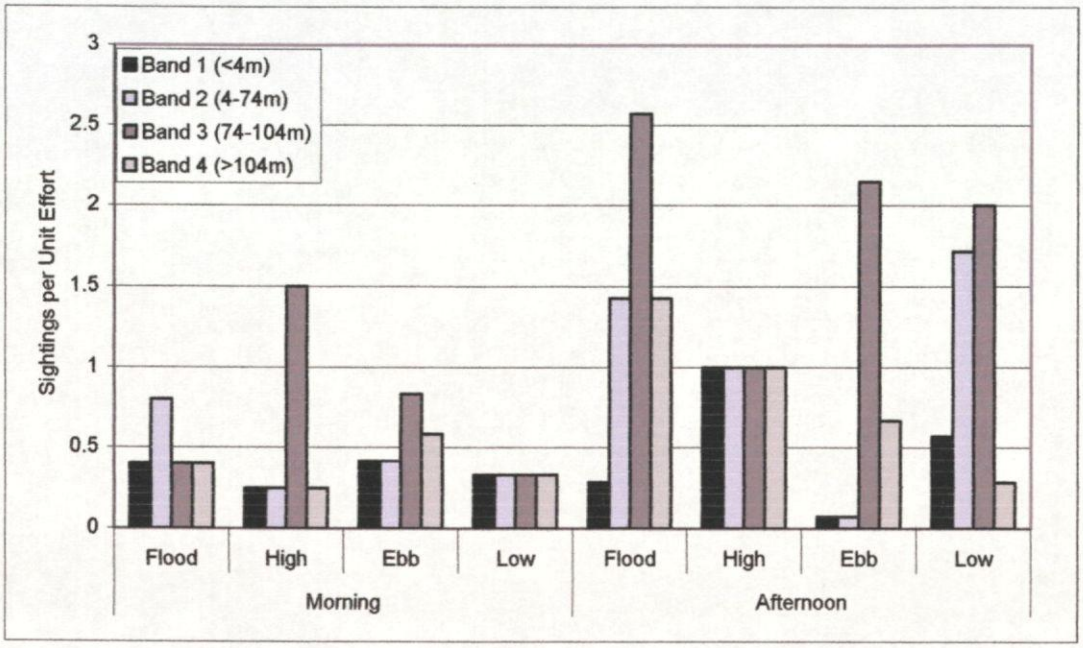


Figure 7: Sightings per unit effort observed in each band (distance from shore), during morning and afternoon watch periods in each tidal state at Morte Point.

Harbour porpoises were observed feeding throughout all tidal and diurnal cycles at Morte Point and although not statistically significant a greater proportion of feeding observations occurred during a flood tide. Group sizes were found to decrease during the afternoon, although high tide appeared to produce aggregations of a number of different sized groups, perhaps coming together to feed. Whilst porpoises' distance from shore was evenly distributed during the morning, with the exception of high tide when they were observed in band 3 (74-104m offshore), during the afternoon they were found in band 3 more frequently. In particular harbour porpoises appear to utilise this band with greater frequency during an afternoon flood and ebb tide.

Lee Bay

A total of 25 sightings were used in the analysis, after assessment for temporal independence. As porpoises were not observed in a large proportion of the study area ($0.5km^2$), grid cells were made larger, totaling 6 cells within each band. Porpoise

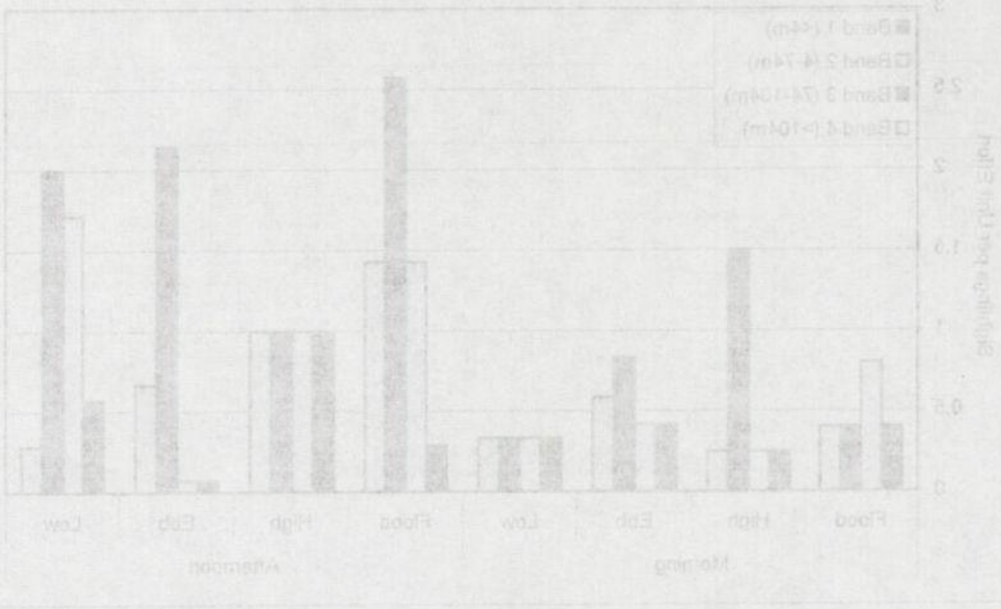


Figure 7. Sightings per unit effort observed in each band (distance from shore) during morning and afternoon watch periods in each tidal state at More Point.

Harbour porpoises were observed feeding throughout all tidal and diurnal cycles at More Point and although not statistically significant a greater proportion of feeding observations occurred during a flood tide. Group sizes were found to decrease during the afternoon, although high tide appeared to produce aggregations of a number of different sized groups, perhaps coming together to feed. Whilst porpoises' distance from shore was evenly distributed during the morning, with the exception of high tide when they were observed in band 3 (7.4-10.4m offshore), during the afternoon they were found in band 3 more frequently. In particular harbour porpoises appear to utilise this band with greater frequency during an afternoon flood and ebb tide.

Lee Rex

A total of 25 sightings were used in the analysis, after assessment for temporal independence. As porpoises were not observed in a large proportion of the study area (0.5km²), grid cells were made larger, totaling 6 cells within each band. Porpoise

sightings were however found to be aggregated in one area of the study site ($\chi^2_{(6)}$ = 33.66, p<0.001) (Figure 4).

Unfortunately due to adverse weather conditions during some of the survey periods, no observations were made during low tide. Therefore the tidal analysis carried out here utilises observations made during either flood, high or ebbing tides. Porpoises were however observed throughout the majority of both diurnal and tidal cycles with no statistically significant difference between sightings (G_{adj} = 0.7149, df = 2, p=0.949). When behaviour (F_{35} = 0.485, p = 0.524 (time of day); F_{35} = 21.197, p< 0.001 (tidal state)), group size (F_{29} = 1.197, p = 0.335 (time of day); F_{29} = 5.553, p< 0.05 (tidal state)) and distance from shore (F_{23} = 0.483, p = 0.525 (time of day); F_{23} = 6.322, p<0.05) were analysed statistically significant differences were observed with tide on all accounts (Figures 8, 9 and 10).

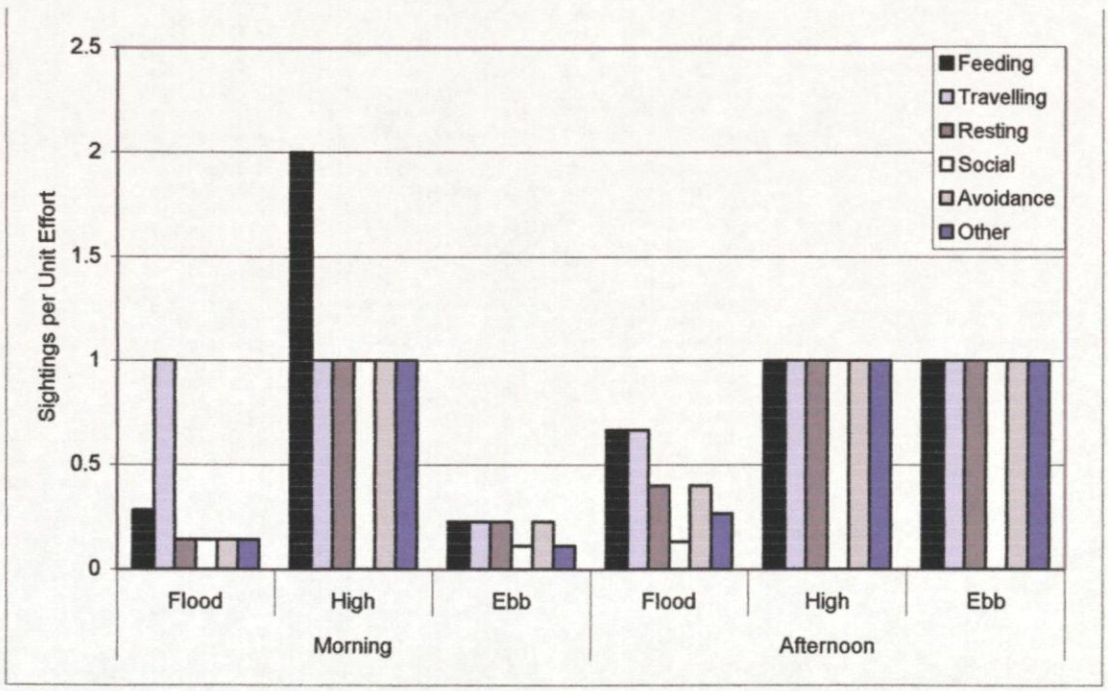


Figure 8: Sightings per unit effort for each behavioural category observed (feeding, traveling, resting, social interactions, avoidance and other) during morning and afternoon watch periods in each tidal state at Lee Bay.

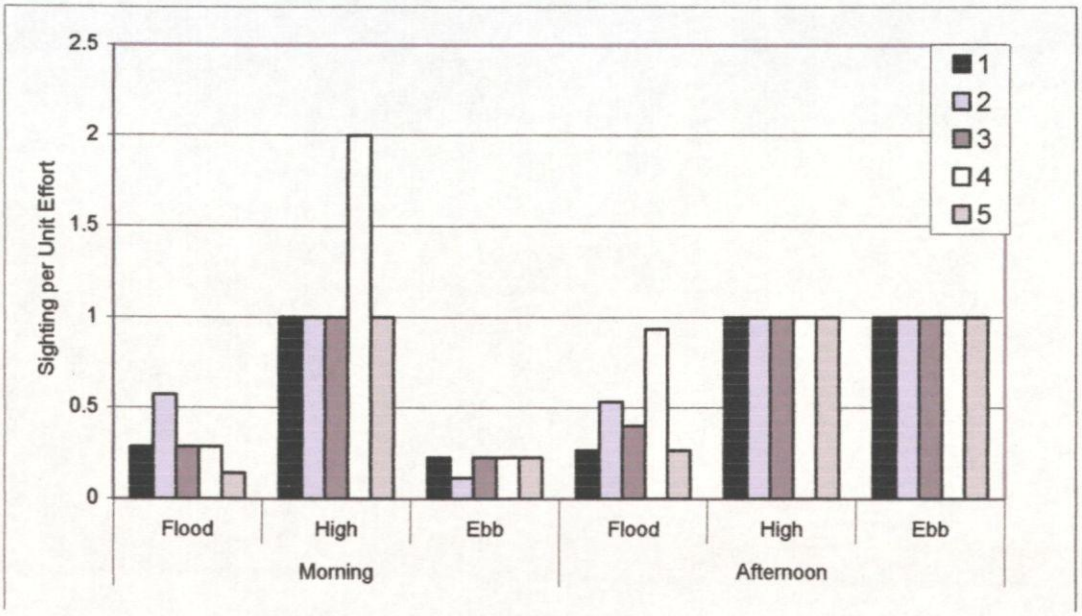


Figure 9: Sightings per unit effort for each group size recorded, during morning and afternoon watch periods in each tidal state at Lee Bay.

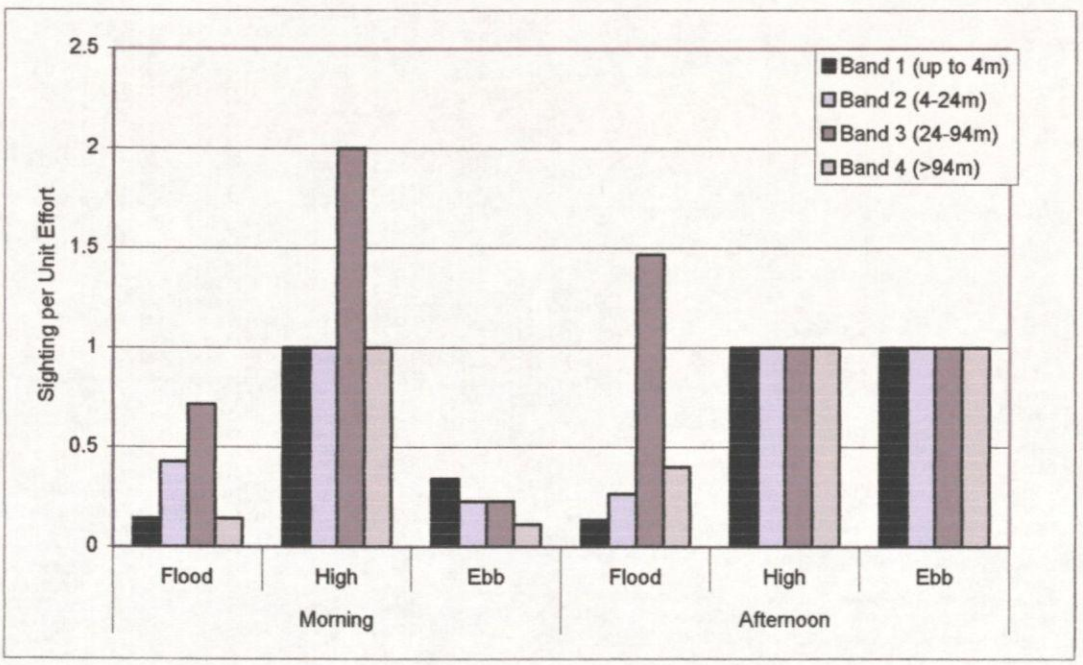
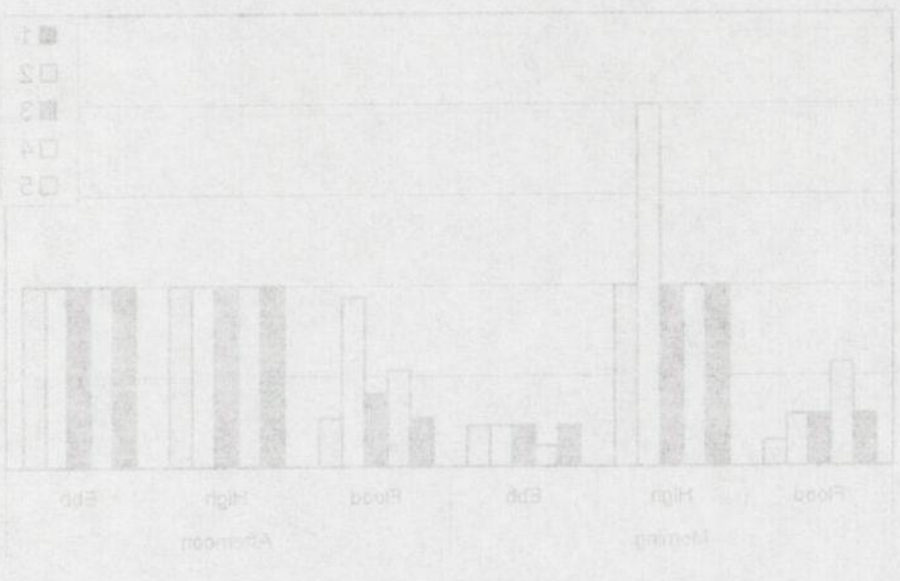
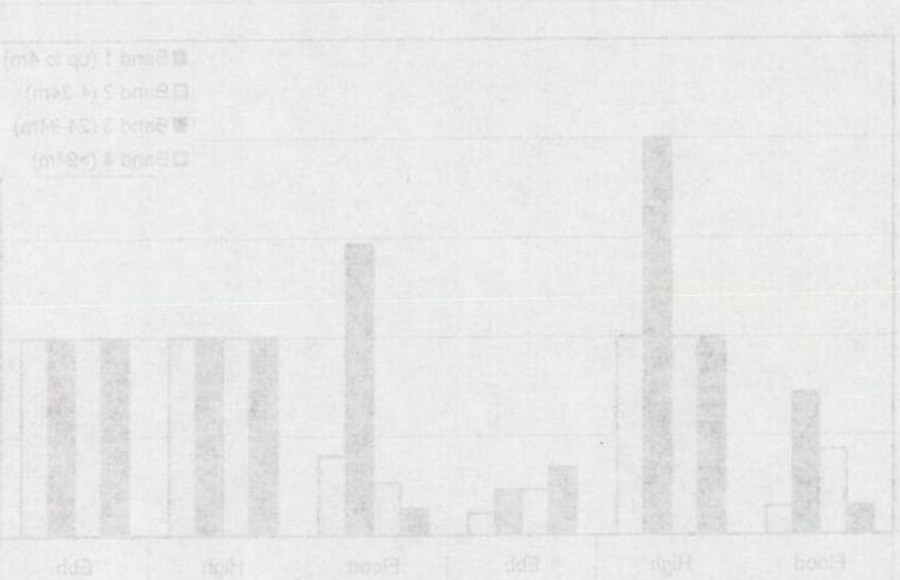


Figure 10: Sightings per unit effort observed in each band (distance from shore), during morning and afternoon watch periods in each tidal state at Lee Bay.

Harbour porpoises were predominantly observed feeding on a high tide, but were found to travel during a flood tide; otherwise there was no variation in behaviours observed during the ebbing tide at Lee Bay. Although not statistically significant porpoises appeared to be more active, demonstrating a range of behaviours during the





afternoon. Group sizes were found to increase during the high tide and an afternoon flood tide, but were observed to decrease during the afternoon high and ebb tides. Whilst porpoises distance from shore was evenly distributed during the afternoon, with the exception of a flood tide when they were observed in band 3 (24-94m offshore), they were found in band 3 more frequently during flood and high tides.

Behaviour

The porpoises were observed for a total of 22.25 hours at Morte Point. During which time they spent 59.9% of the total time feeding in the tidal race (Figure 11). On 32 occasions multi-species feeding associations were observed between gannets (*Morus bassanus*) and porpoises in this area. This relates to 78% of all feeding observed. The porpoise behaviours at Lee Bay were however observed to differ to that recorded for Morte Point, where porpoises were observed feeding 27.6% of the time, compared to 59.9% observed at Morte Point. In contrast they were also recorded travelling through the area 34.7% of the time, whereas at Morte Point travelling constituted 13.96% of the time. These results were not however, found to be statistically significant ($W = 34.0$, $p = 0.470$).

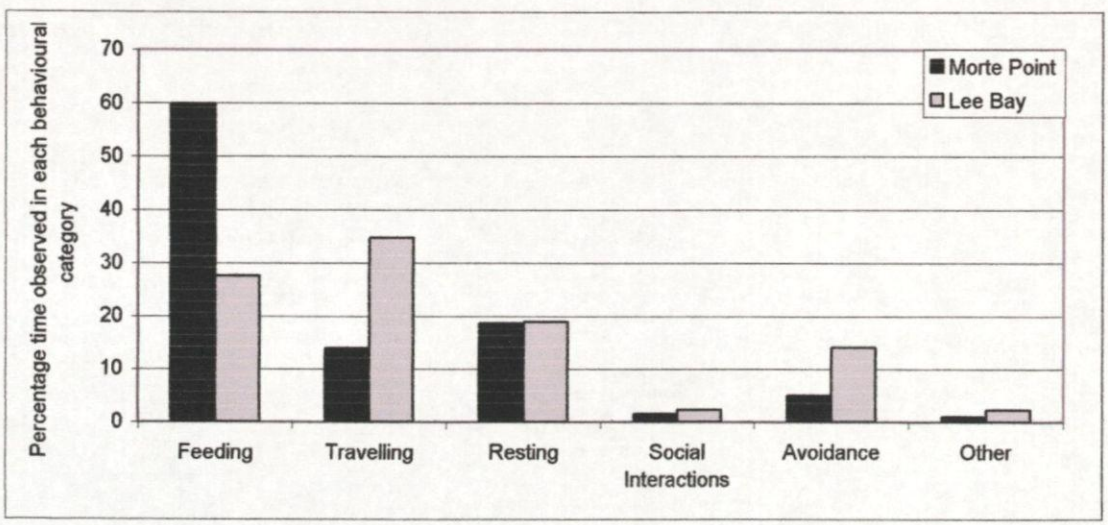
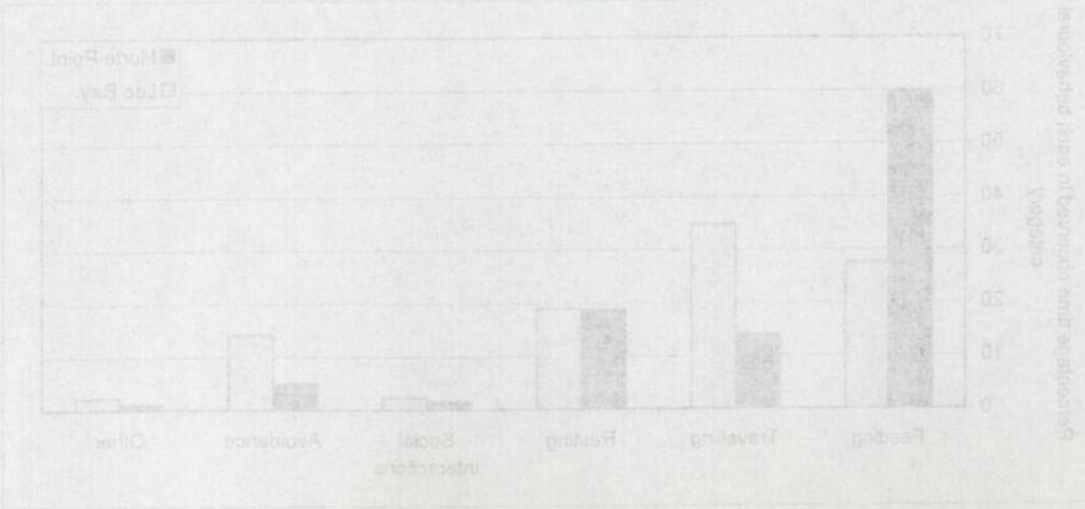


Figure 11: Percentage time observed within each behavioural category (feeding, traveling, resting, social interactions, avoidance and other) at each of the study sites, Morte Point and Lee Bay.



Group Size

The average group size differed little between sites: Morte Point = 2.7 individuals, ranging between 1-10 individuals; Lee Bay = 2.5 individuals, ranging between 1and 6 individuals (Figure 12). Once again there was no statistically significant relationship between sites ($W = 122$, $p = 0.209$).

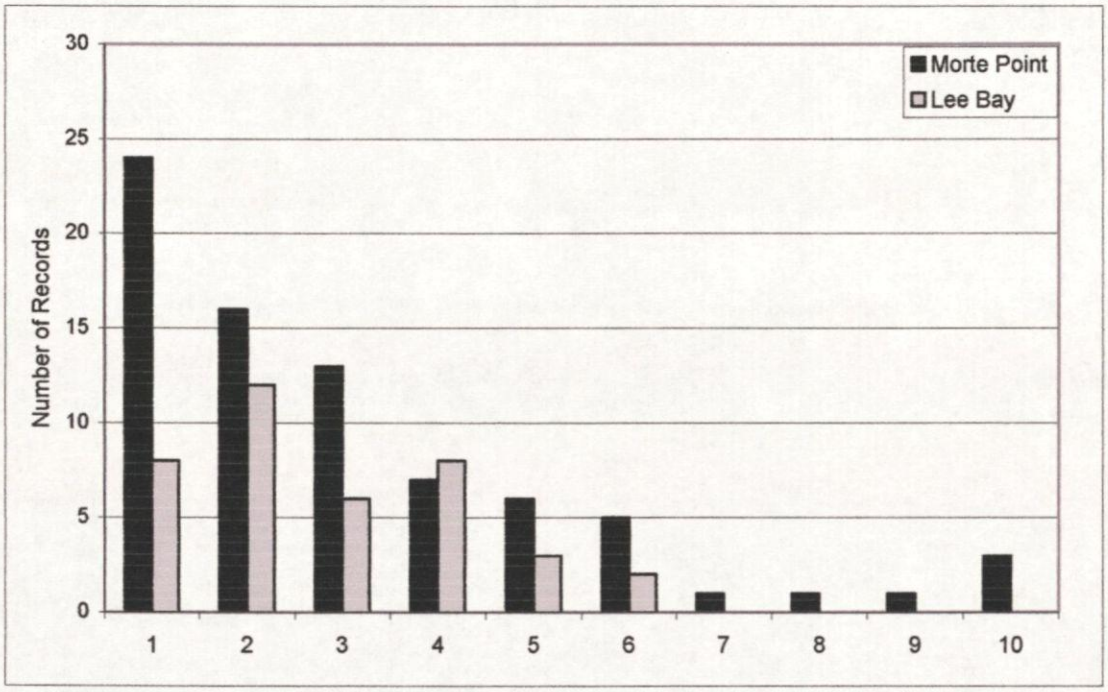


Figure 12: Number of times observations of each group size were made for each of the study sites Morte Point and Lee Bay.

Although both study sites had on average identical group sizes, there were six occasions when 7 or more individuals were observed at Morte Point, whereas the largest group size at Lee Bay constituted only 6 individuals.

Discussion

It is clear from the distribution of sightings, behavioural data, and physical properties of the area that an important feeding ground exists for harbour porpoises off the coast of Morte Point. On 32 occasions multi-species feeding associations were observed between gannets (*Morus bassanus*) and porpoises in this area, which relates to 78% of

all feeding observed. Camphuysen & Webb (1999) describe typical associations of harbour porpoises and white beaked dolphins (*Lagenorhynchus albirostris*) with northern gannets and black-legged kittiwakes (*Rissa tridactyla*), where the cetaceans are believed to act as "beaters" driving the fish to the surface. This type of association is not uncommon, indeed a number of other studies have demonstrated a mutualistic relationship in feeding. Hoek (1992) observed such an association, where an unusually large group of approximately 800 harbour porpoises, one minke whale (*Balaenoptera acutorostrata*) and several sea birds were observed feeding for about 2 hours. Relationships between common dolphin (*Delphinus delphis*), dusky dolphins (*Lagenorhynchus obscurus*) and sealions (*Zalophus californianus*) have also been noted (Wursig & Wursig, 1980).

In this study harbour porpoises demonstrated a statistically significant preference for the area within the tidal race (band 3). The tidal flow at Morte Point ranges from 0.3 – 3.2 knots on spring tides and 0.1 – 1.5 knots during neap tides. Tidal rapids are an area of high prey abundance, which may be being utilised by both the porpoises and gannets, where the majority of sightings occurred during the afternoon. It is assumed that as such the area would be important for prey species such as herring and mackerel (personal communication with local fishermen). Zamon (2003) found that where tidal rips or jets develop, piscivorous predators were also associated due to the interaction of currents, plankton and schooling fish. Observations of porpoises feeding in tidal races have been made in other studies, where groups of up to ten individuals have been observed. The groups however were found to only be temporary - a consequence of utilising an area of high productivity (Pierpoint *et al*, 1994). This supports the findings of this study which found on average, slightly higher group sizes

and increased counts of 7 or more individuals at Morte Point. Additionally, various group sizes were observed during the afternoon on a high tide, which may indicate the aggregation of groups for feeding purposes. Porpoises in Shetland were also found in areas of strong currents, which were thought to be associated with topographical features and an increase in prey species (Evans, 1997). More recently researchers in the Bay of Fundy, Canada, discovered that porpoises actively forage in regions of enhanced relative velocity, tidal streams or island/headland wakes, in response to an increase in prey densities (Johnston *et al*, 2005). The increase in feeding efficiency by utilising an area such as Morte Point probably outweighs the energy required to maintain their position in the tidal currents (Shane, 1980). Indeed behavioural activity did not vary significantly in relation to tidal state, despite feeding being recorded throughout the day and subsequent tidal cycle.

For Morte Point at least, feeding occurred throughout, however at Lee Bay harbour porpoise behaviour, group size and position was found to vary with tide. Lee Bay itself lacks the tidal currents observed around Morte Point, although similar tidal streams may be observed off the promontory cliffs marking either side of the study area. Harbour porpoises did however aggregate in one area of the bay, around the rocks at the base of the cliffs. This may be a consequence of prey densities as was indicated by Hui (1979) in relation to dolphins of the genus *Delphinus*. Hui (1979) hypothesised that as seafloor relief increased, so would the frequency of occurrence of *Delphinus* species. This was based on an underlying assumption that as topographic heterogeneity increases, water movement and mixing increases and available light varies, allowing a greater diversity of microhabitats to form. Prey species may be more abundant in such areas and increase the occurrence of cetacean predators.

At Lee Bay feeding occurred on the high tide, with travel tending to occur on the flood tide. Interestingly, it is on the flood tide that harbour porpoises increased feeding at Morte Point, do porpoises perhaps travel around to Morte Point on the flood tide and come back around to Lee for the high tide, following prey into the region? Additionally supporting this idea is the concurrent decrease in group size at Morte Point, with an increase in group size at Lee Bay during the afternoon, demonstrating a possible linkage between the two areas. Whilst it is recognised that the two sites were sampled during different years, the results of this study do highlight the potential varying use of the sites by harbour porpoises in the region. Lee Bay demonstrated tidal variation in behaviour, group size and distance from shore, whilst at Morte Point only group size and distance from shore exhibited diurnal differences. Research into other cetacean species has found diurnal and tidal trends (Saaymann *et al*, 1973; Shane, 1980; Johnston *et al*, 2005; Klinowska, 1986; Evans, 1997;Amano *et al*, 1998). In particular Evans (1997) found that harbour porpoises in Mousa Sound, Scotland preferentially utilised the area on an ebb tide and in Canada porpoises were also found to demonstrate the same preferential use of an area during an ebb tide (Johnston *et al*, 2005).

Whilst Morte Point appears to represent an important feeding area, porpoise use of Lee Bay is perhaps more complex, with travelling constituting the most frequently observed behaviour, whilst feeding varies with tidal cycle. Previous studies have referred to the harbour porpoise as an opportunistic predator (Recchia & Read, 1989; Santos & Pierce, 2003). By definition though, to be opportunistic would imply that the harbour porpoise is consuming prey as they are encountered, with the inference that prey availability is influencing diet selection (Santos & Pierce, 2003). Donovan &

Bjørge (1995) however, note that the term opportunistic should not be applied to the harbour porpoise, as details concerning prey selection in this species are not known. As the porpoises were observed feeding for a proportion of the time in Lee Bay, it may be concluded that they are perhaps utilising the area as a corridor, between more productive feeding sites, such as Morte Point, but are utilising the area when it presents feeding opportunities, such as at high tide.

Whilst these results do not demonstrate site differences in occurrence during tidal and diurnal cycles, they do however point to site-specific differences in behaviour, group size and distance from shore depending on time of day and tidal cycle. Whilst previous studies have reported both tidal and diurnal variation in cetacean species (Saaymann *et al*, 1973; Shane, 1980; Klinowska, 1986; Evans, 1997; Amano *et al*, 1998; Johnston *et al*, 2005) this study demonstrates that habitat use trends are site-specific. Indeed Bannon (2006) point out that spatial and temporal variations in cetaceans may arise from differences in the biological, hydrographical and topographical structure of the study area. Only by understanding the site-specific nature of cetacean occurrence, behaviour and group size can adequate conservation measures be put in place and maintained.

The behaviour of the harbour porpoise (*Phocoena phocoena*) and the need for precautionary management of cetacean-related tourism in the UK

Chapter Three

The behaviour of the harbour porpoise (*Phocoena phocoena*) and the need for precautionary management of cetacean-related tourism in the UK

Abstract

Behavioural observations of the harbour porpoise were first made in 1974, after which a number of studies have recorded behaviour in conjunction with other investigations, yet despite this there has been no detailed examination of the ethology of the harbour porpoise since 1974. The species has been considered by some to be a shy and perhaps elusive member of the phocoenids. Shore-based studies in North Devon and boat-based studies along the west coast of the UK were conducted between August 2001 and September 2004. In total 178 hours were spent observing harbour porpoise behaviour at the surface. During this time a total of 586 groups were encountered, with an average size of 2 individuals. Calves were present in 5% of the groups, but only observed from July – September, with on average one calf per group. Feeding, travelling, resting, social interactions, avoidance and other behaviours were recorded in all studies. Porpoises did not show significantly different behaviours depending on group size, however porpoises were observed to regularly engage in cooperative feeding and aerial activity, previously considered rare. The behaviours, as recorded from shore, differed considerably to those recorded from the boat. Travelling and avoidance constituted 71% and 12% respectively, from the boat, whereas from shore 60% of the behavioural categories recorded were feeding. This highlights the need for precautionary management to increasing numbers of dolphin watching tour operators in UK waters.

Introduction

The study of behaviour has long fascinated many researchers, who have spent a large amount of time and effort attempting to gain a greater insight into animal behaviour. Whilst the study of any animal in the wild presents a number of challenges, wild cetaceans are particularly difficult to study. They are highly dynamic individuals, which spend the majority of their time beneath the surface, and have the capacity to cover large distances in a short time (Mann, 1999). Where individuals can be identified, movements and interactions may be recorded, however where this is not possible, as is the case with the harbour porpoise, an assessment of "group" behaviour is made. This can however introduce observational bias, where only the behaviour of the more visible or larger individuals is recorded. Additional problems are presented when studying cetaceans as often it is only the surfacing behaviour which is recorded with inference made as to the context and meaning of the behavioural events and states displayed at the surface. Indeed it has been suggested by some that what we may perceive as avoidance behaviour at the surface (when a cetacean dives and spends time submerged) assumed to indicate a disruption in the behavioural state, may only represent a vertical relocation of the activity at depth (Lusseau, 2003) and whilst this can be considered disruption to the behavioural event itself, the behaviour continues at depth, uninterrupted.

Given these problems behavioural research tends to be based upon scientific assumptions: a) that the behaviours observed at the surface are characteristic of the whole group's behaviour and b) that observed behavioural states at the surface can be used to infer behavioural events. The first of these two assumptions can be problematic when cetaceans occur in large aggregations as there will undoubtedly be

submerged individuals who are engaged in differing behaviours, however with harbour porpoises who are often found singularly or in small groups of between 1 – 3 individuals (Reid *et al*, 2003) this is assumed to be less of a problem.

An interesting study by Slooten (1994) provided sequence analysis of behaviours observed in Hector's dolphins. This study identified the complexity of the behavioural repertoire, in that any behaviour is not a single event, but comprises a unique series of states which ultimately culminate in the event which many researchers classify. In the case of single animals, as is often observed for the harbour porpoise, behaviour is likely to be influenced by motivational factors such as hunger and hormone levels (feeding, social/mating). When animals are observed in pairs or groups additional factors take precedent, as each individual may be influenced by the others and by the social context of the group as a whole (Slooten, 1994). Slooten found that behavioural states such as bite, tailsplash and chase were associated with feeding, whilst bubble blow was thought to represent an aggressive behaviour. Lob-tailing, which has been classified by some as also being a sign of aggression, was here identified to indicate high levels of motivation which may or may not be associated with aggression. Aerial behaviour was kept separate in Slooten's study, but was thought to be associated with sexual, aggressive and feeding behaviours. Research into Dall's porpoises has also highlighted behavioural states such as high speed lunges, irregular splashes and rooster tailing which are believed to be part of the feeding process (Jefferson, 1991; Amano *et al*, 1998).

Research into harbour porpoise behaviour, first began in the early 1970's, when Amundin & Amundin (1974) described behavioural observations in the wild. Since

then whilst behavioural observations have been published as part of larger studies (Amundin, 1974; Hoek, 1992; Pierpoint *et al*, 1994; Evans *et al*, 1994; Scheidat & Palka, 1996; Evans, 1997; Otani *et al*, 1998), no comprehensive behavioural assessment for the harbour porpoise has been made.

In 1974, Amundin & Amundin described behavioural observations of the harbour porpoise in the wild. The paper details mother-calf interaction, meeting behaviour and leaping, fright reactions and resting. Although all notes are descriptive, it was the first study to consider the ethology of the harbour porpoise in any detail. In mother-infant interactions the pair were observed to regularly traverse the bay, where interactions ensued when other individuals approached the pair. Fright reactions were observed when vessels approached to within 100-200m, with speed boats eliciting a more pronounced response. A number of different leap behaviours were also noted, including high leaps, clean out of the water. This was considered of interest as the harbour porpoise was not considered to normally exhibit this behaviour except in captivity, under training. Amundin & Amundin (1974) were unable to state the purpose of these high leaps and concluded that further research was required. Pierpoint *et al* (1994) also described leaping behaviour in harbour porpoises off West Wales, UK. Breaching seemed to occur during both foraging behaviour and in an apparent social context amongst individuals, which supports the findings by Slooten (1994) for the Hector's dolphin. Pierpoint *et al*, (1994) also described tail flip dives, where the porpoise rolls forward quickly, lifting the flukes and exposing the ventral surface on diving. The more regularly defined behaviours of foraging, milling, resting and travelling are also described. In 1997, Evans described the behaviours observed as part of a larger ecological harbour porpoise survey in Shetland, North Scotland. The

regular behaviours of transiting, foraging/feeding, milling, tail slapping, play and sexual behaviour were again described in brief, however once again breaching was mentioned as "*rare*" with "*no individual being observed to leave the water fully*".

In 1992, Hoek, described an unusual aggregation of harbour porpoises in the Jacques Carrier Passages, Gulf of St Lawrence, Canada. Here a group of 800 harbour porpoises covering an area of at least 2km^2 were observed initially feeding, then resting at the surface in small cohesive pods, for approximately two hours. After such time, the groups gradually dispersed. Other than a feeding aggregation, no other explanation has been given or reported since. Slooten (1994) notes that the definition of a group, used in her study i.e. two or more individuals in close contact, <20m from each other and closer to one another than individuals belonging to another group, had meaning to the dolphins, as they changed their behaviour when two or more groups came together. This large aggregation of harbour porpoises may have altered the behavioural events of the individual groups, or more likely the large group would have consumed a large quantity of fish in the area at that time and sated themselves, before moving off after a rest period. This however demonstrates that whilst the harbour porpoise is typically known for small groups, large groups can occur, which may alter the behavioural states or event of the group.

In 1994 and later in 1996, researchers considered the effects of boating traffic on harbour porpoises. Evans *et al* (1994) considered reactions to varying boat types in Shetland, Scotland, UK. They discovered that porpoises reacted differently to varying vessel type, and although all reactions were negative, (i.e. change direction and move away) high speed vessels such as speed boats and jet skis were found to elicit a

greater number of negative reactions compared with other boat types. Scheidat & Palka (1996) in Germany supported these results, where porpoises demonstrated a change in behaviour and swimming direction in response to the survey vessel.

As the UK becomes more environmentally aware, and dolphin watching holidays increase, the harbour porpoise is potential facing an ever increasing threat from boat traffic. Whilst our ports and harbours are seeing the number of recreational vessels rise, the UK is also witnessing an increase in the number of dolphin watching operators, as this becomes the fastest growing branch of nature-based tourism in the world. In West Scotland alone, cetacean-related activities have been estimated to account for £7.8 million (Parsons *et al*, 2003) as people visit the area to see the whales and dolphins and subsequently spend additional money during their stay. Whilst the elusive and shy harbour porpoise is perhaps not high on the operators list of species which can be observed, as the most frequently sighted cetacean in UK waters (Evans *et al*, 2003) it is perhaps at greater risk of disturbance.

The main aim of this study is to examine, in detail, harbour porpoise behaviour observed from both shore- and boat-based platforms. Given the apparent lack of information and considered rarity of aerial behaviour in this species, additional notes will be made relating to aerial behaviour observed and the context in which it occurs. This will provide an ethogram which may be used in future studies and will then be used to discuss the potential level of threat to the species from increasing cetacean-related tour operators in the UK. Recommendations are made in order to mitigate this threat within UK waters.

Methods

Shore-based survey

Observations were conducted during August and September, 2001 from Morte Point (51° 11.290'N, 04° 13.559'W) and during August and September, 2002 from Lee Bay (51° 11.918'N, 04° 10.764'W). Both sites are found on the North Devon coastline, situated between Ilfracombe and Woolacombe (Figure 1). Harbour porpoises were observed regularly from both shore-based stations.

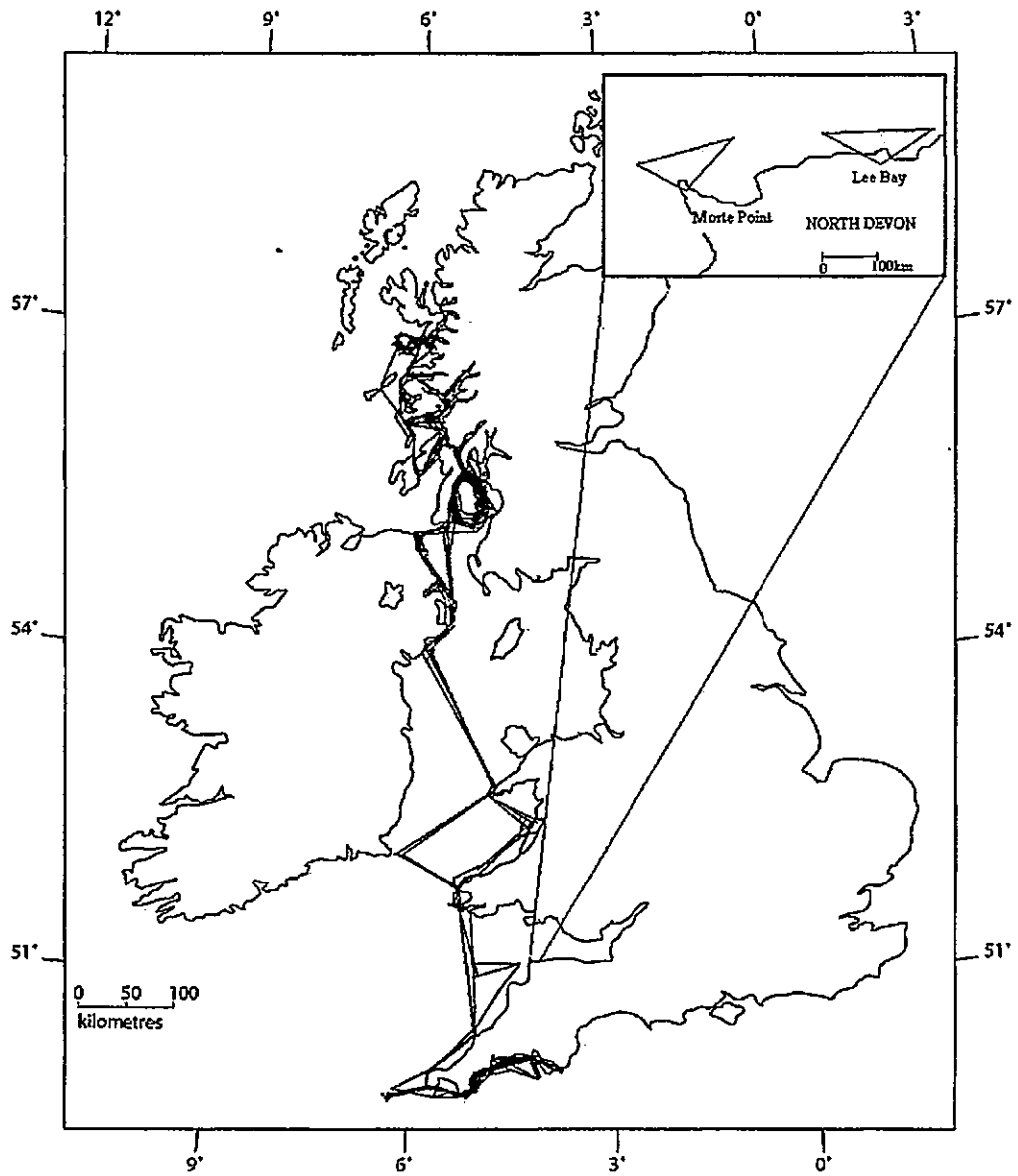
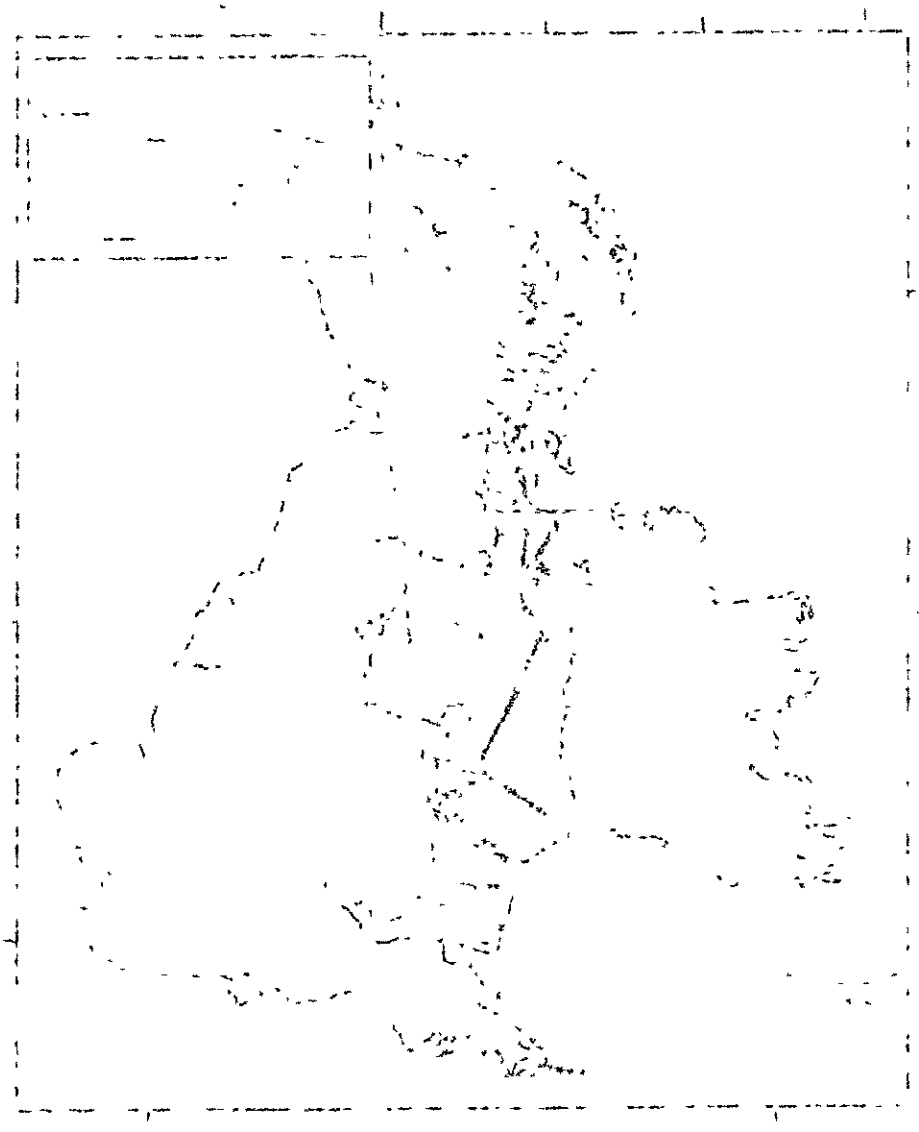


Figure 1: Map of the UK indicating the areas covered by both the shore based surveys from Morte Point (2001) and Lee Bay (2002), highlighted in the inset and the line transects covered as part of the boat surveys during 2002 – 2004.



The seabed surrounding Morte Point consists mainly of sand, shingle and gravel, alternating between gravel and fine sand further out. The Morte Stone buoy not only marks the large rock formations, which protrude out into the sea, but also acts to mark an area of tidal rapids, which form due to the prominent nature of the point. These vary from 0.1 – 1.5 knots during neap tides and 0.3 – 3.2 knots during spring cycles. The seabed in Lee Bay is largely homogeneous, consisting of fine sand, with gravel patchily distributed. A number of submerged rock formations are present at the base of the cliffs on either side of the bay. Although no strong tidal rapids exist within the study area, those that form off Bull Point may be viewed on the far western side of the area.

The level of boating traffic was recorded continuously throughout both studies. Although small fishing boats utilise the area close inshore, their numbers are few (1-2 vessels per watch). The area is generally quiet in terms of marine traffic, with only one boat offering coastal tours and all large cargo ships remaining on the horizon (approximately 2.5 nautical miles offshore). Therefore all porpoise behaviour recorded is presumed to be that of undisturbed individuals.

Watches lasted for 4 hours and were spaced throughout daylight hours, from 10:00 to 18:00. This ensured that all time periods were covered and that fatigue did not influence sighting efficiency. During a watch the area was scanned every fifteen minutes, using a telescope and a pair of binoculars. When a group of porpoises entered the area they were surveyed using a focal group follow (Mann, 2000), which lasted either until the watch ended or until the porpoises left the study area. A group was defined as two or more individuals in close contact, <20m from each other and

closer to one another than individuals belonging to another group (Slooten, 1994). Should another group enter the study area during the observation period, the recorder remained with the original group, unless this group left the study area before the end of the watch period. If individuals joined or left the focal group this was recorded and a new group number was assigned. In the case of a group splitting, the recorder remained with the larger of the remaining groups. A minimum estimate of group size was also made; this was defined as the maximum number of animals seen on surface at any one time. Although it was not possible to distinguish between individuals, due to a lack of distinctive markings, the presence of calves was recorded. A calf was defined as an animal half the body length of an adult porpoise, and usually lighter in colouration. The animal was also observed to swim just slightly back and alongside an adult, presumed to be the mother. The porpoises behaviours were monitored continuously with the aid of a dictaphone, however a time interval of fifteen minutes was selected to ensure that behavioural counts were temporally independent (Altman, 1974).

Boat-based survey

A survey of the West Coast of the UK was undertaken during May and September in years, 2002, 2003 and 2004 (Figure 1). The research vessel, SRV Forever Changes, is an 11.7m Dufour sailing yacht. Line transect surveys were carried out between fixed positions both inshore and offshore, using a standardised methodology. Two observers were employed at all times, each scanning one side of the vessel, with a third crew member recording the vessels position every half hour via a Furuno GP-32 GPS/WAAS Navigator interfaced with a DELL notebook computer operating SeaPro Pro navigational software and ARCS electronic charts. When harbour porpoises were

encountered point sampling recordings were noted, providing a "snapshot" of events. Group size, presence of calves and behavioural observations were also recorded.

Although there is no standardised list of behavioural terms for cetaceans, most researchers describe feeding, travelling, resting, milling, social interaction, mating and avoidance, where studies are focussing on disturbance or boat interaction (Au & Perryman, 1982). In both the shore- and boat-based surveys presented here, porpoise behaviour was classified using an ethogram of 6 categories: feeding, travelling, resting, social interactions, avoidance and other (Table 1) (Shane *et al*, 1986). *Ad libitum* notes were also made, which included interactions with vessels, other species present or unusual behaviour to ensure that all aspects of the harbour porpoises behaviour are captured, including those behaviours which may only represent behavioural states. Aerial behaviour is not given as an individual category here, due to the perceived rarity of the behaviour for this species (Amundin & Amundin, 1974) and the indication by Slooten (1994) that it may have many different connotations (feeding, social, sexual). It will however be included in additional *ad libitum* notes as this is an area which has previously been mentioned requires further research (Amundin & Amundin, 1974; Pierpoint *et al*, 1994).

Table 1: Behavioural categories and definitions used in all observational recordings.

Behaviour	Definition
Feeding	Porpoises were observed chasing or in association with fish. When groups of porpoises were observed in association with feeding seabirds, usually northern gannets (*Morus bassanus*), it was assumed that the porpoises were engaged in feeding behaviour (Camphuysen & Webb, 1999).
Travelling	A constant movement in a particular direction
Resting	Surfacing and slow or undirectional movement within a given area.
Social Interactions	When more than one porpoise engaged in leap, chase, or surface rushing behaviour when there was no evidence of feeding or directed travel.
Avoidance	When the animals were observed to change direction, dive, remain submerged for longer periods or leave the area.
Other	This category was established for behaviour that could not be classified into one of the above.

Behavioural observations were considered for each individual study area. Group sizes from all surveys were analysed for differences between years using an analysis of variance (ANOVA). Mean, median, and modal group sizes were calculated. As previous findings demonstrated differences in porpoise habitat use between Morte Point and Lee Bay (See: Chapter Two: Diurnal and Tidal variations in Habitat Use of the Harbour Porpoise (*Phocoena phocoena*) in Southwest Britain), results from the two study sites remain separate. Number of behavioural observations in each category from the boat-based surveys were analysed for differences between years using an ANOVA and were subsequently combined. As the data for time observed engaged in each behavioural category, for each site were distributed non-normally, the non-parametric Scheirer-Ray-Hare extension of the Kruskal-Wallis test was used to assess differences. Group size in respect of behaviour and site was also considered using the Scheirer-Ray-Hare test, under the hypothesis that harbour porpoises in large groups demonstrated different behaviours, e.g. reaction to vessels and feeding aggregations. *Ad libitum* notes are described in detail, where they provide interesting descriptions of harbour porpoise behaviour.

Results

A total of 178 hours were spent observing harbour porpoises in the wild. This included 8 weeks of data collection at both Morte Point and Lee Bay, with 22.25 hours and 18 hours collected respectively. For the boat-based survey, during 2002, a total of 20 weeks were spent at sea, with 34.25 hours observing the porpoises. In 2003, 22 weeks of data were collected, 52.5 hours observing the porpoises. In 2004, 22 weeks of data were once again collected, with 51.2 hours observing the porpoises.

Between 2001 and 2004, 586 groups of harbour porpoises were observed either from shore- or boat-based stations. No variation between year was observed in group size ($F_{(3,39)} = 0.66$, $p = 0.58$), therefore all group size estimates were compiled to establish a mean group size ($x \pm$ s.d.) 1.97 ± 1.25, median group size of 2 and a modal group size of 1, $n = 586$, range = 1-10 (Figure 2). Calves were present in only 5% of the groups recorded, with only 1 calf per group. Calves were only recorded from July - September. As no statistically significant difference was observed between years ($F_{(5,17)} = 1.57$, $p = 0.25$) the boat data were combined. Group size was not found to be statistically different across site or behavioural categories ($H_{(2)}=1.967$, $p=$, $H_{(5)}=2.32$, $p \geq 0.10$), although both feeding and travelling were found to have greater group size when observed from shore. The average group sizes for each behavioural category and site are plotted in Figure 3.

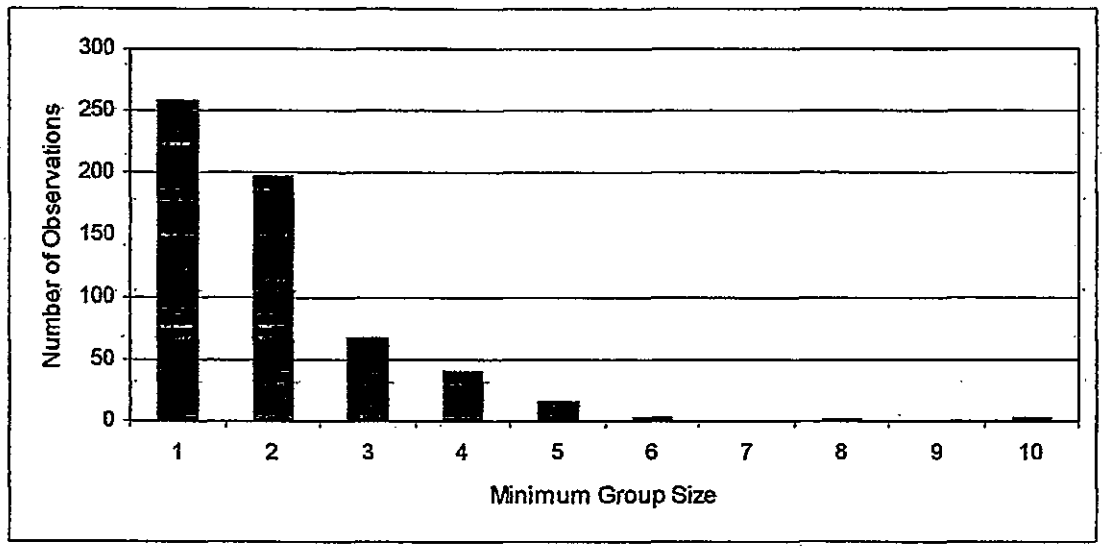


Figure 2: Distribution of minimum group size estimates made for all surveys.

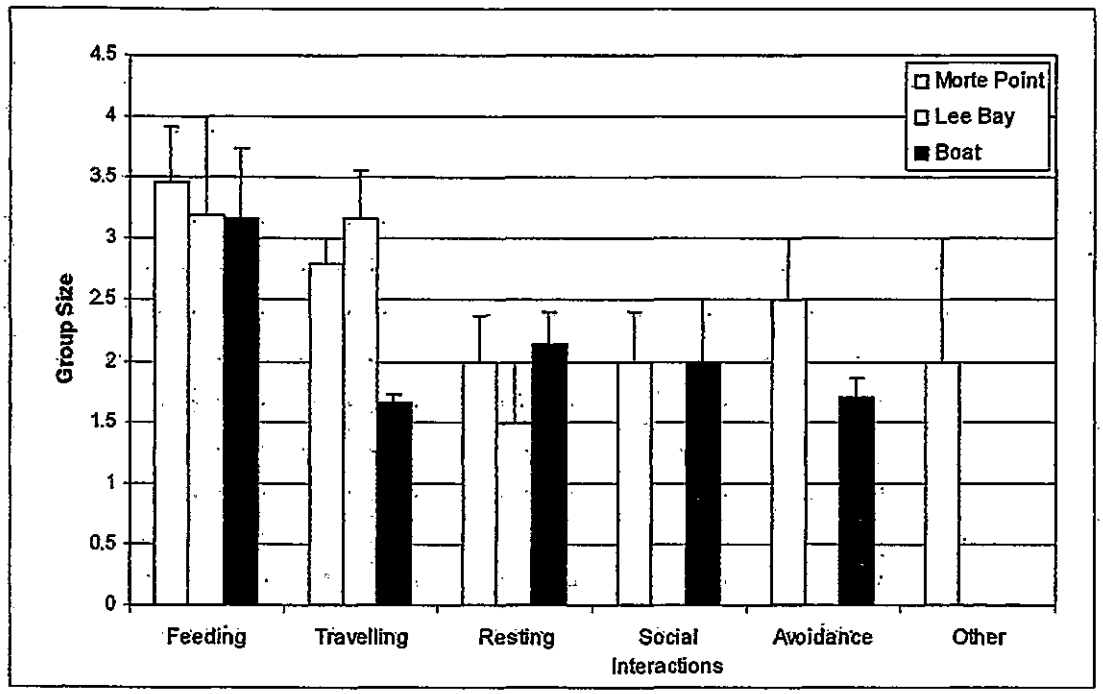


Figure 3: Average group size observed for each behavioural category (feeding, travelling, resting, social interactions, avoidance and other) in relation to each of the study sites (Morte Point, Lee Bay and the Boat) with standard error bars.

At both shore-based sites feeding and travelling constituted >70% of the observations. At Morte Point this comprises 59.9% feeding and 14.0% travelling, whilst at Lee Bay, travelling was observed more frequently, 34.7% and feeding 27.6%. In comparison to the suite of behaviours observed at either shore-based station, the boat-based recordings differ in composition. Porpoises were only observed feeding for 11% of

the observations. Conversely travelling and avoidance constituted 72% and 12% respectively with fewer observations of resting or social interactions (Figure 4). In this instance travelling may have been recorded in place of avoidance, because of a lack of observational material before encountering the porpoise group. The Scheirer-Ray-Hare test however did not reveal statistically significant results when comparing the site and each behavioural category ($H_{(2)}$=1.97, p≥0.10).

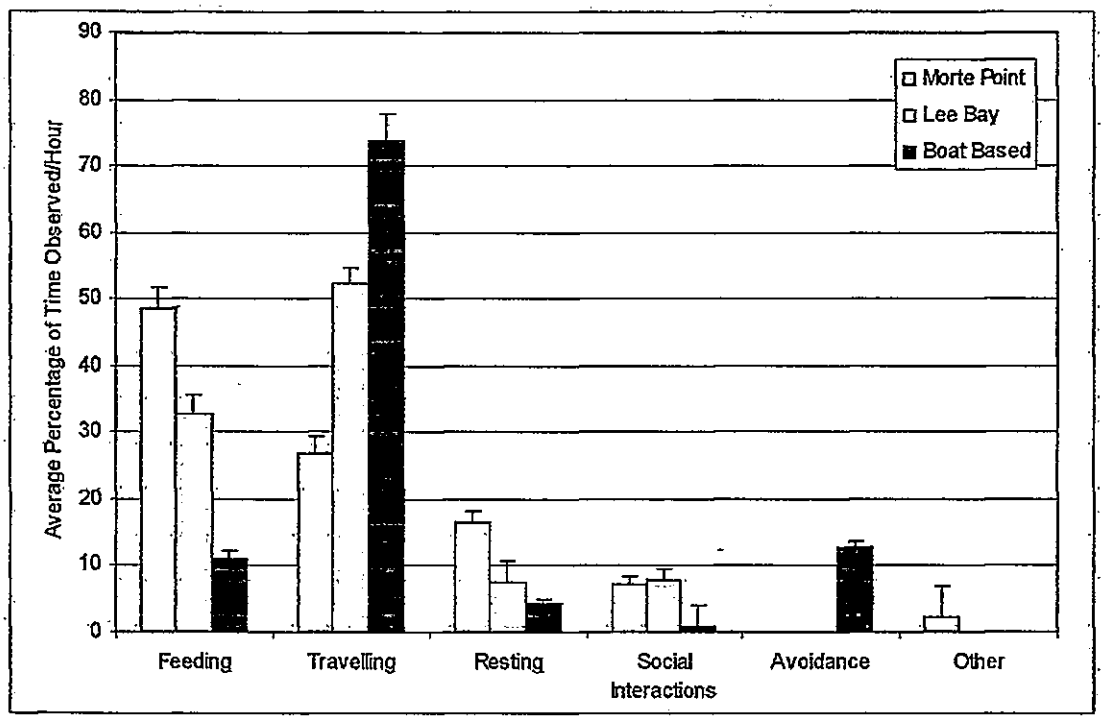


Figure 4: Average percentage of time observed engaged in each behavioural category per hour for records made at both the shore-based and boat-based stations.

Descriptive behavioural notes

Feeding

Porpoises were seen engaged in multi-species feeding associations on 39 occasions. The majority of these involved northern gannets (*Morus bassanus*), however porpoises were also seen feeding alongside grey seals (*Halichoerus grypus*) on 2 occasions, a common dolphin (*Delphinus delphi*) and minke whales (*Balaenoptera acutorostrata*) on 4 occasions.

In this study, feeding has been classified when porpoises were seen chasing or consuming fish or when in association with diving gannets. When observing feeding associations develop, if porpoise minimum group size numbered 6 or more the group would split into two, both remaining in the same vicinity. On one such occasion, 10 minutes after the group spilt, gannets began to circle, 10 minutes later the gannets began to dive and presumably feed. After a further 10 minutes porpoises could be seen surfacing in a feeding frenzy, with more than 30 seabirds diving and surface feeding. Whilst this description occurred off the coast of North Devon, at Morte Point, there were occasions when these large feeding groups were observed from the boat, however these were never observed in the South West of England, where sightings were few. Off the coast of West Scotland, on the approach to the Crinan Canal, researchers observed surface activity ahead of the research vessel, which turned out to be harbour porpoises engaged in a feeding frenzy. Whilst the normal response of the porpoises to the boat on transect would be to dive and reappear elsewhere - often behind the vessel, on this occasion the animals appeared oblivious to the vessel passing and instead carried on feeding. This gave the author a unique opportunity to observe a group of over 10 individuals consuming fish at the surface, utilising a number of behavioural states, from surface rushing, which is when a porpoise maintains swimming, usually at speed, through the surface water, creating a large splash and wake, to belly-up swims, where the ventral surface comes out of the water.

Travelling

Whilst porpoises were observed travelling from both shore-based stations, this behaviour was more frequently seen from the boat. In both shore-based locations porpoises would remain in a close group formation i.e. <10m between individuals,

and would maintain movement in a constant direction. Occasionally individual porpoises were observed to split off from the main group and either rejoin further along their trackline, or in the case of the boat, individuals have been observed to actually approach the vessel. At approximately 10m from the vessel the individual would then turn, and rejoin the original group.

Resting

Shore-based observations detailed occasions when porpoises would enter water <10m in depth and lie motionless on the surface, or were seen to bob just beneath the surface, constantly maintaining position, rising to the surface to breath. This lasted for no more than 15 minutes before they would either leave the area or become more active, engaging in another behaviour.

Social interactions & aerial behaviour

Within this study 78% of all behavioural observations conducted from shore included aerial activity. This includes porpoises leaping out of the water, where the whole body is visible above the surface of the water, conducting belly-up swims, or seen in vertical dives, with their tail clearly coming out of the water. When conducting aerial activity in which the porpoise leaves the water, the height was still within 1 metre of the water surface. They were not seen engaged in high acrobatic leaps as is more commonly observed in the bottlenose dolphin (Bel'kovich *et al*, 1991). This behaviour however, was not observed from the boat, except in the form of surface rushing, which was only observed when porpoises were feeding.

Avoidance

Both shore-based areas are relatively quiet in terms of marine traffic, yet there were incidences when the porpoises encountered marine craft. In general, porpoises would often react to an approaching vessel very early on. This could be when the vessel appeared around the headland, with the porpoises situated on the other side of the bay, approximately 2000m away. Unfortunately it was not possible to reliably record positions of both porpoises and boats and therefore it is impossible to give a reaction distance. In all porpoise-boat interactions observed from shore, behaviour was observed to change. Often the porpoise's response would be to dive, only surfacing again when the vessel had passed over them or out of the study area. This was observed on five occasions. The porpoises however, left the area entirely on two occasions, and resurfaced as two separate groups on another two occasions.

As in the feeding description provided above qualitative differences in avoidance behaviour between the South West of England and the North West coast of Scotland were also observed from the research vessel. In the South West when porpoises were encountered (typically in small group sizes) the behavioural response would be to dive, or change direction and swim away from the vessel. Off the coast of Scotland, where porpoise sightings were elevated and the frequency of seeing larger groups increased, porpoises seemed less reactive to the presence of the research vessel. Here the typical response would simply be a continuation of the encountered activity and if travelling the porpoises had been observed to split a large group and travel either side of a passing vessel, before re-grouping once the vessel had passed.

Discussion

Behavioural observations of the harbour porpoise were first made in 1974, after which a number of studies have recorded behaviour in conjunction with other investigations, yet despite this there has been no detailed examination of the ethology of the harbour porpoise since 1974. The species has been considered by some to be a shy and perhaps elusive member of the phocoenids, however this study has shown that the behavioural repertoire of the harbour porpoise does regularly include aerial activity and that observed behavioural events and states may vary depending on a number of factors, including the location, the number of porpoises in the area, the group size and whether a shore- or boat-based platform is utilised. This has implications for future behavioural research and may be indicative of the potential effects of increasing boat traffic and dolphin watching tourism in UK waters.

The average group size of 2 ($x = 1.97$) individuals and the presence of calves from July – September, observed in this study is consistent with previous research (Read, 1999b) and the known calving period for the species (May-June) (Evans *et al*, 2003); however larger aggregations and multi-species associations were seen on 39 occasions. On two occasions when feeding was recorded, minimum porpoise group size consisted of 10 individuals. This could indicate that although porpoises may forage independently for the majority of the time that they do engage in larger feeding associations. Perhaps it is initiated by other species, which have already corralled the fish, or the presence of others, such as gannets, which highlight the presence of prey. When porpoise groups were found to be larger than 6 individuals there were occasions when the group would split, after which a multi-species (i.e. inclusive of gannets) feeding aggregation would develop. Although this in itself is not unusual as

many marine animals feed in association with others (Bel'kovich *et al*, 1991), the group split may indicate a level of co-operative feeding behaviour. Porpoises were also frequently observed moving in a circular motion when engaged in feeding, at the time it was assumed that they were corralling the fish, as has been observed for the bottlenose dolphin (Bel'kovich *et al*, 1991). The feeding behaviour noted is similar to Dall's Porpoises, which have been seen lunging at high speed, making large splashes and frequently changing direction, often in association with large aggregations of seabirds (Amano *et al*, 1998). Pierpoint *et al*, (1994) have also noted similar behaviour for the harbour porpoise in West Wales, UK. Here they observed groups of 10 porpoises forming temporary associations, before dispersing after intense activity bouts. A later study in Shetland (Evans, 1997) additionally documented surface rushing and encircling of prey, indicative of a group effort. They found that the frequency of circling behaviour increased with group size.

Although many cetacean species engage in acrobatic leaps when socialising, communicating or feeding this has seldom been reported for the harbour porpoise (Amundin & Amundin, 1974; Pierpoint *et al*, 1994) and has been considered rare by most researchers, indeed most cetacean identification handbooks do not describe aerial behaviour in association with the harbour porpoise. During this study harbour porpoises were observed engaged in aerial activity during 78% of all observations. This supports the original findings by Amundin & Amundin in 1974, who said that this unusual behaviour, previously thought to only occur in captivity, under training warranted further investigation. Harbour porpoises were often observed to breach completely, sometimes emerging from the water belly-up. This was also observed by Pierpoint *et al*, (1994) however the exact function of these leaps remains unknown. It

is possible that they facilitate communication or co-operative feeding in large aggregations. In spinner dolphins (*Stenella longirostris*) different leaps have different connotations; many breaches are associated with excitement or aggression (Pryor, 1990). Whereas in Dusky dolphins (*Lagenorhychus obscurus*) aerial leaps are believed to communicate a source of prey to other individuals in the area (Carwardine, 1995). Whilst the precise functions of the aerial activity remains unknown, it appears to play an important role in the behavioural repertoire of the harbour porpoise, given the high level of occurrence throughout the shore-based observations. It is interesting to note, however that aerial activity was never observed from the boat.

In terms of travelling, the second most frequently recorded behavioural event, a number of unique encounters warrant further discussion, for instance the breaking away of a single individual to apparently investigate the research vessel. This individual may function as a "scout", as has been highlighted for the bottlenose dolphin (Bel'kovich *et al*, 1991), however as it was not possible to identify individuals, or indeed to repeatedly encounter the same group it is impossible to state whether harbour porpoise groups have the same level of individual complexity as is observed in the bottlenose dolphin and other odontocetes.

Furthermore, recordings taken from the research vessel demonstrate an increase in travelling behaviour. This could have resulted from the porpoises responding to the approaching vessel before observers on the vessel had noted them. Therefore the behaviour may be recorded as travelling, when in fact they were avoiding the vessel and had only initiated movement in response to its approach. This has implications for

the increase in dolphin watching tourism in that it may be indicative of an increased threat to the species. Indeed on two occasions the resurfacing of two separate groups where there had been a single group before the passing of a motor vessel could indicate two groups, which had formed a larger aggregation in the first instance or a result of a startle response in attempting to avoid the oncoming craft. Constantine *et al* (2004) caution that whilst there is documented growth in the tourism industry there has been little consideration or either short- or long-term effects of the industry on cetacean behaviour and ultimately on their ecological fitness. Changes in surfacing behaviour of the group noted here may be indicative of a detrimental effect on the group as a whole. This has been observed in the bottlenose dolphin, where Hastie *et al* (2003) observed a disrupted surfacing synchronicity. Whilst in the short-term individuals may move away from the point of disturbance, in this case, a motor vessel, repeated or long periods of disturbance may cause not only individuals but whole groups to abandon an area, which may have represented important habitat for the species.

It is well known that the most crucial behaviour to disrupt for any animal is rest. For cetaceans both Constantine *et al* (2004) and Lusseau & Higham (2004) highlight that cetaceans are more susceptible to disturbance during rest periods than any other behavioural event. It is perhaps surprising that this was observed infrequently in this study. Indeed Hoek (1992) observed a large aggregation of harbour porpoises apparently resting at the surface for a period of two hours. However, it should be noted that in this study harbour porpoises were principally observed resting when observations were made from the shore; only a few instances occurred when resting animals were encountered on the boat, after which the animals would move away and

so their resting periods were disrupted. For any long-lived, slow breeding species the long-term effects of reduced resting on fitness, reproductive success and ultimately population size could go unnoticed for many years. Indeed Wilson *et al* (1999) and Thompson *et al* (2000) estimate that the effects of disturbance could take 30 years to detect, highlighting the urgent need for precautionary action, in light of short-term studies such as this, which perhaps only elucidate a small proportion of the true effects of boat disturbance on the species.

Whilst the behavioural events used in this study did not demonstrate a statistically significant difference between shore- and boat-based platforms, examination of the additional notes indicates that behaviour observed from the shore had a greater diversity and range of characteristics than that observed from the boat. There are also a number of additional behavioural states and events which were disrupted by the presence of either the research vessel or other boats in the vicinity of observation. Previous research has indeed demonstrated negative reactions on all accounts for harbour porpoises in the vicinity of marine craft (Evans *et al*, 1994). One of the perhaps more interesting factors to arise out of this study has been the locational variation in behaviour (between the South West of England and the North West of Scotland), which is thought to be due to the differences in the number of animals in each region. Whilst encounters with marine craft are overall negative for the harbour porpoise, these were perhaps more pronounced in the South West of England, where harbour porpoises sightings are few. Conversely where harbour porpoise sightings are frequent (Scotland), although negative responses did occur, there were occasions when the presence of the vessel did not deter the animals from whatever behaviour they were engaged in (e.g. observations made on the entrance to the Crinan Canal).

Although other species, such as the bottlenose dolphin have been shown to habituate to marine traffic (Shane, 1990), this is perhaps more likely for the harbour porpoise off the coast of Scotland than the South West of England, although additional research is needed to investigate this further.

Given the varying behavioural responses of the harbour porpoise to vessel traffic depending on location, the number of porpoises in the area and group size it would appear that there is an effect of vessel traffic on the species. The level of this effect requires further investigation, however whilst vessel traffic increases and dolphin watching is perceived as an environmentally friendly industry, adopting the precautionary approach to protect these animals would seem prudent. There have been a number of codes of conduct in existence for a number of years now however, the number of operators which strictly abide by them remains to be seen. One organisation, MER Consultants Ltd have now taken this to another level and offer accredited training for boat owners and tour operators nationwide through the WiSe scheme. This takes a precautionary approach to the problem of increasing vessel traffic by encouraging self-management by the industry.

As other researchers have warned that we may not see the effects of the industry on cetacean populations for at least 30 years, the effects on the shy and elusive harbour porpoise may go completely unnoticed. It is clear that the harbour porpoise probably engages in cooperative feeding strategies and utilises aerial behaviour more frequently than was previously thought. However these findings only compound the evidence for disrupted behavioural events and states from vessel traffic as these behaviours were not observed when research was undertaken from a boat-based platform.

Acoustic Monitoring of the Harbour Porpoise (*Phocoena phocoena*) around Bottom-set Gillnets in the Celtic Sea

Chapter Four

Acoustic Monitoring of the Harbour Porpoise (*Phocoena phocoena*) around Bottom-set Gillnets in the Celtic Sea

Abstract

The incidental take, or bycatch of the harbour porpoise (*Phocoena phocoena*) in commercial fisheries represents the greatest threat to the species. Whilst the 2001 meeting of ASCOBANS (Agreement on the Conservation of Small Cetaceans of the Baltic and North Sea) recommended a reduction in bycatch to 1.7% of the best population estimate, the UK set a precautionary objective to reduce bycatch to less than 1%, yet despite this it is thought that bycatch figures in the UK currently exceed this recommendation. There is a conservation need to understand why harbour porpoises get caught in fishing nets and to mitigate this problem accordingly. As part of another study, between October 1999 and March 2000, Celtic Sea gill-netters working out of Newlyn, Cornwall, were equipped with self-contained echolocation listening devices (Proto-PODs). These passively listen for and log cetacean echolocation click trains. The Proto-PODs store click counts and time until data can be retrieved and downloaded to a computer. A total of 2979 hours were recorded over 114 deployments. Data were analysed for effort within the fishery (month), number of deployments per vessel and time throughout the day and night. There was a statistically significant difference between boats. Analysis of the spatial distribution of deployments found differences over the region studied. There was no effect of time of day either within number of click positive minutes or click rate. These results demonstrate that harbour porpoises are present around bottom-set gillnets on average for 7 minutes of every hour of the day. Given the detection distance of the Proto-POD and average entanglement per km of fishing net, results demonstrate that harbour

porpoises are avoiding entanglement for 99.75% of encounters. This clearly demonstrates that harbour porpoises possess the ability to negotiate bottom-set nets, despite the high level of bycaught individuals recorded.

Introduction

Throughout its entire distribution, the harbour porpoise (*Phocoena phocoena*) is subject to bycatch in "bottom-set" or "sink" gillnets. This poses the greatest, worldwide threat to the harbour porpoise (IWC, 1994; Jefferson & Curry, 1994) and in many regions this has contributed to a severe depletion of the population (Reeves & Leatherwood, 1994). Annual bycatch figures indicate that the harbour porpoise population in the UK is being severely affected. Results published in 2000 estimate that 2300 animals are being taken annually by UK and Irish offshore netters (Tregenza, 2000). A study conducted by Kirkwood *et al*, (1997) which examined stranded cetaceans from the coasts of England and Wales demonstrated that bycatch figures had risen from 22% of all deaths in 1990 to 65% in 1995. The number of porpoises being caught in UK waters is currently thought to be unsustainable. The 2001 meeting of ASCOBANS (Agreement on the Conservation of Small Cetaceans of the Baltic and North Sea) agreed that as an intermediate precautionary objective, bycatch should be reduced to less than 1.7% of the best available population estimate, with the UK introducing an intermediate, precautionary objective to reduce it to less than 1%, with an ultimate goal to reduce to zero. Harbour porpoises are unlikely to be able to sustain even a moderate level of bycatch, given their short life span and late maturation (Woodley & Read, 1991).

4 [illegible]

[illegible]

[illegible]

[

Whilst action is required, it is first important to establish and understand the reasons for incidental capture in gillnets. One theory which has been proposed by Dawson *et al* (1991) is that porpoises may occasionally forage without using echolocation, and therefore do not detect the presence of the net. The intermittent use of echolocation activity has been observed in both Hector's dolphins (*Cephalorhynchus hectori*) and bottlenose dolphins (*Tursiops truncatus*) (Wood & Evans, 1980; Dawson, 1991). Both species were able to approach objects or even chase and consume fish without the need for echolocation. Dawson (1991) highlighted that both porpoises and dolphins, may make greater use of hearing than previously thought. Other theories suggest that porpoises may detect the net, but do not perceive it as a threat as their concentration is elsewhere (i.e. foraging, actively feeding) or that they may detect the net, but make a navigational error (Jefferson *et al*, 1992).

Research has shown that harbour porpoises are able to detect a monofilament gillnet in the water at a distance of 3-6m, in a low noise environment (Kastelein *et al*, 2000). Although this distance is increased to a theoretical, 13-26m using the results by Villiadsgaard *et al*, (2007) who found that harbour porpoises in the wild are capable of producing sounds more intense than captive animals, which subsequently provides a greater detection distance of both fish and nets. It also acts to increase the distance at which acoustic data loggers may detect the harbour porpoise (Villiadsgaard *et al*, 2007). Whilst harbour porpoises are capable of detecting the presence of the net, Goodson, (1994) highlighted echolocation characteristics which may affect net detection. For instance, both the headline and leadline of the gillnet are considered to be acoustically reflective to the harbour porpoise and as such proposals to mitigate bycatch considered increasing the reflectivity of the headline. Goodson (1994) points

out that, due to the low sonar power (180dB re 1 Pa) and narrow beamwidth (18 degrees) of their echolocation, a foraging porpoise concentrating on the seabed, may not detect a headline situated more than 3m above the seabed.

It is clear that in order to mitigate the problem of bycatch, further research is required. It was originally thought that the usual outcome of a porpoise encountering a net was entanglement; however initial echolocation studies by Tregenza (2000) indicated that porpoises can be active around nets without getting caught. The presence of nets may actually attract porpoises to the area, given the numbers of fish caught within them.

The primary aim of this study is to attempt to gain a better understanding of why harbour porpoises get caught in bottom-set gillnets. Previous research has clearly demonstrated their ability to detect the thin monofilament twine (Goodson, 1994; Kastelein *et al*, 2000), yet each year hundreds of animals are dying as a result of entanglement (NHM, 2005). In order to adequately mitigate against potential declines in the harbour porpoise population we need to understand the mechanisms which lead to them being entangled. Through assessment of echolocation activity around bottom-set gillnets, it is hoped that a greater understanding of their behaviour will permit an insight into the potential reasons for entanglement and subsequently be able to inform bycatch mitigation. Assuming that echolocation activity indicates successful negotiation of bottom-set gillnets, the null hypothesis that harbour porpoises are not acoustically active around gillnets will be tested. Additionally this hypothesis will be applied to the seasonal, spatial and temporal variation in data collation to provide a better understanding of when and where porpoises are encountering nets.

Methods

During 1999 and 2000 a pinger (acoustic deterrent device) trial was conducted in the Celtic Sea hake (*Merluccius merluccius*) fishery. Fishing vessels were issued with both live or dummy pingers (Dukane, Netmark 2000 pingers) and an acoustic listening device, known as the Proto-POD. The aim of the project was to assess the levels of bycatch and subsequent effectiveness of pinger deployment on bottom-set gillnets, using simultaneous acoustic monitoring. The results analysed here however arise from the dummy pingered nets, equipped with acoustic detection equipment (Proto-PODs), which was not analysed during the original trial. The data were provided by the original researchers (N. Tregenza & S. Northridge) for analysis. The results demonstrate, what is considered to be normal harbour porpoise echolocation activity around bottom-set gillnets.

The Celtic Sea is delimited by the 48°30'N and 52°N lines of latitude and between 4°W longitude and the 1000m depth contour of the edge of the continental shelf (Tregenza *et al*, 1997). The fishery studied was specifically gill-netters working from Newlyn, Cornwall. Whilst hake is the primary target species, other whitefish caught include pollack (*Pollachius pollachius*), saithe (*Pollachius virens*), ling (*Molva molva*) and cod (*Gadus morhua*). The bottom-set net consisted of 100-150mm mesh, which when stretched had a diagonal spacing of approximately 120mm. All nets had a headline with floats attached and a leadline weighted to the seabed. Most nets ranged from 5-9m in depth and were approximately 1600m in length. They were generally set at an approximate depth of 40-80m.

The Proto-POD is a self-contained submersible system which uses an analogue click detection process with digital timing of click durations. It logs counts of clicks heard within a logging period of one second or more and uses pairs of comparisons of energy levels to identify narrowband click types centred at or near three different frequencies (High, Mid, Low) (See Chapter Five: Acoustic Detection of the Harbour Porpoise: Towing the T-POD, for details).

Nine fishing vessels were issued with the dummy pingers and Proto-POD's, between October 1999 to March 2000. The dummy pingers were attached at regular intervals on the headline of the net, with the Proto-POD being attached to the bridle line at the base of the net. All nets were deployed in approximately 40-80m and rose 5-9m off the seabed. The location (GPS co-ordinates) was recorded at deployment, to aid recovery of the fishing gear and acoustic equipment. Proto-POD data were downloaded to a laptop computer at regular intervals between hauling and re-setting the nets, after a return to port. Once downloaded, the data were exported to Microsoft Excel, where both the modal click categories and total number of click positive minutes were viewed. The Proto-POD classifies number of clicks according to various size classes (Table 1). For instance where the modal number of clicks in any 30 second time period was 10, the time period would be classified with a click category of 5. A click positive minute is where two consecutive 30 second periods recorded clicks. An increase in click category could be indicative of intense activity within 1 or more individuals, or the presence of several animals all actively echolocating.

Table 1: Number of clicks recorded for each of the modal click categories used in classification.

Click Category	Number of Clicks
1	1
2	2
3	3-4
4	5-8
5	9-16
6	17-32
7	33-64
8	65-128
9	129-256
10	257-512
11	513-1024
12	1025-2048
13	2049-4096

As the Proto-POD also detects boat sonar, a number of false positives may be identified. The data were validated by looking for click count clusters which demonstrate identical successive counts. This would be expected as boat sonar is regular and repetitive and so would produce a series of identical click counts which may be punctuated by a rise and fall of the count either side as the vessel moves toward/away from the Proto-POD. The same rate index, which is the percentage of positive counts that are the same as the one before, should be below 20% for cetaceans and above 40% for boat sonars.

The hypothesis that there were differences between click activity between boats was tested using a repeated measures analysis of variance (ANOVA). This was to allow for the fact that the measurements were taken on the same experimental unit (i.e. Proto-POD), although on differing boats. This was assessed to establish initially whether variation occurred between vessels, which could be explained by spatial

variation in deployment. Whilst limited GPS data was collected, the spatial distribution of deployments was tested using a chi-squared analysis. A two-way AVOVA was used to test the hypothesis that there were differences over time between each vessel's deployments. It was also hypothesised that there was seasonal variation in deployment, which again was tested using a repeated measures analysis of variance. The spread of data across the 24 hour time scale was also considered after pooling the data, to verify complete coverage of all time periods. Proto-POD data did not meet all of the assumptions of an ANOVA (i.e. they were not normally distributed), therefore they were analysed using a non-parametric analysis, the Kruskal-Wallis test to assess any diurnal trends in porpoise presence. Echolocation levels (click categories) were also considered after pooling, in relation to time of day and again a Kruskal-Wallis test was used.

Results

In total 114 deployments were made between the nine fishing vessels, during October, 1999 and March, 2000. During this time a total of 3105 hours of data were recorded, however as only whole hours have been included in the analysis, this reduces the total number of hours recorded to 2979.

Data validation found that the same rate index was less than 4% of all counts, indicating that the data are that of echolocating harbour porpoises and not biased by positive detection of boat sonar.

The number of deployments between the fishing vessels differed (Figure 1). Analysis of number of click positive minutes per deployment revealed that there was a

statistically significant difference in individual boat deployment ($F_{(8,114)}$=2.36, p=0.024). Therefore spatial variation in deployment sites utilised by varying vessels may exist and as such potentially influence the results. Whilst it is recognised that the GPS locations recorded are limited a chi-squared analysis of the deployment sites indicate a non-random distribution of deployment (χ^2=23.70, df=12, p<0.001). Visual inspection of Figure 2, clearly indicates that Excellent, Girl Patricia and Nova Spero operate within the same areas, it is only the Ben Loyal which appears to vary location. Whilst the data were unfortunately too limited to permit a full individual spatial analysis for each vessel, the number of clicks recorded per minute in each hour, were assessed for variation, between vessels, (after taking a subset to account for varying number of deployments and provide equal sample sizes for each vessel sampled) (Figure 3). Visual inspection of Figure 3 reveals a slightly higher number of clicks recorded by deployments from "Ar Bag", unfortunately no GPS co-ordinates were recorded for this vessel. Despite this, no statistically significant difference was observed between vessels ($F_{(23,215)}$=0.76, p= 0.77).

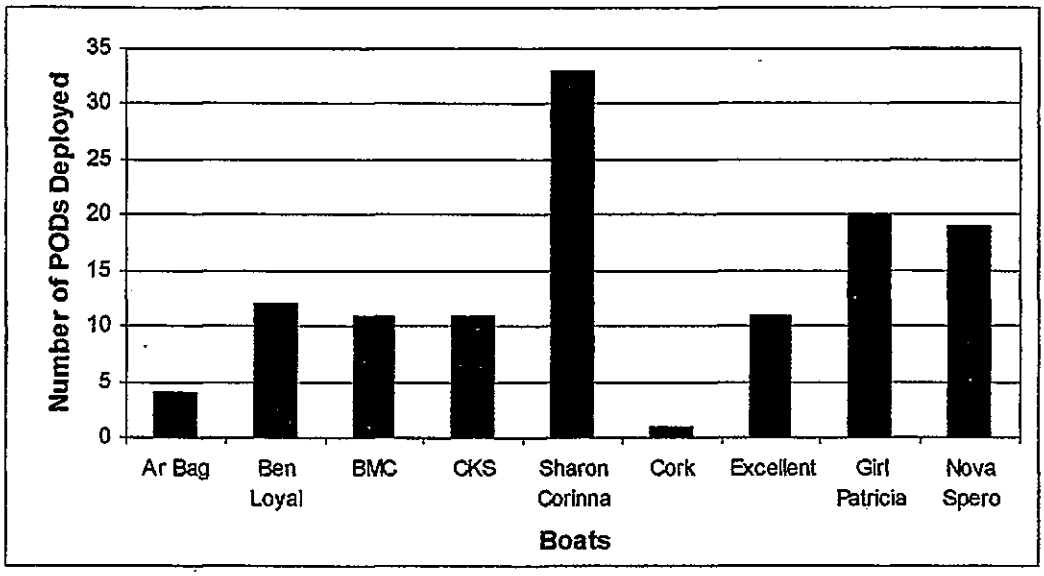


Figure 1: Number of POD deployments recorded per vessel involved in the study (Ar Bag, Ben Loyal, BMC, CRS, Sharon Corinna, Cork, Excellent, Girl Patricia & Nova Spero relate to vessel names).

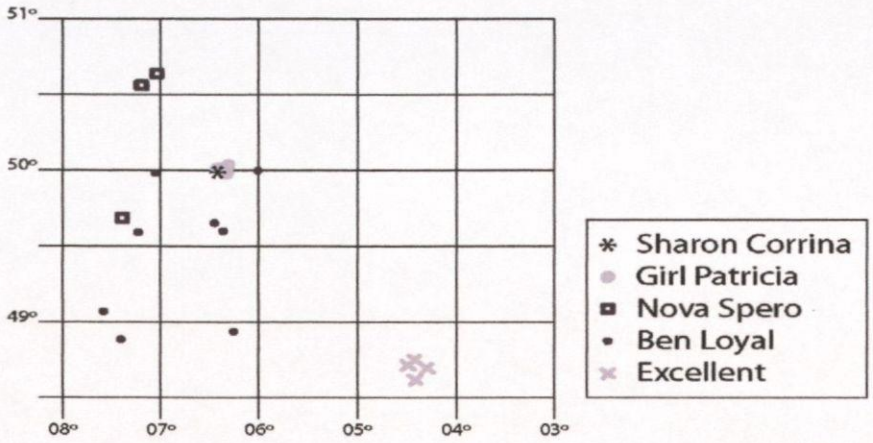


Figure 2: Deployment and fishing effort locations in the Celtic Sea, between October, 1999 and March 2000.

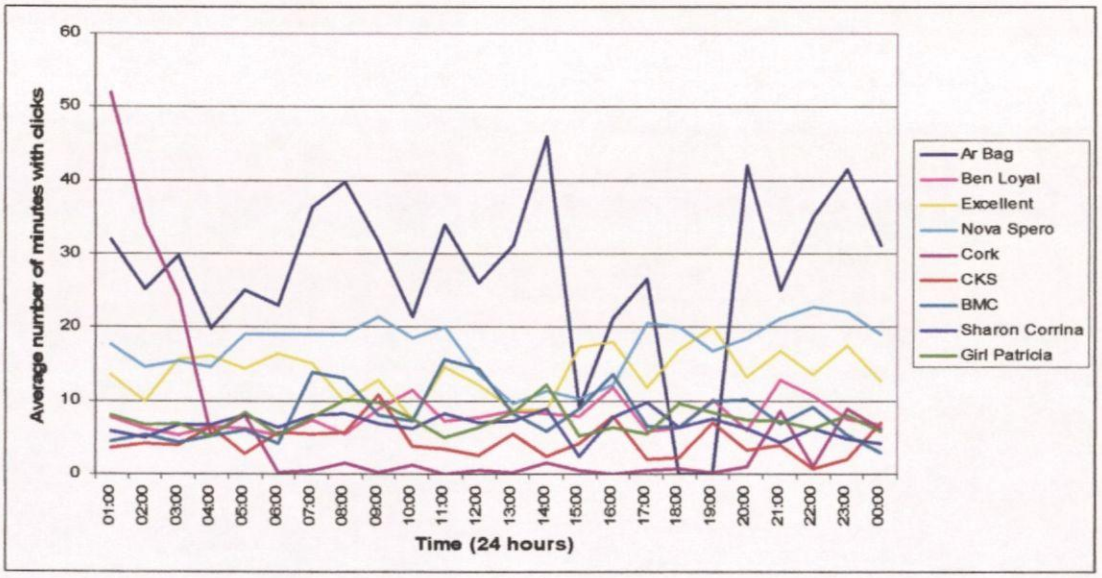


Figure 3: Average number of minutes with clicks, for each vessel used in deployments (Ar Bag, Ben Loyal, Excellent, Nova Spero, Cork, CKS, BMC, Sharon Corrina, Girl Patricia) across 24 hours.

Monthly variation in deployment effort (Figure 4) was also noted, which proved to be statistically significant ($F_{(5,114)}=3.48$, $p=0.006$) in terms of click positive minutes (Figure 5). Once again a subset was taken to control for variation in deployment effort and provide equal sample sizes. It was assumed that this represented seasonal variation in porpoise presence.

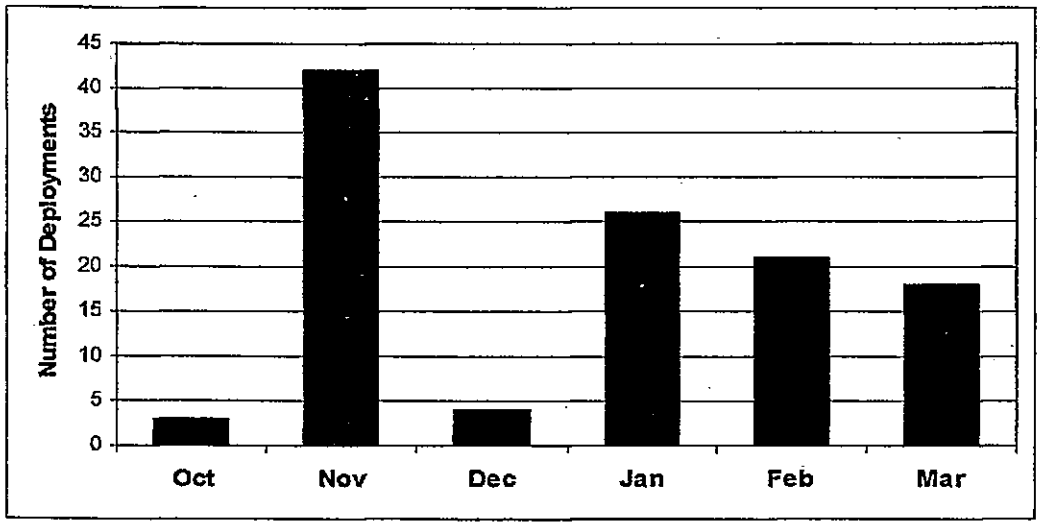


Figure 4: Pod deployment/fishing effort in relation to month between October, 1999 and March, 2000, for the Celtic Sea gill netters.

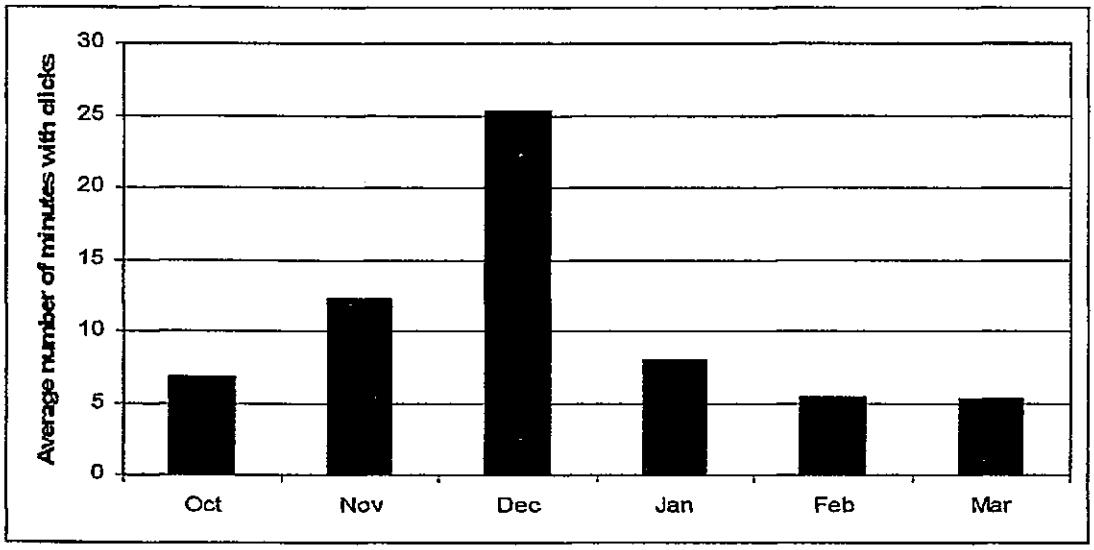


Figure 5: Average number of minutes with clicks for each month surveyed in deployments from vessels (Ar Bag, Ben Loyal, Excellent, Nova Spero, Cork, CKS, BMC, Sharon Corrina, Girl Patricia).

Consideration of deployment time was also made (Figure 6). Although there is a slight decrease in effort between the hours of 12:00 and 00:00, this was not considered limiting, as all time periods have over 100 recorded hours. There was no statistically significant variation in click positive minutes during the day (Figure 7) ($H_{(23)}$=13.29, p=0.945), highlighting porpoise presence for on average 7 minutes of every hour over 24 hours. In addition to this there was no variation in modal click category recorded by the Proto-POD's for each hour. The most frequently occurring

click category for each hour was 1 which relates to 1 click being recorded. The maximum recorded click category was 13 (2049-4096 clicks in a minute). The rate of clicks i.e. modal click count/number of minutes recorded, does not differ over time ($H_{(23)}$=17.24, p=0.798) (Figure 8).

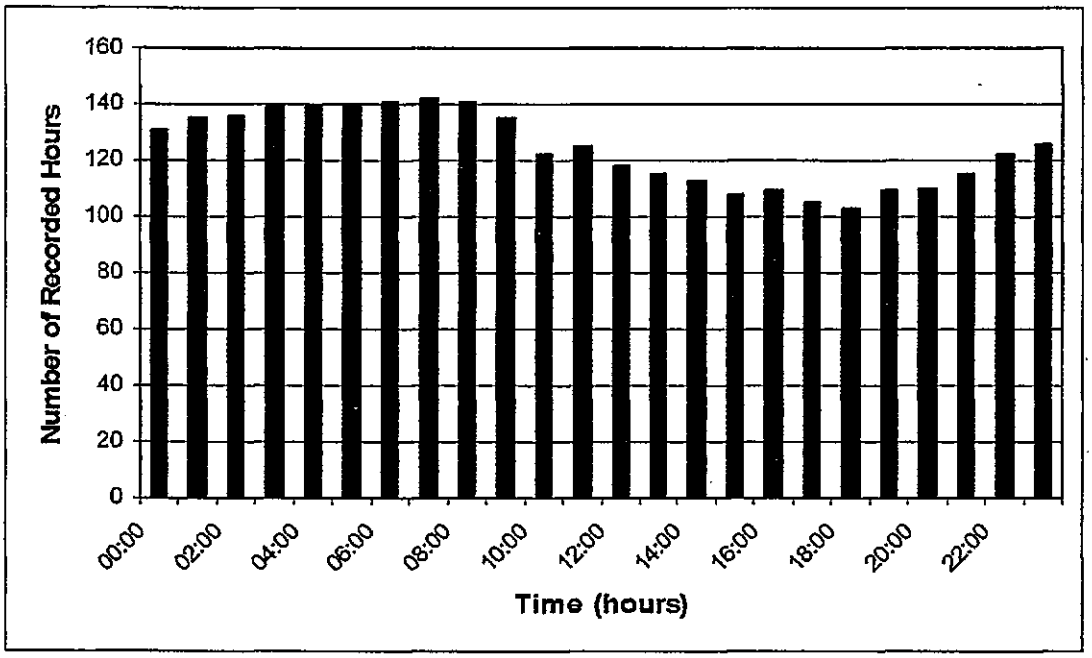


Figure 6: POD deployment time in relation to hour, across a 24 hour time period, for the entire study period, October 1999 – March, 2000.

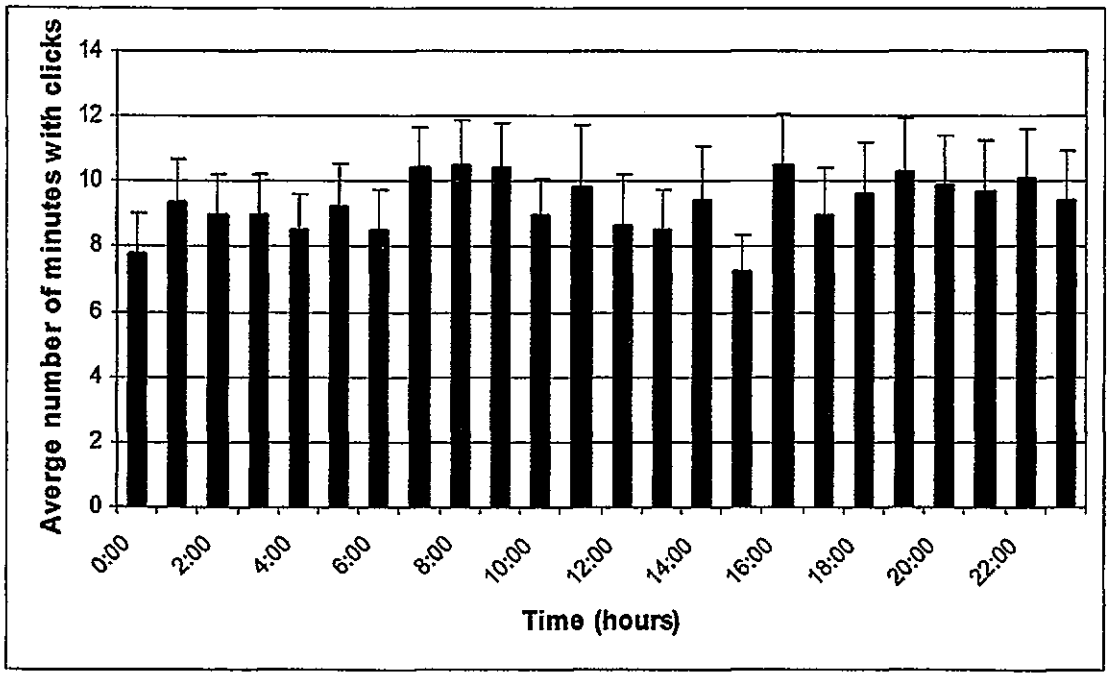


Figure 7: Average number of click positive minutes per hour for the harbour porpoise throughout the day and night.

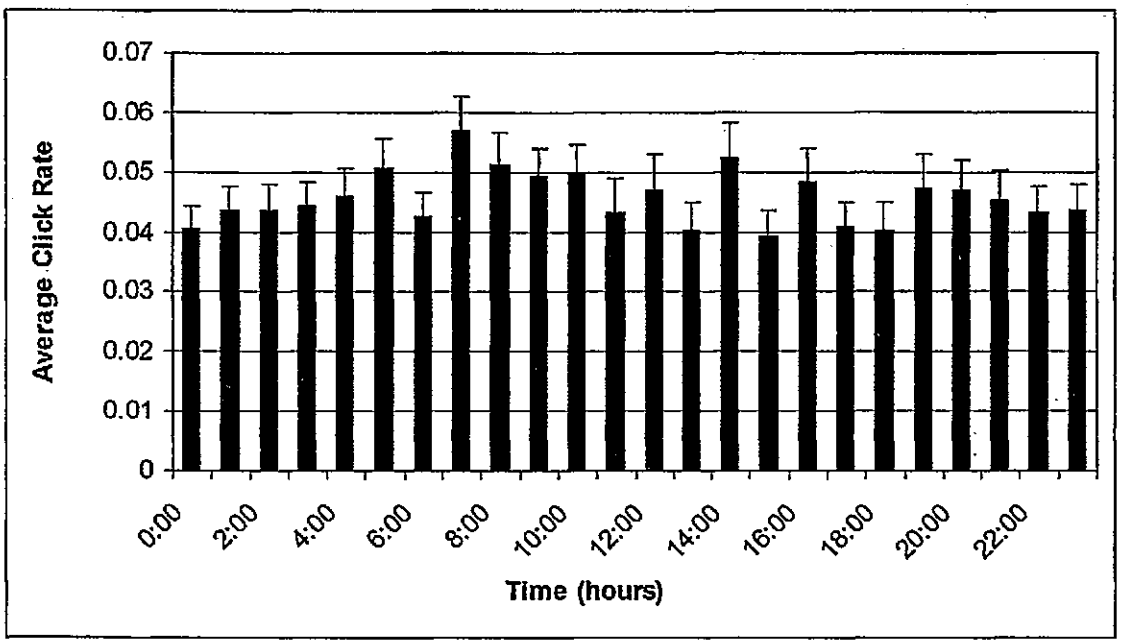


Figure 8: Average click rate per hour for the harbour porpoise throughout the day and night.

Discussion

The results of this study demonstrate that harbour porpoises are present and actively echolocating around bottom-set gillnets, throughout the day. No diurnal variation in either porpoise presence, or click rate was observed. This may be considered surprising, as Klinowska (1986) point out that where data exist, diurnal patterns have been found in all families of Cetacea. Indeed, Saayman *et al* (1973) demonstrated clear diurnal patterns in feeding behaviour for the bottlenose dolphin in the Indian Ocean. Previous studies of the harbour porpoise have also shown a rise in echolocation activity during the night. Hypothesised reasons for this include greater exploration of the seabed and environment, or investigation of objects at close range, perhaps used whilst engaging in foraging behaviour (Tregenza, 2000; Carlstrom, 2005). Akamatsu *et al* (1992) identified a peak in echolocation rate during the evening, which decreased during the early hours of the morning. Researchers proposed that the peak was associated with feeding bouts and investigation of their surroundings. Whilst the study by Akamatsu *et al* (1992) has considered echolocation

rate over a 24 hour scale from captive animals, only Villiadsgaard *et al* (2007) have considered echolocation of individual harbour porpoises at sea, where an increased maximum source level was found.

In a previous study the echolocation behaviour of porpoises around gillnets was found to vary with depth, space and time of day (Cox & Read, 2004). The study, conducted in Canada, monitored nets used to catch cod, saithe, haddock (*Melanogrammus aeglefinus*) and white hake (*Urophycis tenuis*). The researchers concluded that the variation in space and time in the echolocation activity of the harbour porpoises was potentially due to the diel vertical migration of the principle prey item in the region, Atlantic herring (*Clupea harengus*). In this study it is not clear what the precise function of the echolocation activity relates to, although it is likely to be feeding and foraging (Carlstrom, 2005). Whilst it is not possible to comment on the prey species which may be being consumed due to the diverse diet of the harbour porpoise in UK waters, porpoises have been found to consume greater quantities of whiting (*Merlangius merlangus*) during the winter months in Scotland (Santos *et al*, 2004). Whilst some researchers have hypothesised that there exists a vertical migration in different size classifications of whiting, researchers did not find evidence of this through stomach content analysis of the fish caught in the North Sea (Rindorf, 2003). They found that that the occurrence of bottom dwelling prey for whiting increased significantly during the night whereas free swimming prey and prey migrating towards the demersal layer during the day were eaten mainly in the daylight hours – whiting consume prey which is available rather than migrating in response to diel migration of their prey (Rindorf, 2003). Assuming that harbour porpoises are

consuming whiting this may account for the appearance of echolocation activity around the bottom-set gillnets throughout the diurnal cycle.

It remains unknown as to why porpoises become entangled, yet this study clearly demonstrates that porpoises are active around bottom-set gillnets on average for 7 minutes of every hour of the day. Previous POD data from the Celtic Sea indicate that less than a 0.5km radius will be entered by the porpoises about three times a day (Tregenza, 2000). Additionally Jefferson *et al* (2002) identified the Proto-POD as having a detection distance of approximately 250-350m. As entanglement, on average only occurs about once every 50km per day (Tregenza, 2000), with a presumed successful encounter rate for 7 minutes every hour, per 350m of net, this indicates that harbour porpoises are successfully avoiding the nets on 99.75% of encounters.

Whilst these results provide an important piece of the puzzle in understanding harbour porpoise bycatch in inshore fisheries, it still remains unknown as to the circumstances which ultimately lead to the entanglement and death of the porpoise. Is it, as has already been hypothesised that porpoises do not always utilise their echolocation when feeding (Jefferson *et al*, 1992) and hence fail to detect the presence of the net? Is it a navigational error or that their concentration is elsewhere whilst engaged in feeding or the result of a last minute miscalculation? Whilst the percentage of encounters which result in a fatal entanglement are low (0.25%), the number of harbour porpoises washing up on south western beaches of the UK indicate that bycatch remains a significant problem for this species (Jepson *et al*, 2005). These results would suggest that either there are large numbers of harbour porpoises active around the nets or that there are large amounts of net in the region.

Results from SCANS II (Small Cetacean Abundance of the North Sea, conducted during 2005) survey indicate that since SCANS I, conducted in 1994 the numbers of harbour porpoises in the Celtic Sea region have risen from 36,280 (CV = 0.57) in 1994 to 80,600 (CV = 0.5) in 2005 (Hammond & MacLeod, 2006). Despite what may appear initially as a significant increase, numbers for the whole survey area have varied little, indicating that this may represent a redistribution of the population (341,000 (CV = 0.14) in 1994; 386,000 (CV = 0.20) in 2005). The numbers of harbour porpoises in the Celtic Sea could account for the continual increase in bycatch-related harbour porpoise deaths which are observed each year (Jepson *et al*, 2005; Goodwin & Edwards, 2007), however in addition to these population estimates there has also been a concurrent increase in the average length of net set by any one fishing vessel operating in the region. It is thought that average net lengths are now 120km per vessel (Goodwin & Ross, 2007) and whilst the total length of net at sea will vary according to a number of factors, including: the number of vessels operating, weather conditions, soak time and time of year (target species) the threat to harbour porpoises from entanglement in fishing gear remains ever present.

The presence of harbour porpoises around bottom-set gillnets could of course be a consequence of attraction to the net and the entangled fish, as much as it could be a simultaneous attraction to the area, as both fishermen and porpoise take advantage of highly productive sites. This has the potential to cause increasing conflicts between fisheries and the harbour porpoise, amongst other cetacean populations. Depredation of catch can decrease the value and quantity of the catch and has been identified for a number of cetacean species, including: the bottlenose dolphin in the king mackerel (*Scomeromorus cavalla*) troll fishery (Read *et al*, 2003; Zollet & Read, 2006), killer

whales (*Orcinus orca*) preying on tuna (*Thunnus spp.*) and swordfish (*Xiphias gladius*) in longline fisheries (Dalla Rosa & Secchi, 2007), pilot whales (*Globicephala spp.*) feeding on Atlantic mackerel (*Scomber scombrus*) in trawl fisheries off the north eastern United States and sperm whales (*Physeter macrocephallus*) on the longline Patagonian toothfish (*Dissostichus eleginoides*) fishery in the South Atlantic (Purves *et al*, 2004). Spatial overlap of the Celtic Sea hake fishery and the presence of the harbour porpoise, combined with behavioural learning may act to encourage the occurrence of depredation in this fishery and may account for the clear, regular presence of harbour porpoises around bottom-set gillnets.

Whilst the precise function of the echolocation activity and the behavioural reason for harbour porpoise presence around bottom-set gillnets remains unknown it is clear that harbour porpoises are capable of safely negotiating the nets. This has important implications for bycatch mitigation and fishery management solutions as the research also indicates that harbour porpoises are present around the nets throughout the diurnal cycle. These findings should be taken into consideration when attempting to mitigate against harbour porpoise bycatch in the bottom-set gillnet fishery.

Acoustic Detection of the Harbour Porpoise (*Phocoena phocoena*):

Towing the T-POD

Chapter Five

Acoustic Detection of the Harbour Porpoise (*Phocoena phocoena*): Towing the T-POD

Abstract

Technological advancements have enabled researchers to address new aspects of cetacean behaviour and ecology. The T-POD, a self-contained, submersible hydrophone and computer, originally designed for static acoustic monitoring of the harbour porpoise (*Phocoena phocoena*) was developed for towing during 2002 and 2003. Detection of sonar and engine noise emitted from the research vessel were assessed by comparison of total click counts recorded in 2002, however only engine noise was found to be significantly different between trial and control tests. During 2003 detection distance for both marine vessels and harbour porpoises were estimated through simultaneous comparison of both visual and acoustic detections when encountered. Additionally group size variance and distance were assessed for bias in visual detection. The hypothesis that only larger groups would be detected at distance was disproved. A detection distance of 300m is provided for the T-POD given the confirmed visual observations of harbour porpoises and motor vessels in the study area. Whilst the difficulties associated with cetacean research at sea are acknowledged given the T-POD was found to detect 10% of all harbour porpoises encountered which were not detected visually this device offers a complimentary means of survey to any visual vessel-based study. Additionally this device also offers a means of survey when visual observation is not possible.

Introduction

Researchers face a number of difficulties when studying the behaviour, ecology and conservation of cetaceans. Whales and dolphins are highly mobile and typically spend the majority of their time beneath the surface of the water. Initially behavioural research consisted of visual observation of behaviour both in the wild (Amundin & Amundin, 1974; Lockyer & Morris, 1986) and in captive facilities (Saayman *et al*, 1973). However, a number of technological advancements have been made which have facilitated research methods and increased our understanding of cetaceans in the wild.

Whilst time-depth recorders (TDRs) and satellite transmitters have aided research into cetacean movement and migration (Read & Westgate, 1997; Westgate & Read, 1998; Wells *et al*, 1999), hydrophones and acoustic loggers have enabled an increased understanding of echolocation abilities and characteristics (Freitag & Tyack, 1993; Akamatsu *et al*, 1994; Kamminga & Wiersma, 1981; Au *et al*, 1999). Indeed a number of researchers have combined technology to facilitate research. Westgate & Read (1998), tagged 14 harbour porpoises with satellite transmitters and a further 9 harbour porpoises with time-depth recorders. Their results not only highlighted the potential threat to the porpoises, as they frequented fishing grounds, but also supported claims that porpoises can and do dive to depths at which gillnets are set (on average 40-80m) (Westgate & Read, 1998).

When studying echolocation in the wild, many researchers have utilised hydrophone technology to listen for and identify cetacean species (Watkins, 1980; Purves & Pilleri, 1983). Since the first hydrophones became available a number of other

echolocation listening devices have also been produced. In 1999 an automatic porpoise detector was developed (Tregenza & Northridge, 1999) termed the Proto-POD. This was a self-contained echolocation click logger which used an analogue detection process with timing of click durations. It logged counts of clicks heard within a logging period of one second or more and used pairs of comparisons of energy levels to identify click types centred at or near three different frequencies. The Proto-POD proved highly discriminating in the detection of porpoise clicks, but with several limitations. Many small craft sonars and echo sounders operate in the same frequency band as phocoenids (c 50-200kHz) and so can generate distinctive sequences of false detections. Some delphinids also produce high frequency clicks which resemble porpoise clicks and can lead to misidentification. The Proto-POD could not distinguish the short broadband clicks produced by dolphins from many similar clicks.

Following the Proto-POD came the production of the T-POD in 2000. This self-contained submersible hydrophone and computer differed from the Proto-POD in a number of aspects, which included the ability to change frequency filters during use, the ability to log time of occurrence and duration of click to 10μs resolution, larger memory (8Mb), and a longer running time. As a passive acoustic monitoring (PAM) device, it listens to any sound in the sea through a ceramic transducer embedded in its wall. It detects clicks by comparison of the outputs of two filters, which select energy from two different frequency bands of the sound spectrum. Click detection is initiated by the occurrence of relatively higher levels of sound energy at the target frequencies when compared with the reference frequencies. The minimum ratio in sound energy between the filter outputs required for detection can be varied by the user. This two

filter design is less discriminating than the previous filter system. Discrimination is subsequently raised to a much higher level by detection of trains of clicks, characteristic of cetaceans.

The T-POD can be set to listen solely for harbour porpoises or when working in an area in which either species may be encountered, a combination of dolphin and porpoise criteria can be set. A tilt switch has been incorporated into the T-POD design which permits the user to specify angles at which the T-POD will activate or deactivate logging thereby facilitating ease of deployment.

The T-POD stores all detections, until information is downloaded to a PC via a parallel port. This may be completed either at the end of the study period or at regular intervals in long-term research projects. Six alkaline D-cell batteries will maintain the running capacity of the T-POD for approximately eight weeks. A double pack may be utilised when longer running periods are desired. Once the data have been downloaded the T-POD software provides a train detection algorithm, which finds trains and classifies them into high or low probability of having a cetacean origin. The algorithm also identifies possible boat sonar pulses which may have been recorded. A number of graphical display options are also available on download: click duration, inter-click interval and pulse repetition rate. Two hours of interval counts from one are shown in Figure 1. Data may also be exported into a summary file, highlighting total click counts, percentage of click positive minutes or number of encounters. This facilitates statistical analysis of the data as the exported information may be opened directly into spreadsheets, such as Microsoft Excel.

assessment of the effects of construction were made. The T-POD was towed on ten occasions and detected 11.5% of the visual sightings recorded.

Boat-based visual studies have inherent observational difficulties. Cetaceans are particularly difficult to see in sea states greater than Beaufort scale 3 and they only spend a limited amount of time at the surface (Westgate *et al*, 1995). Individuals may also react adversely to the research vessel before being observed and therefore may be missed (Evans *et al*, 1994). With the technological advancements in acoustic research, monitoring of cetacean species from a boat-based platform may be combined with visual studies to accurately assess cetacean populations. Two published studies have towed the T-POD in cetacean research, however only one, by Tougaard *et al*, (2003) considered its efficiency in towing, from which the authors concluded that the T-POD was not suitable for towing despite an 11.5% detection rate (Jefferson *et al*, 2002; Tougaard *et al*, 2003).

This research is essentially a technical exercise however, should initial towing experiments prove a success, the ability to tow a submersible hydrophone and computer, which does not require a live link could substantially improve cetacean research in the wild. This ability would permit more accurate data recording of cetacean abundance and behaviour in wild populations. Furthermore through a better understanding of wild groups better conservation measures could be implemented. The aim of this research was to identify the optimum methodology, and conditions in which to tow the T-POD. Sonar and engine noise emitted from the research platform were used to test the hypothesis that these do not affect data recording by the T-POD. Additionally the weather and sea state was used to evaluate the hypothesis that the T-

POD can facilitate research when visual monitoring is not possible. The hypothesis that towing the T-POD results in detection of harbour porpoise groups and passing vessels was tested in a number of sea trials, through comparison of simultaneous visual and acoustic recordings. Finally an assessment was made of the distance at which different group sizes were visually observed to check for bias in visual methodology, the hypothesis that only larger groups would be visually detected at greater distances from the vessel was tested.

Methods

The first trials of towing were conducted onboard a small fishing vessel, MV Osprey, which operates out of Ilfracombe, North Devon, UK. This allowed the initial towing rig to be established and trialled in an area of high porpoise density. The first rig, developed by Nick Tregenza, consisted of a towing board, designed to surf along behind the vessel, followed by a length of line approximately 3 metres in length attached to the T-POD, onto which were fixed two fins at the forward end, which forced the T-POD to dive whilst under tow. This version of the T-POD also had a hollow length of plastic tubing attached, which enabled the T-POD to float at the surface whilst the vessel was stationary, thereby marking its position, when stationary, or in the event that it became detached. The whole rig may then be towed at varying distances behind the vessel, without any concomitant change in depth.

This rig was then trialled during May, 2002, onboard SRV Forever Changes, an 11.7m Dufour sailing yacht, with a Perkins 4.108 auxiliary diesel engine, Variprop feathering propeller and an Interphase Twin Scope sonar working on the frequency of 200kHz, at an average speed of 6 knots. During May to September Forever Changes

surveyed the west coast of UK, involved primarily in basking shark (*Cetorhinus maximus*) research. Line transect surveys were carried out between fixed positions both inshore and offshore, using a standardised effort-corrected methodology. Two observers were employed at all times, each visually scanning one side of the vessel, equipped with 8×40 binoculars, with a third crew member recording the vessel's position every half hour via a Furuno GP-32 GPS/WAAS Navigator interfaced with a DELL notebook computer operating SeaPro Pro navigational software and ARCS electronic charts. Additional navigational and environmental data recorded each half hour include vessels bearing, wind direction and speed, sea state, weather, cloud cover, depth and sea temperature. When harbour porpoises were encountered the following information was recorded: time, GPS location, vessel heading, bearing to cetaceans, distance, depth, sea temperature, minimum group size. Observers were rotated every three hours, to prevent misidentification or missing animals through fatigue. The vessel did not break the transect route in order to approach the animals.

Whenever weather conditions allowed, the T-POD was deployed and towed at a distance of 100m behind the vessel. When sea state increased beyond Beaufort scale 5 it was deemed unsafe to deploy the rig. The engine and sonar were also recorded as on or off throughout the duration of deployment. The T-POD was deployed for approximately 9.5 hours in each state of the sonar and/or engine being on/off. It should be noted however, that due to the nature of the survey and varying weather conditions during this time it was not possible to tow the T-POD in the same area or at the same time of day, whilst varying the levels of sonar and/or engine noise. Data were collected opportunistically when conditions allowed (i.e. it was safe to operate without sonar) and when the weather permitted a choice between engine or sail.

Following the results of the survey in 2002, further developments were made not only to the towing rig, but also to the T-POD software. For 2003, an updated version of the T-POD, was deployed, with a modified rig. This was essentially the same as the 2002 version, except (1) the plastic flotation tubing had been replaced with wooden dowelling (Figure 2), and (2) swivels had been attached between the towing board and the boat, as a means of avoiding the towing line becoming twisted (preventing the POD spinning, should the board be hit by a wave and upturned). A length of line was also attached behind the POD, acting as a streamer drogue. This helped the POD to maintain a uniform position in the water column, and to track in a straight line, whilst being towed (Figure 3).

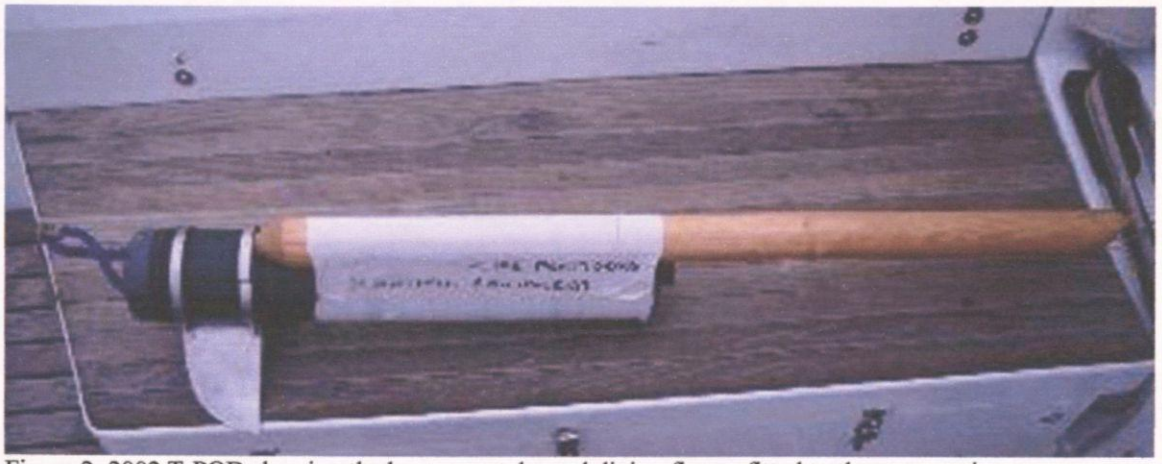


Figure 2: 2002 T-POD showing the buoyancy tube and diving fins as fitted to the outer casing.

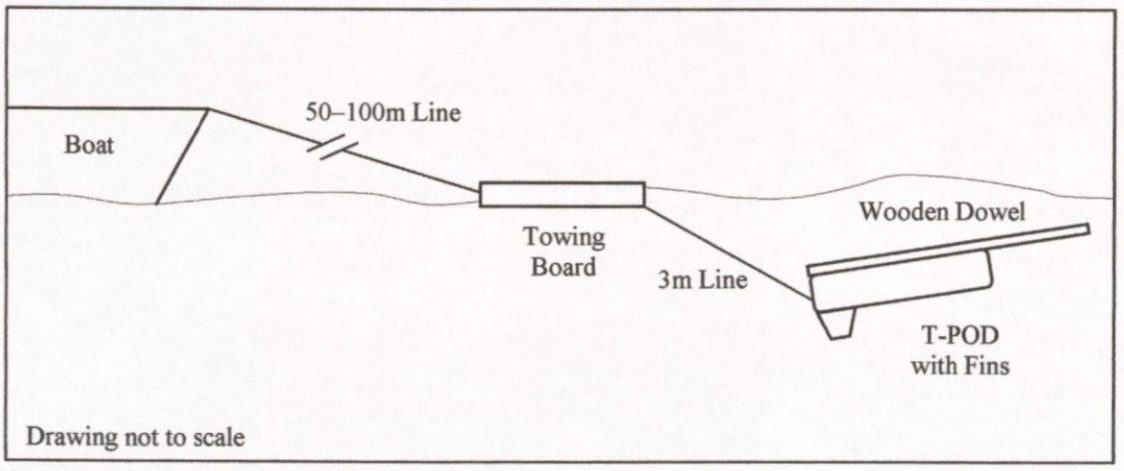


Figure 3: Schematic diagram of T-POD under towing conditions, from a side profile.

Unfortunately, communication problems were encountered with the PC in use and later the tilt switch within the POD malfunctioned. This resulted in only 4 weeks of data collection throughout the season, between 16th to 26th of June and 27th July to 7th August 2003. The data collated were analysed in respect of visual versus acoustic detections, as a means of validating the T-POD. The data from the T-POD cannot, as yet, be viewed in real time therefore the observers did not know what the T-POD was recording until the end of the day. This eliminates any possible bias in the comparison of the two survey methods. To help facilitate identification of extraneous noise and to further validate the accurate detection of sound by the T-POD, any vessels which approached or passed by were also recorded, noting the time, location (port/starboard), distance and direction of travel.

Results from towing in 2002 were analysed in respect of the effects of both sonar and engine noise emitted from the research vessel in use. It was hypothesised that there would be no effect of these variables given the modifications to the sailing vessel in use, including a feathering Variprop propeller and sound insulation around the engine housing. Should either the sonar or engine be producing additional noise which could interfere with and be detected by the T-POD, it was assumed that there would be an overall increase in total click counts for the periods when either of these devices was operational. The null hypothesis was evaluated by a one-way analysis of variance (ANOVA) on total click count for the categories: on, sonar, engine, off and two separate paired t-tests to compare mean click counts for sonar and engine with a control tow when neither were in use (Off).

A comparison of boat encounters, during 2003, was made to assess the level of accuracy and detection distance of the T-POD. A paired t-test was used to test for differences in visual and acoustic (with visual confirmation) detections. Unfortunately it was not possible to assess the effects of environmental variables (weather, sea state, wind speed and swell height) in 2003 due to a lack of variation in the weather. An assessment of both visual and acoustic detections of the harbour porpoise was also made using a paired t-test, in order to further validate the use of the T-POD in towed acoustic cetacean surveys.

Group size variance and estimated distance from the vessel were compared with a linear regression analysis, to establish whether group size influenced visual detectability.

Results

2002 - Sonar and engine effects

On 13 days, during May 2002, a total of 34 hours were spent towing the T-POD. The mean sampling interval was 176.077 ± 29.56 (s.e.) minutes. Due to the opportunistic nature of data collection only 6 tows were made in each category. The mean click count recorded for each category ($On_{(Sonar\ \&\ Engine)}$, Sonar $on_{(Engine\ Off)}$, Engine $on_{(Sonar\ Off)}$, $Off_{(Sonar\ \&\ Engine)}$) is illustrated in Figure 4. Analysis of total click counts detected by the T-POD did not demonstrated a statistically significant difference ($F_{23} = 0.65$, $p=0.593$) between categories. However engine noise was found to have a statistically significant effect on the mean number of clicks recorded (Sonar, $t_5 = 1.46$, $p = 0.10$; Engine, $t_{11} = 2.71$, $p<0.05$).

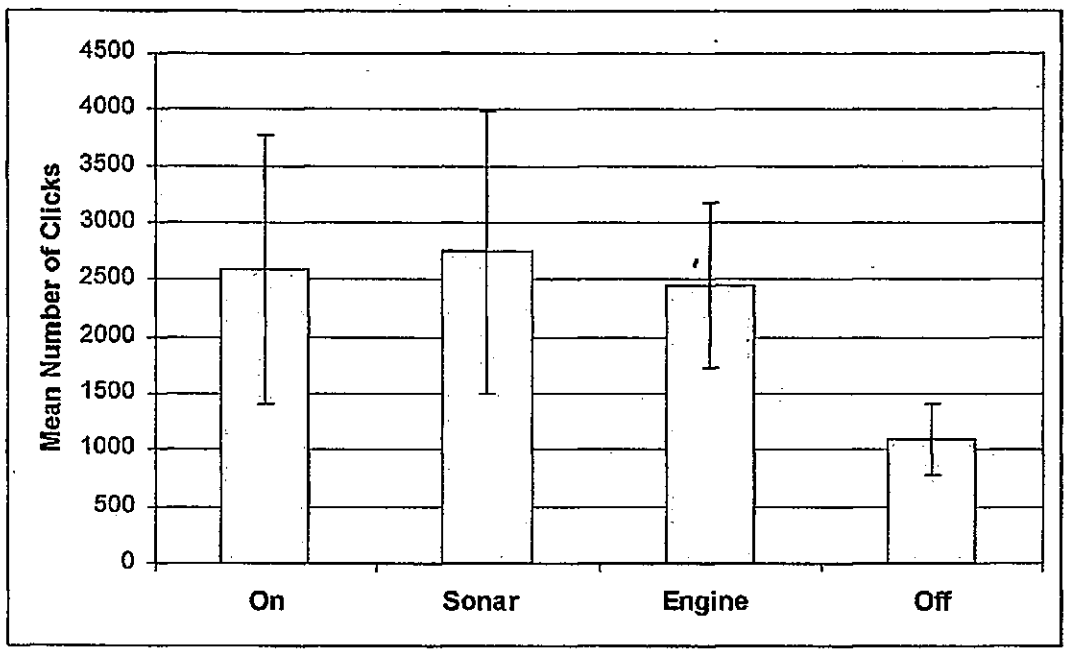


Figure 4: Mean (± s.e.) number of clicks recorded in each category i.e. On(Sonar & Engine), Sonar on(Engine Off), Engine on(Sonar Off), Off(Sonar & Engine), whilst towing the T-POD, during 2002.

2003 – Environmental Variables

Due to favourable, calm weather conditions throughout the study period, not enough data were collected to permit analysis of the T-POD working in a variety of conditions. Sea state was on average recorded as Beaufort scale 3 (range 2-4) with an average wind speed of Beaufort scale 3 (range 2-4). Swell Height was <1m on 88% of the towing trials and weather was recorded as Fair, except on three occasions.

2003 – Boat Sonar Pulse, Train Detections

During the four week period, from 16th June – 26th June and 27th July – 7th August, 2003, the T-POD was towed on 22 occasions, for a total duration of 123.35 hours. A comparison of the number of boats detected both visually and acoustically was made (Figure 5). Where boats were detected visually an estimate of distance was also recorded. The times of the visual observations were later compared to the acoustic detection data. Where observations were within 5 minutes of one another a match was

recorded and the estimated visual distance was used in the subsequent analysis of acoustic detection distance. The paired t-test highlighted significant differences between the two methods employed (visual and acoustic), $t_{(20)}=4.35$, $p<0.001$. The T-POD made 17 false boat detections and only recorded 13% of all boats observed during deployment. The average distance of confirmed detection of boats (i.e. detected both acoustically and visually) by the T-POD was 228.8m. Taking this into consideration, if a limit of 300m is assumed as the detection distance then the T-POD recorded 17.3% of boats, as the other boats were recorded as being greater than 300m away and would therefore not be recorded acoustically.

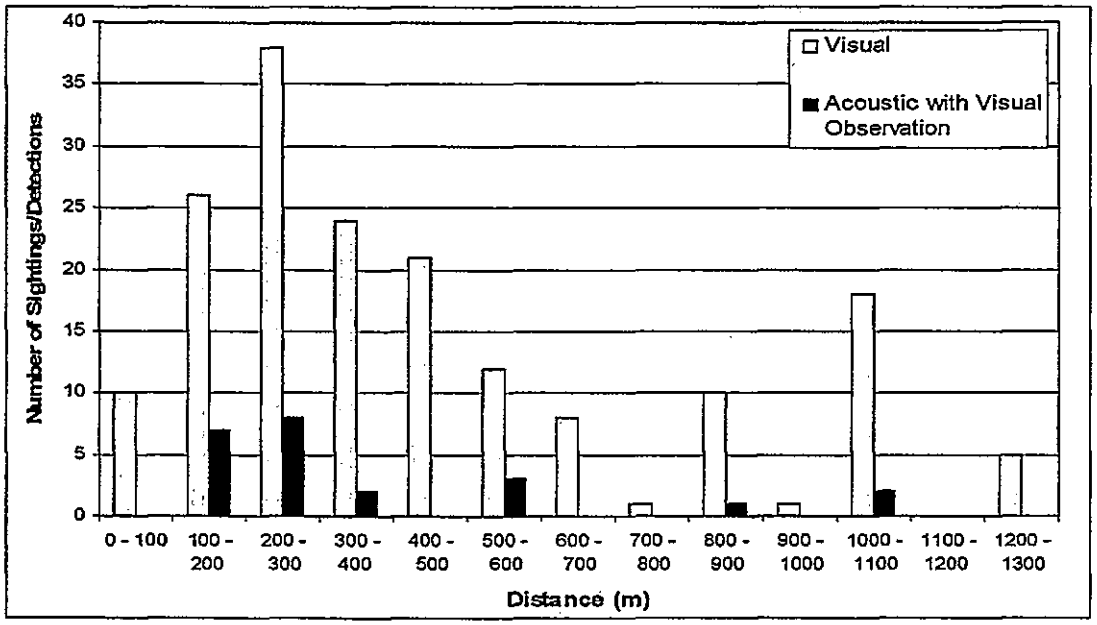


Figure 5: The distance at which boats were recorded for both visual and acoustic surveys, during July & August, 2003.

2003 – Harbour Porpoise Detections

During the four week trial a total of 53 harbour porpoise group sightings were made, with 13 acoustic detections (Figure 6). A paired t-test demonstrated a statistically significant difference in efficiency between the methods employed (visual and acoustic) $t_{(20)}=2.34$, $p=0.01$. On 6 occasions porpoises were detected but not observed, and observed but not detected on 43 accounts. The 6 accounts of "missing" porpoises,

detected acoustically by the T-POD, could be due to a number of reasons: (1) the porpoises were engaged in activity beneath the surface of the water (2) the porpoises had already responded to the approach of the vessel (3) the click trains in questions were falsely identified by the T-POD.

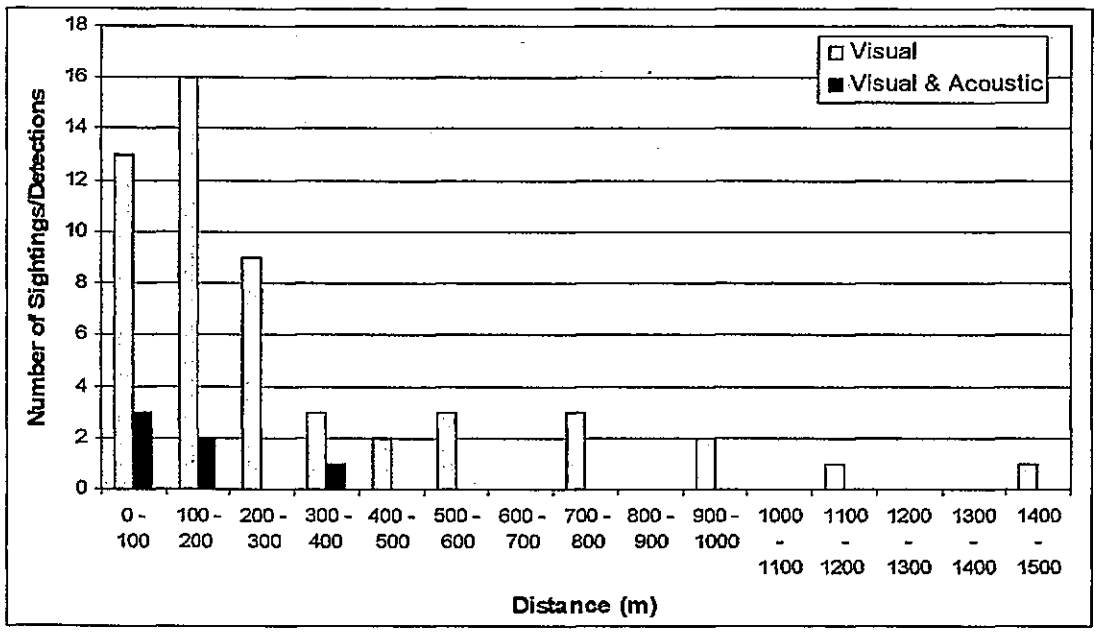


Figure 6: The distance at which porpoises were recorded for both visual and acoustic surveys during July & August, 2003.

Assuming a total number of groups of 59 (53 observed plus the 6 not observed), the T-POD is recording 22% and missing 78% of the total number of groups in the area, assuming that all porpoises are actively echolocating in the direction of the T-POD. If, however, the porpoises are not echolocating when the T-POD is within detection range, it is not missing any detections. Taking into consideration the 6 groups which were detected by the T-POD but not observed indicates that at least 10% of the population are unrecorded in this visual survey, if they were correctly identified as harbour porpoises, by the T-POD in these instances.

To evaluate whether group size influenced identification at distance, the variance of the group sizes and the estimated distance recorded were plotted for both visual and acoustic data (Figure 7). Whilst this demonstrates that at distances of <200m group size records vary more than when observed up to 1200m away, the linear regression analysis did not demonstrate a statistically significant relationship between the two variables (r^2=0.07, $F_{1,16}$=1.083, P=0.315). Therefore whilst some group size estimates are perhaps underestimated when recorded at distance, no bias is thought to exist as a consequence of larger group sizes.

As with the boat records, the same process of matching visual with acoustic detections was repeated in order to obtain estimates of detection distance for the harbour porpoise. The average detection distance of confirmed detection of harbour porpoises by the T-POD was 183.33m.

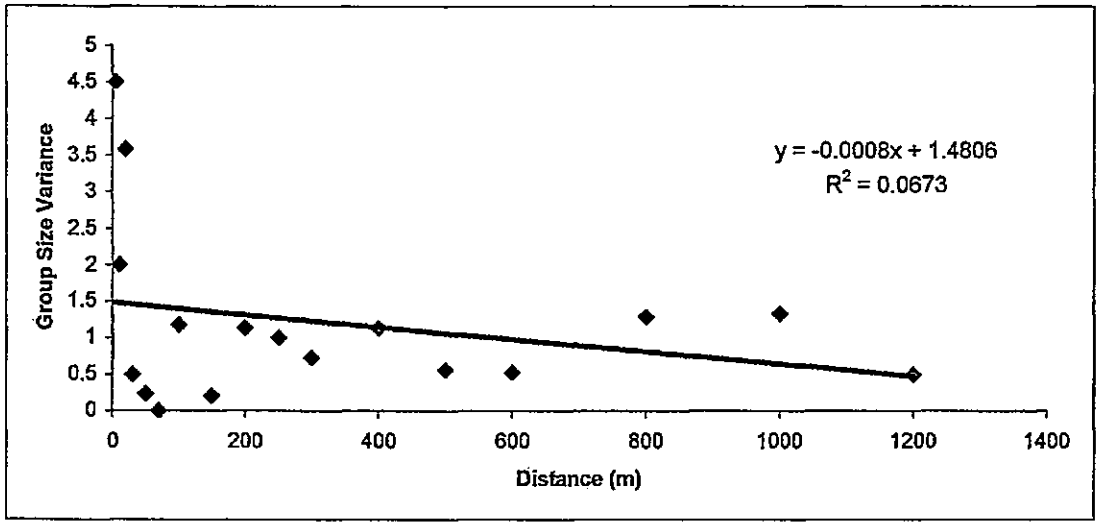
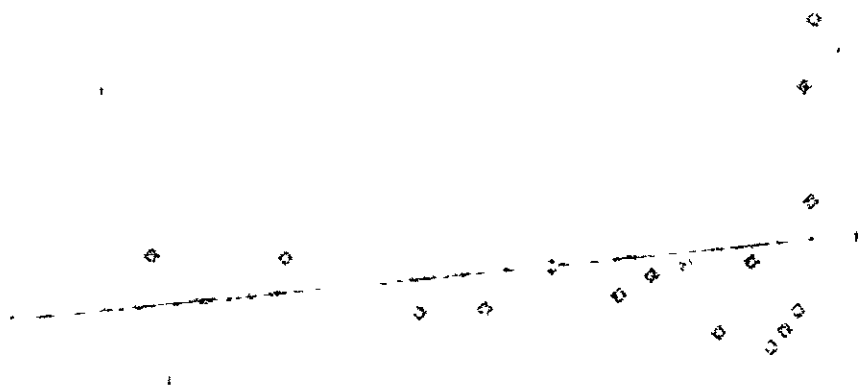


Figure 7: The estimated distance for the group size variance recorded in both the visual and acoustic surveys, during 2003.

Discussion

The T-POD was originally designed for static deployment however results of this study demonstrate the potential which the T-POD provides for enhancing visual



surveys of the harbour porpoise. This research has refined the towing rig and methodology for deployment and retrieval to a working model. Despite what may appear as low levels of detection, the T-POD was shown to pick up an additional 10% of encounters of the harbour porpoise which had not been detected visually. As responsive movement of animals is a problem to both visual and acoustic surveys (Palka & Hammond, 2001), this finding is significant. When conducting any boat-based survey the research is based on a number of assumptions i.e. that all cetaceans on the track line are recorded, that cetaceans do not respond to the approach of the vessel before detection by an observer and that sightings are independent of each other (Mann, 2000). As the T-POD does not rely on visual confirmation it provides a complimentary tool to vessel-based survey.

Additionally though, the T-POD also comes with a number of caveats to be considered when interpreting the results of this research. It is based on the assumption that all harbour porpoises encountered will be actively echolocating in the direction of the T-POD when encountered. Whilst animals may have initiated movement in response to the vessels they may still be observed at the surface, however if they have turned away from the T-POD they may not be detected due to the highly directional nature of the device (personal communication, Nick Tregenza). Previous research has additionally shown that porpoises are, on occasion, silent (Cox *et al*, 2001) which could explain why animals were seen but not detected by the T-POD. If the device is used in conjunction with visual survey methods however, it is likely to enhance and improve the chances of recording an encounter. The T-POD also provides a means of observation during the night and/or in poor conditions when it is not possible to sample an area visually. Although based on the assumption that all animals are

echolocating, in areas where very little is known or areas where no research has been conducted previously, the T-POD offers a quick and cheap means of conducting preliminary research.

The Proto-POD was identified as having a detection distance of 250-350m (Jefferson *et al*, 2002). Under the assumption of actively echolocating harbour porpoises, this study provides a detection distance of 300m for the T-POD in line with the findings of Jefferson *et al* (2002). Whilst the detection distance (228m) and percentage of confirmed detections (17.3%) for motor vessels was calculated these should be treated with caution, given the unknown parameters of the individual vessels involved. Boat detection by the T-POD is nearly always a consequence of echoes, where the vessel sonar is rebounding off the seabed. Therefore detection will be affected by water depth, substrate and varying sonar type and power. Some vessels such as the research vessel used here may prove to be relatively quiet in terms of detection by the T-POD, due to the frequency band the T-POD is set to listen on, the sonar employed and the mechanical modifications of the vessel itself, such as the folding propeller to minimise cavitation. Other vessels however may be comparatively noisy or have sophisticated sonar systems which would be detected by the T-POD. In this study no effect of sonar was observed, however ambient noise levels and so the average number of clicks recorded were observed to rise whilst the research vessel was travelling under motor as opposed to sail. The author advises that where possible towed acoustic work with the T-POD should be conducted under sail power. Should work be conducted from other vessels in the future, an assessment of sonar and engine should be completed to ensure any additional noise is kept to a minimum. It is noted however that since this piece of research was carried out there have been a number of

modifications to the T-POD software which enhances detection of boats and provides the opportunity to filter this information from confirmed cetacean detection.

The water movement around the T-POD, its casing and rig may also affect the number of clicks recorded and interfere with detection of harbour porpoises. As the rig was modified over the two year period to mitigate these factors, any effects are thought to be negligible. The effects of weather, i.e. sea state, wind speed, weather and swell height were also recorded to facilitate assessment of the effects of towing in differing conditions. Given the methodology utilised in deployment and retrieval of the T-POD system, it was concluded that the rig should not be deployed in sea state greater than Beaufort scale 5 due to safety implications (i.e. manoeuvrability on deck, handling of the T-POD system, deployment during roll of vessel in high swell etc.). Unfortunately, weather conditions were constant and favourable to the visual survey which did not permit deployment in a variety of conditions and assessment of performance. The benefit of an acoustic system is that it may be deployed when weather conditions restrict visibility, i.e. rain, heavy cloud. The T-POD is not suitable for use in fog or mist, due to the safety considerations of operating a vessel with a 50+m tow. However, it has the potential to facilitate study in sea states greater than Beaufort scale 3, but less than Beaufort scale 5, in >1m swell or in rain when visibility is reduced. Further research is required to assess the effects of varying weather conditions on the T-POD's detection capabilities.

Whilst visual studies often add valuable information on density estimates, distribution, movements and behaviour, these remain based on a number of assumptions. The T-POD as a towed, passive acoustic monitoring (PAM) system

offers enhanced detection for the harbour porpoise in the wild, a species which is small in size, is considered shy of boats and spends a large proportion of time beneath the surface of the water (Westgate *et al,* 1995). Used in conjunction with standard visual survey methods the T-POD offers the potential for increased detection rates and an effective means of survey when visual observation is not possible.

Discussion

Of the 28 cetacean species found in UK waters, it is the bottlenose dolphin (*Tursiops truncatus*) with which most people are familiar, yet it is the harbour porpoise (*Phocoena phocoena*) which is the most frequently sighted (Evans *et al*, 2003). It is surprising perhaps, given that the harbour porpoise is a diminutive and shy animal (Carwardine, 1995), spending only 5% of its time at the surface (Westgate *et al*, 1995). It is however, a continental shelf species, found close to shore in waters on average up to 200m in depth (Westgate & Read, 1998) which perhaps explains the high frequency of encounters. The harbour porpoise can readily be seen throughout UK waters from both boat and shore. From the shore however, a diverse range of behaviours may be observed which are often lacking from a boat-based platform.

It is this very coastal existence which places the species at threat from a number of anthropogenic activities including entanglement in fishing gear (bycatch), over-fishing, boat disturbance and climate change. Fifteen years ago entanglement in fishing nets was identified as a problem for this species. Research conducted in the 1990's demonstrated that as many as 6.2% of the total population were being killed annually within the Celtic Sea hake fishery (Tregenza *et al*, 1997), whilst other studies demonstrated that even a 4% annual reduction would be unsustainable at the population level (Woodley & Read, 1991). More recently, results published in 2000 indicated that as many as 2300 animals per year are being taken by UK and Irish offshore netters, whilst 4500 are being caught annually by Danish gill-netters

(Tregenza, 2000). The number of fishing vessels working the bottom-set gill and tanglenet fisheries may have decreased, but the length of net set by any one fishing vessel, operating in the region, has increased and is now thought to average 120km per vessel (Goodwin & Ross, 2007). It is recognised that the total length of net at sea will vary according to a number of factors, including: the number of vessels operating, weather conditions, soak time and time of year (target species). Yet with an increasing number of dead harbour porpoises found washed ashore, whose death is attributed to bycatch (Jepson *et al*, 2005; Goodwin & Edwards, 2007), it appears that the number of porpoises being caught in UK waters is currently unsustainable.

In order to mitigate this threat accordingly there is a conservation need to understand why and how harbour porpoises become entangled in the fishing nets. Many theories exist including that porpoises detect the net, but do not perceive it as a threat as their concentration is elsewhere (i.e. foraging, actively feeding) or that they detect the net, but make a navigational error (Jefferson *et al*, 1992). Another suggestion from Dawson *et al*, in 1991, arose from the discovery that porpoises occasionally forage without using echolocation and it is the 'silent' porpoise which does not detect the net and is therefore a subject of bycatch. Indeed foraging silently has been observed for other cetacean species, with both Hector's dolphins (*Cephalorhynchus hectori*) and bottlenose dolphins (*Tursiops truncatus*) able to approach objects or even chase and consume fish without the need for echolocation (Wood & Evans, 1980; Dawson, 1991).

The results of this research clearly demonstrate that harbour porpoises have the ability to encounter and safely negotiate bottom-set gillnets, as they did in 99.75% of all

encounters. Additionally, no diurnal variation in either click rate or porpoise presence was observed, indicating their presence around the nets on a 24 hour basis. This may be considered somewhat surprising given that almost all cetacean species exhibit some kind of diurnal pattern in occurrence, distribution or behaviour (Saaymann *et al*, 1973; Shane, 1980; Klinowska, 1986; Evans, 1997; Amano *et al*, 1998; Johnston *et al*, 2005), yet if porpoises are feeding around the nets, as is assumed, then their presence is more likely to be correlated with that of their prey, rather than regulated by any other internal or external cue. In this study, research was carried out during the winter months, when harbour porpoises (in Scottish waters) are known to consume larger quantities of whiting (*Merlangius merlangus*) than they do in summer (Santos *et al*, 2004). Rindorf (2003) found that whiting consume prey which is available rather than migrating in response to diel migration of their prey. As such the consumption of whiting during the time of the research could account for the constant presence of harbour porpoises around the nets. Additionally, results from the shore-based study off the coast of North Devon demonstrate that diurnal and/or tidal trends in harbour occurrence, behaviour, group size and distance from shore may be site-specific. Whilst the study on the bottom-set gillnet fishery occurred offshore in deeper water, the biological, hydrographical and topographical structure of the study area (Bannon, 2006) combined with the temporal and spatial variation in prey species will undoubtedly influence the trends observed at this site. For any other fishery and/or site the diurnal trend in harbour porpoise presence may be different.

Unfortunately negative impacts of the fishing industry on the harbour porpoise also include over-fishing and declines in key species such as the sandeel (*Ammodytes sp.*) which may increase starvation rates in harbour porpoises. MacLeod *et al* (2006)

examined the consumption of sandeels by harbour porpoise in the Scottish North Sea and found a lower proportion of sandeels in the diet in years during which a higher proportion of porpoises died of starvation. These findings support Evans *et al*, (1997), who found that changes in local harbour porpoise abundance were related to annual variation in sandeel populations. Between 1984-92 when sandeel spawning stock biomass declined markedly, coastal summer porpoise populations also declined, demonstrating a shift in distribution. Conversely during 1993 and 1994, when sandeel spawning stock biomass was relatively high, local harbour porpoise abundance was also high. With climate change presenting an ever increasing threat to marine ecosystems, changes in species distribution and abundance will unquestionably occur. For some marine species we are already beginning to observing the changes, whereas for others such as the harbour porpoise the effects may be more subtle and go unnoticed for years as they are secondary, being affected by changes in their prey (MacLeod *et al*, 2006).

The second most important threat to the harbour porpoise is a subtle one – boat disturbance. For other cetacean species such as the bottlenose dolphin the effects of boat disturbance are easy to observe and document as the species is charismatic and playful and so will regularly engage with marine craft. For a small and shy species such as the harbour porpoise which regularly avoids boats, the effects may be unseen. There is no doubt that the UK, as a nation, is becoming more environmentally aware and, as it does so, members of the public are seeking out eco-holidays and dolphin watching pursuits as a means to engage with the world in which they live. In west Scotland alone, cetacean-related activities have been estimated to bring in £7.8 million (Parsons *et al*, 2003) as people visit the area to see the whales and dolphins

and subsequently spend additional money during their stay. Whale and dolphin watching is one of the most rapidly growing forms of nature-based tourism in the world (Constantine *et al*, 2004), yet researchers and conservationists alike have highlighted the possible detrimental effects of boat disturbance to cetaceans.

A study by Evans *et al* (1994), conducted off the coast of Scotland, demonstrated negative reactions (i.e. change direction and move away) in almost all encounters with the harbour porpoise. High speed vessels such as speed boats and jet skis were found to elicit a greater number of negative reactions compared with other boat types. Scheidat & Palka (1996) in Germany also supported these results, showing that porpoises changed their behaviour and swimming direction in response to the survey vessel. The present study examined behavioural observations made from both a shore- and boat-based platform. The principal findings indicate that the behaviour recorded for the harbour porpoise differed between observations made from the shoreline and those from onboard a boat. In particular the occurrence of aerial behaviour, which can have many different connotations (Pryor, 1990; Carwardine, 1995) and large feeding aggregations, where co-operative feeding behaviour was displayed, were not observed from the boat-based platform. Of particular importance was the potential disruption to rest periods for the harbour porpoise. Previous work has demonstrated that cetaceans are more susceptible to disturbance during rest than during any other behavioural event (Constantine *et al*, 2004; Lusseau & Higham, 2004). As very few observations of rest were made from the boat, as opposed to the shore, it is thought that those periods were disrupted. Indeed when rest was observed from the boat, the porpoises' immediate response was to move away – so their resting periods were disrupted. Given the harbour porpoise's small and shy characteristics, unless one is actually

focused on looking for them, it would be exceptionally easy to miss them and consequently any effect of the encounter on them as well. The harbour porpoise is a relatively long-lived, slow breeding species in which any detrimental effects or reduced fitness could have significant consequences for the population. Without long-term monitoring of the effects of boat disturbance on this species the impact of dolphin watching tourism could have significant effects on the UK's harbour porpoise population.

In order to mitigate against these effects and control new or as yet unseen threats there are a number of pieces of protective legislation in force. Indeed the harbour porpoise is covered by National, European and International legislation (Wildlife & Countryside Act 1981; Countryside and Rights of Way (CROW) Bill 2000; Nature Conservation (Scotland) Act 2004; IUCN; UK Biodiversity Steering Group Report; Appendix II of CITES; Appendix II of the Bonn Convention; Appendix II of the Berne Convention; Annexes II and IV of the EC Habitats Directive and on a list of threatened and declining species by OSPAR; ASCOBANS; European Commission Regulation (No. 812/2004)). Despite what may appear comprehensive coverage by a number of agreements, the UK does not, at present, have specific cetacean protective legislation as is the case with the Marine Mammal Protection Acts of the USA and New Zealand. Current legislation in the UK is very general and suffers from the fact that it has used terrestrial legislation as a basis. Subsequently it is notoriously difficult to enforce.

There are however four key pieces of legislation relating to cetacean conservation in the UK: the Wildlife & Countryside Act 1981, the CROW Bill, European

Commission Regulation (No. 812/2004) and the EC Habitats and Birds Directive. The Wildlife & Countryside Act states that cetaceans cannot be intentionally killed, injured, captured or harassed, whilst the CROW Bill provides species protection from reckless disturbance. As has already been discussed the emphasis on 'intentional' and 'reckless' have heightened the requirement for clear evidence in such cases, which has meant that many perpetrators have failed to be prosecuted. In the case of disturbance to cetaceans and in particular the harbour porpoise, a species where the effects may go unnoticed, it is imperative that a precautionary approach be taken to address the problem. Many conservation groups and non-governmental organisations (NGOs) now have to make the distinction between "responsible" and "irresponsible" operations. However, the difficulty lies not only in limiting the increasing number of operators but in educating them in responsible boat handling and managing the industry effectively. Harbour porpoises are not likely to ever be the focus of dolphin watching activities, yet the impacts on them could be substantial. Accredited courses such as the WiSe scheme, carried out by MER Consultants Ltd, take a precautionary approach to the problem by educating and encouraging self-management by the industry.

European Commission Regulation (No. 812/2004), was heralded as a major breakthrough in bycatch mitigation as it made the use of pingers mandatory across both bottom-set gill and tanglenet fisheries, for vessels over 12m in length. Despite being in force since June 2005 in the North Sea, from January 2006 for the South West and January 2007 for the South East, the regulation is yet to be properly implemented, monitored or enforced. Fishermen prosecuting the over 12m, bottom-set gill and tanglenet fishery are doing so without any acoustic deterrent device fitted to

the nets. Even so, the implementation of pingers across the fishery will only be effective if they are regularly checked to ensure they are working and there is continuous monitoring of bycatch within pingered nets. Pingers were never proposed as the long-term solution to the problem of cetacean bycatch and within the Government, conservation community and fishery industry, have only ever been seen as the short-term solution to the problem. Undeniably what has been called for, for a number of years, has been a better understanding of the problem; how and why harbour porpoises are getting caught in fishing nets. This research makes a first step towards understanding the problem from an ecological perspective, however further action is required if cetacean bycatch is to be reduced to zero as agreed by member states signed up to ASCOBANS.

Finally, through the EC Habitats and Birds Directive there is an obligation on member states to implement an ecologically coherent network of Special Areas of Conservation (SACs) under Natura 2000. These are designed to protect natural habitats and species considered important at the EU level, including the harbour porpoise. Additionally, the UK Government has recently committed to providing a Marine Bill within the parliamentary session 2007/08. This promises to provide a marine planning system, streamlined regulatory regimes for licensing, new mechanisms for marine nature conservation, a marine management organisation (MMO) and new arrangements for inshore fisheries and related environmental enforcement. As part of new laws for marine nature conservation the Government have committed to providing a series of Marine Conservation Zones (MCZs) within which Highly Protected Marine Reserves (HPMRs) will be designated.

Given the high mobility of the harbour porpoise, it is recognised that it may not be possible to achieve a high level of representation of this species within the Natura 2000 network (Evans & Wang, 2002). It is still important to classify areas, however to date no such sites have been proposed (although Evans and Wang (2002) do highlight areas of particular importance for porpoises). The research presented here, conducted along the west coast of the UK has demonstrated the widespread distribution of the species along this coast and has highlighted particular sites. It has confirmed the importance of sites such as the west coast of Scotland and Wales but has also identified the Firth of Clyde as representing an area of frequent use by the species and presents some of the first quantitative data for Northern Ireland. Of particular concern however is the continued decline in relative abundance estimates for the South West of the UK, despite opposing results showing little change by the SCANS II survey (Hammond & MacLeod, 2006).

Small-scale inspection of habitat use has also produced some interesting findings which have highlighted the site-specific characteristics of porpoise habitat use. Porpoises in Morte Point and Lee Bay on the North Devon coastline were found to exhibit site-specific differences in behaviour, group size and distance from shore depending on time of day and tidal cycle, despite the close geographical proximity of the two sites. Morte Point represents an important feeding area, whilst Lee Bay appears to offer a corridor between more productive sites. What is particularly interesting about these sites is how much harbour porpoise behaviour, group size and distance from shore can change in a relatively small distance. Furthermore the large-scale research on the west coast of the UK and modeling of effects of environmental factors demonstrated a peak in porpoise presence around the 100m depth contour.

It is this increased understanding of harbour porpoise habitat use which should feed into the debate on protected areas for this species and be taken into consideration when considering areas for designation, whether as SACs or other Marine Conservation Zones (MCZs) currently proposed within the UK Governments' consultation on the coming Marine Bill. Additionally, Evans & Wang (2002) stated that cetacean-focused areas should be identifiable on the basis of: continuous or regular presence of the species, good population density and a high ratio of young to adults during certain periods of the year. This information on harbour porpoise presence and other factors such as observed social and sexual behaviour should also be considered important to site classification. Another key feature of protected areas (SACs or MCZs) for cetaceans relates to the speed and flexibility of the site designation itself, in order to take into consideration the highly mobile nature of species. A study of the SAC designation for the Moray Firth found that in the time taken to designate the area as protected there has been a distributional shift in bottlenose dolphin occurrence, such that they are now frequently observed outside of the designated area (Wilson *et al*, 2004). It will however only be in the coming designation and implementation of protected sites (SACs or MCZs) that the true value of them for harbour porpoise conservation may be assessed.

For any piece of protective legislation or measure, the degree of compliance or rather the amount of illegal activity arises through a combination of factors – (a) knowledge of the law, (b) understanding its purpose (c) the likelihood of getting caught (d) the penalty enforced if caught and prosecuted and (e) any possible economic benefit from complying. Unless there is adequate monitoring and enforcement of legislation, the piece of legislation is worthless as it will not be viewed as an adequate deterrent to

irresponsible behaviour, such as boat disturbance, illegal fishing activity etc. As such the only way to truly conserve cetacean species such as the harbour porpoise is through targeted measures which address core problems, and through monitoring to ensure that measures are being adhered to and that no new detrimental trends or threats emerge.

Cetaceans, by their very nature, are particularly difficult to see in sea states greater than Beaufort scale 3 and only spend a limited amount of time at the surface (Westgate *et al*, 1995). Individuals may also react adversely to the research vessel before being observed and therefore may be missed (Evans *et al*, 1994). This means that observational research is based on a number of limitations and/or assumptions, i.e. that all cetaceans on the track line are recorded (or that the proportion missed can be estimated), that cetaceans do not respond to the approach of the vessel before detection by an observer and that sightings are independent of each other (Mann, 2000). Part of this research refined a rig and deployment methodology for towing the T-POD, a passive acoustic monitoring (PAM) device. Whilst the results come with certain caveats and limitations of their own, the T-POD was shown to pick up an additional 10% of encounters of the harbour porpoise which had not been detected visually. This finding is thought to be significant given that responsive movement of animals is a problem to both visual and acoustic surveys (Palka & Hammond, 2001). Additionally the T-POD benefits over standard observational surveys in that it may be deployed in sea states greater than Beaufort scale 3, when the swell is greater than 1 metre or when in rain/poor visibility. As the T-POD does not rely on visual confirmation it provides a complimentary tool to any boat-based survey and may further provide additional means of monitoring the harbour porpoise within the UK.

The results presented here have increased our knowledge and understanding of the ecology and conservation of harbour porpoises along the west coast of the UK. Surveys conducted on a large-scale have highlighted areas where the harbour porpoise is encountered frequently and demonstrates inter-annual changes in relative abundance. The study has provided some of the first quantitative results for Northern Ireland and has considered habitat use on a small-scale, considering two sites on the North Devon coastline. This close inspection of behaviour and movements over both diurnal and tidal cycles has emphasised the importance of site-specific consideration of problems and conservation measures. The potential for detrimental effects of the leisure craft and dolphin watching industry have also been highlighted, with different behaviours being encountered when observed from shore as opposed to from a boat. One of the key findings of this research has been the discovery that harbour porpoises can and frequently do negotiate bottom-set gillnets without getting entangled. This provides a first step in understanding the problem and of eventually finding a solution to mitigate it effectively. Whilst discussion of conservation measures within the UK runs throughout this thesis, any measure is ineffective without adequate monitoring and enforcement. As such, development of a PAM system for monitoring harbour porpoises has also been investigated. Results found that the T-POD presented a cheap and quick method of acoustic monitoring which detected an additional 10% of all porpoise encounters which were not detected visually. As threats to the harbour porpoise remain ever present it is hoped that this research will feed into the conservation debate to adequately protect this species.

Literature Cited

Addink, M.J., Sørensen, T.B. & Hartmann, M.G. (1995) Aspects of reproduction and seasonality in the harbour porpoise from Dutch waters. In *Whales, Seals, Fish and Man* (A.S. Blix, L. Walløe & Ø.Ultang eds.) Elsevier Science.

Akamatsu, T., Wang, D., Wang, K., & Wei, Z. (2001) Comparison between visual and passive acoustic detection of finless porpoises in the Yangtze River, China. *Journal of the Acoustical Society of America* 1009(4), p 1723-1727.

Allen, M.C. & Read, A.J. (2000) Habitat selection of foraging bottlenose dolphins in relation to boat density near Clearwater, Florida. *Marine Mammal Science* 16, p 810-824.

Amano, M., Yoshioka, M., Kuramochi, T. & Mori, K. (1998) Diurnal Feeding by Dall's Porpoise, *Phocoenoides dalli*. *Marine Mammal Science* 14(1), p 130-135.

Amundin, M. & Amundin, B. (1974) On the Behaviour of the Harbour Porpoise, *Phocoena phocoena*, in the Wild. *Investigations on Cetacea* 5, p 317-328.

Au, D. & Perryman, W. (1982) Movement and Speed of Dolphin Schools Responding to an Approaching Ship. *Fishery Bulletin* 80(2), p 371-379.

Au, W. W. L, Kastelein, R.A., Rippe, T., Schooneman, N. (1999) Transmission beam pattern and echolocation signals of a harbor porpoise (*Phocoena phocoena*). *Journal of the Acoustic Society of America* 106 (6), p 3699 - 3705.

Ballance, L.T., Pitman, R.L. & Fiedler, P.C. (2006) Oceanographic influences on seabirds and cetaceans of the eastern tropical Pacific: A review. *Progress in Oceanography* 69(2-4), p 360-390.

Bannon, S.M. (2006) Diversity and relative abundance of cetaceans in three areas off the west coast of Scotland. European Research on Cetaceans – 20. *Proceedings of the 20th Annual Conference of the European Cetacean Society*, Gydnia, Poland. European Cetacean Society, Cambridge.

Barlow, J. (1987) Abundance estimation of harbour porpoise (*Phocoena phocoena*) based on ship surveys along the coasts of California, Oregan and Washington. *Administrative report LJ-87-05. National Marine Fisheries Service.* Southwest Fisheries Center.

Bejder, L. and Dawson, S. (2001) Abundance, Residency and Habitat Utilisation of Hectors Dolphins (*Cephalorhynchus hectori*) in Porpoise Bay, New Zealand. New Zealand. *Journal of Marine and Freshwater Research* 35(2), p 277-287.

Bel'kovich, V.M., Ivanova, E.E., Yefremenkova, O.V., Kozarovitsky, L.B. & Kharitonov, S.P. (1991) Searching & Hunting Behavior in the Bottlenose Dolphin

(*Tursiops truncatus*) in the Black Sea. In. *Dolphin Societies: Discoveries & Puzzles* (K. Pryor & K.S. Norris eds.). University of California Press, Berkeley.

Blane, J.M. & Jackson, R. (1994) The impact of ecotourism boats on the St. Lawrence beluga whales. *Environmental Conservation* 21, p 267-269.

Borges, L. and Evans, P.G.H. (1996) Spatial Distribution of the Harbour Porpoise and Fish Prey and their Associations in Southeast Shetland, N. Scotland. European Research on Cetaceans - 10. (P.G.H. Evans, ed.) Proceedings of the 10th Annual Conference of the European Cetacean Society, Lisbon, Portugal. European Cetacean Society, Cambridge.

Borjesson, P., Berggren, P. & Granning, B. (2003) Diet of harbour porpoises in the Kattegat and Skagerrak seas: Accounting for individual variation and sample size. *Marine Mammal Science* 19 (1), p 38-58.

Brager, S. (1993) Diurnal and seasonal behavior patterns of bottlenose dolphins (*Tursiops truncatus*). *Marine Mammal Science* 9(4), p 434-438.

Brodie, P.F. (1995) The Bay of Fundy/Gulf of Maine harbour porpoise (*Phocoena phocoena*): some considerations regarding species interactions, energetics, density dependence and bycatch. *Report of the International Whaling Commission* 16, p 181–187.

Bull, K.S.E. & Laffoley, D.d'A. (2003) Networks of Protected Areas in the Maritime Environment. A Report for the Review of Marine Nature Conservation and the Marine Stewardship process on a stakeholder workshop, June 2003, Peterborough: *English Nature Research Reports*, No. 537, 35pp.

Cañadas, A., Sagarminaga, R., De Stephanis R., Urquiloa, E. & Hammond, P.S. (2005) Habitat preference modelling as a conservation took proposals for marine protected areas for cetaceans in southern Spanish waters. *Aquatic Conservation – Marine and Freshwater Ecosystems* 15(5), p 495-521.

Carlstrom, J. (2005) Diel variation in echolocation behaviour of wild harbour porpoises. *Marine Mammal Science* 21 (1), p 1-12.

Camphuysen, K. C. J. & Webb, A. (1999) Multi-Species Feeding Associations in North Sea Seabirds: Jointly Exploiting a Patchy Environment. *Ardea* 87(2), p 177-198.

Carwardine, M. (1995) *Whales, Dolphins and Porpoises* (P. Evans & M. Weinrich eds.). Dorling Kindersley Handbooks, London.

Cockcroft, V.G., Ross, G.J.B. & Peddemors, V.M. (1990) Bottlenose dolphin *Tursiops truncatus* distribution in Natal's Coastal Waters. *South African Journal of Marine Science* 9, p 1-10.

Constantine, R., Brunton, D.H. & Dennis, T. (2004) Dolphin-watching tour boats change bottlenose dolphin (*Tursiops truncatus*) behaviour. *Biological Conservation* 117(3), p 299-307.

Cox, T.M. & Read, A.J. (2004) Echolocation behavior of harbor porpoises *Phocoena phocoena* around chemically enhanced gill nets. *Marine Ecology Progress Series* 279, p 275-282.

Cox, T.M., Read, A.J., Solow, A. & Tregenza, N. (2001) Will harbour porpoises (*Phocoena phocoena*) habituate to pingers? *Journal of Cetacean Research & Management* 3(1), p 81-86.

Culik, B.M., Koschinski, S., Tregenza, N. & Ellis G.M. (2001) Reactions of harbor porpoises *Phocoena phocoena* and herring *Clupea harengus* to acoustic alarms. *Marine Ecology Progress Series* 211, p 255-260.

Da Silva, V.M.F. & Best, R.C. (1994) Tucuxi *Sotalia fluviatilis*. In. *Handbook of Marine Mammals Vol. 5: The First Book of Dolphins* (S.H. Ridgeway & R. Harrison eds), Academic Press, London, p 43-70.

Dalla Rosa, L. & Secchi E.R. (2007) Killer whale (*Orcinus orca*) interactions with the tuna and swordfish longline fishery off southern and south-eastern Brazil: a comparison with shark interactions. *Journal of the Marine Biological Association of the UK* 87(1), p 135-140.

Dawson, S. M., Read, A. & Slooten, E. (1998) Pingers, Porpoises and Power: Uncertainties with using pingers to reduce bycatch of small cetaceans. *Biological Conservation* 84, p 141-146.

Dawson, S.M. (1991) Modifying Gillnets to Reduce Entanglement of Cetaceans. *Marine Mammal Science*, 7(30, p 274-282.

Donovan, G.P. and Bjørge, A. (1995) Harbour porpoises in the North Atlantic: edited extract from the Report of the IWC Scientific Committee, Dublin. In *Biology of the Phocoenids* (A. Bjørge & G.P. Donovan, eds.) International Whaling Commission, Cambridge.

Evans, P.G.H. (1992) *Status Review of Cetaceans in British and Irish Waters.* Report to UK Department of Environment. Sea Watch Foundation, Oxford.

Evans, P.G.H. (1997) *Ecological studies of the harbour porpoise in Shetland, North Scotland.* A Report for WWF-UK, November 1997.

Evans, P.G.H., Fisher, Q.C.P., Jordon, W., Limer, R. & Rees, I. (1994) A Study of the Reactions of Harbour Porpoises to Various Boats in the Coastal Waters of Southeast Shetland. European Research on Cetaceans - 8. (P.G.H. Evans, ed) Proceedings of the 8th Annual Conference of the European Cetacean Society, Montpellier, France. European Cetacean Society, Cambridge.

Evans, P.G.H., Weir, C.R. & Nice, H.E. (1997) Temporal and spatial distribution of harbour porpoises in Shetland waters, 1990-1995. European Research on Cetaceans - 10. (P.G.H. Evans, ed) Proceedings of the 10th Annual Conference of the European Cetacean Society, Kiel, Germany. European Cetacean Society, Cambridge.

Evans, P.G.H. & Wang, J. (2002) *Re-examination of Distribution Data for the Harbour Porpoise around Wales and the UK with a view to Site Selection for this Species.* Sea Watch Foundation, Oxford.

Evans, P.G.H., Anderwald, P., and Baines, M.E. (2003) *UK Cetacean Status Review.* Report to English Nature & Countryside Council for Wales. Sea Watch Foundation, Oxford.

Findlay, K.P. and Best, P.B. (1996) Assessment of heterogeneity in Sighting Probabilities of Humpback Whales within viewing range of Cape Vidal, South Africa. *Marine Mammal Science* 12(3), p 335-353.

Freitag, L.E. & Tyack, P. (1993) Passive acoustic localization of the Atlantic bottlenose dolphin using whistles and echolocation clicks. *Journal of the Acoustic Society of America* 93 (4) part 1, p 2197-2205.

Gaskin, D.E. (1968) Distribution of *Delphinidae* (Cetacea) in relation to sea surface temperatures off eastern and southern New Zealand. *New Zealand Journal of Marine and Freshwater Research* 2, p 527-534.

Gaskin, D.E., Smith, G.J.D., Watson, A.P., Yasui, W.Y. & Yurick, D.B. (1984) Reproduction in the porpoises (Phocoenidae): implications for management. *Report to the International Whaling Commission* (Special Issue 6), p 135-148.

Gill P. & Gibson L. (1997) *Whales, Dolphins & Porpoises.* Reader's Digest Explores. The Reader's Digest Association New York.

Goodson, A.D. (1994) Bottom set gillnet: Problems of perception for dolphins and porpoises. European Research on Cetaceans - 8. (P.G.H. Evans, ed.) Proceedings of the 8th Annual Conference of the European Cetacean Society, Montpellier, France. European Cetacean Society, Cambridge.

Goodson A.D. & Sturtivant C.R. (1996) Sonar characteristics of the harbour porpoise (*Phocoena phocoena*): source levels and spectrum. *ICES Journal of Marine Science* 53, p 465-472.

Goodwin, L. & Edwards, J. (2007) The South West Dolphin Report, A joint publication produced by *Marine Connection & The Wildlife Trusts.*

Goodwin, L. & Ross, A. (2007) Collection and provision of fishing effort data. *Document for ASCOBANS Meeting of Parties*, San Sebastian, Spain. Presented by Marine Connection & Whale and Dolphin Conservation Society.

Gordon, J. & Northridge, S.P. (2003) *Potential impacts of acoustic deterrent devices on Scottish marine wildlife.* Contract report to Scottish Natural Heritage.

Grellier, K. & Wilson, B. (2003) Bottlenose dolphins using the sound of Barra, Scotland. *Aquatic Mammals* 29, p 378-382.

Gregory, P.R. and Rowden, A.A. (2001) Behaviour patterns of bottlenose dolphins (*Tursiops truncatus*) relative to tidal state, time-of-day and boat traffic in Cardigan Bay, West Wales. *Aquatic Mammals* 27(2), p 105-113.

HMSO (1995) *Biodiversity: The UK Steering Group Report.* Volume 2: Action Plans. Produced by DDP Services.

Hamazaki, T. (2002) Spatiotemporal prediction models of cetacean habitats in the mid-western North Atlantic Ocean (from Cape Hatteras, North Carolina, USA to Nova Scotia, Canada). *Marine Mammal Science* 18(4), p 920-939.

Hammond, P.S., Berggren, P., Benke, H., Borchers, D.L., Collet, A., Heide-Jørgensen, M.P., Heimlich, S., Hiby, A.R., Leopold, M.F. & Øien, N. (2002) Abundance of harbour porpoise and other cetaceans in the North Sea and adjacent waters. *Journal of Applied Ecology* 39, p 361-376.

Hammond, P.S. & MacLeod, K. (2006) SCANS II – Report on Progress. *Document for ASCOBANS Meeting of Parties*, Egmond aan Zee, The Netherlands.

Hastie, G.D. & Tibshirani, R.J. (1990) *Generalized Additive Models.* Monographs on Statistics and Applied Probability. Chapman & Hall, 335pp.

Hastie, G.D., Swift, R.J., Slesser, G., Thompson, P.M. & Turrell, W.R. (2005) Environmental models for predicting oceanic dolphin habitat in the Northeast Atlantic. *ICES Journal of Marine Science* 62(4), p 760-770.

Heide-Jørgensen, M.P., Teilman, J., Benke, H. & Wulf, J. (1993) Abundance and distribution of harbour porpoises *Phocoena phocoena* in selected areas of the western Baltic and the North Sea. *Helgolander Meeresunters*, 47, p 335-346.

Hoek, W. (1992) An Unusual Aggregation of Harbour Porpoises (*Phocoena phocoena*). *Marine Mammal Science* 8(2), p 152-155.

Hui, C.A. (1979) Undersea Topography and Distribution of Dolphins of the Genus *Delphinus* in the Southern California Bight. *Journal of Mammalogy* 60, p 521-527.

ICES (2005) Report of the Working Group on Marine Mammal Ecology (WGMME) ICES Advisory Committee on Ecosystems ACE:05, 9-12 May 2005, Savonlinna, Finland.

International Whaling Commission (IWC) (1994) *'Gillnets and Cetaceans'* Special Report 15, p 629.

Janik, V.M. & Thompson, P.M. (1996) Changes in surfacing patterns of bottlenose dolphins in response to boat traffic. *Marine Mammal Science* 12, p 597-602.

Jefferson, T.A. (1991) Observations on the distribution and behaviour of Dall's porpoise (*Phocoenoides dalli*) in Monterey Bay, California. *Aquatic Mammals* 17(1), p 12-19.

Jefferson, T.A. & Curry, B.E. (1994) A global review of porpoise (*Cetacea: Phocoenidae*) mortality in gillnets. *Biological Conservation* 67, p 167-183.

Jefferson, T.A., Hung, S.K., Law, L, Torey, M. & Tregenza, N. (2002) Distribution and abundance of finless porpoise in Hong Kong and adjacent waters of China. *The Raffles Bulletin of Zoology* 10, p 43-55.

Jepson, P.D., Sabin, R.C., Spurrier, C.J.H., Chimonides P. D. J., Deaville, R., Perkins, M., Cunningham, A.A., Reid, R.J., Patterson, I.A.P., Foster, G., Barley, J., Penrose, R., Law, R.J. (2005) Trends in Cetacean Strandings around the UK Coastline and Cetacean and Marine Turtle Post-Mortem Investigations, 2000 to 2004 inclusive (Contract CRO 238) *Report No. ECM 516T/05. NHM Consulting*, London.

Johnston, D.W., Westgate, A.J. & Read, A.J. (2005) Effects of fine scale oceanographic features on the distribution and movements of harbour porpoises *Phocoena phocoena* in the Bay of Fundy. *Marine Ecology Progress Series* 295, p 279-293.

Kamminga, C. & Wiersma, H. (1981) Investigations on Cetacean Sonar II. Acoustic Similarities and Differences in Odontocete Sonar Signals. *Aquatic Mammals* 8 (2), p 41 - 62.

Karakosta, C.V., Jepson, P.D., Ohira, H., Moore, A., Bennett, P.M. & Holt, W.V. (1999) Testicular and ovarian development in the harbour porpoise (*Phocoena phocoena*). *Journal of the Zoological Society of London*, 249, p 111-121.

Karczmarski, L. and Cockcroft, V.G. (1999) Daylight behaviour of Humpback dolphins *Sousa chinensis* in Algoa Bay, South Africa. *International Journal of Mammalian Biology* 64(1), p 19-29.

Kastelein, R.A., de Hann, D., Goodson, A.D., Staal, C. & Vaughan, N. (1997) The effects of various sounds on a harbour porpoise (*Phocoena phocoena*). In. *The Biology of the Harbour Porpoise* (A.J. Read, P.R. Wiepkema & P.E. Nachtigall, eds.) De Spil Publishers, Woerden, The Netherlands, p 367-383.

Kastelein, R.A., Au, W.W.L. & de Haan, D. (2000) Detection distances of bottom-set gillnets by harbour porpoises (*Phocoena phocoena*) and bottlenose dolphins (*Tursiops truncatus). Marine Environmental Research* 49, p 359-375.

Kelleher, G. & Phillips (1999) *Guidelines for Marine Protected Areas.* IUCN – The World Conservation Union, 107pp.

Kenney, R.D. & Winn, H.E. (1986) Cetacean High-Use Habitats of the Northeast United States Continental Shelf. *Fishery Bulletin* 84(2), p 345-357.

Kirkwood, J.K., Bennett, P.M., Jepson, P.D., Kuiken, T., Simpson, V.R. & Baker, J.R. (1997) Entanglement in fishing gear and other causes of death in cetaceans stranded on the coasts of England & Wales. *The Veterinary Record* 141, p 94-8.

Klinowska, M. (1986) Diurnal Rhythms in Cetacea - A Review. *Report to the International Whaling Commission* (Special Issue 8) SC/A82?BW13, pp 75-88.

Koopman, H.N. and Gaskin, D.E. (1994) Individual and geographical variation in pigmentation patterns of the harbour porpoise, *Phocoena phocoena* (L.) *Canadian Journal of Zoology* 72, p 135-143.

Kraus, S., Read, A., Anderson, E., Baldwin, K., Solow, A., Spradlin, T. & Williamson, J. (1997) Acoustic alarms reduce incidental mortality of porpoises in gill nets. *Nature* 388, p 525.

Kruse, S. (1991) The interactions between killer whales and boats in Johnston Strait, B.C. In: K. Pryor & K.S. Norris (eds.) *Dolphin Societies: Discoveries and Puzzles.* Pp. 149-159. University of California Press, Berkeley.

Lockyer, C. (1995) Investigation of Aspects of the Life History of the Harbour Porpoise, *Phocoena phocoena*, in British Waters. In *Biology of the Phocoenids* (A. Bjørge & G.P.Donovan eds.) International Whaling Commission, Cambridge.

Lockyer, C. (1999) Application of a new method to investigate population structure in the harbour porpoise, *Phocoena phocoena*, with special reference to the North and Baltic seas. *Journal of Cetacean Research & Management* 1(3), p 297-304.

Lockyer, C. & Morris, R.J. (1986) The history and behaviour of a wild, sociable bottlenose (*Tursiops truncatus*) off the north coast of Cornwall. *Aquatic Mammals* 12(1), p 3-16.

Lusseau, D. (2003) Effects of tour boats on the behavior of bottlenose dolphins: Using Markov chains to model anthropogenic impacts. *Conservation Biology* 17(6), p 1785-1793.

Lusseau, D. & Higham, J.E.S. (2004) Managing the impacts of dolphin-based tourism through the definition of critical habitats: the case of bottlenose dolphins (*Tursiops spp.*) in Doubtful Sound, New Zealand. *Tourism Management* 25(6), p 657-667.

MacLeod, C.D., Santos, M.B., Reid, R.J., Scott, B.E. & Pierce, G. (2007) Linking consumption and the likelihood of starvation in the Scottish North Sea: could climate change mean more starving porpoises? *Biology Letters, Marine Biology* doi: 10.1098/rsbl.2006.0588

MacLeod, K. (2004) Abundance of the Atlantic white-sided dolphin (*Lagenorhynchus acutus*) during summer off northwest Scotland. *Journal of Cetacean Research and Management,* 6(1), p 33-40.

MacLeod, K., Simmonds, M.P. and Murray, E. (2003) Summer distribution and relative abundance of cetacean populations off north-west Scotland. *Journal of the Marine Biological Association of the UK* 83(5), p 1187-1192.

Mann, J. (1999) Behavioral Sampling Methods for Cetaceans: A Review & Critique. - *Marine Mammal Science* 15(1), p 102-122.

Mann, J. (2000) Unraveling the Dynamics of Social Life: Long-term Studies & Observational Method. In. *Cetacean Societies: Field Studies of Dolphins & Whales.* University of Chicago Press.

Mann J., Connor R.C., Tyack P.L. & Whitehead H. (2000) *Cetacean Societies: Field Studies of Dolphins and Whales.* University of Chicago Press.

McDonald, M.A., & Fox, C.G. (1999) Passive acoustic methods applied to fin whales population density estimation. *Journal of the Acoustical Society of America* 105(5), p 2643-2651.

Mendes, S., Turrell, W., Lutkebohle, T., & Thompson, P. (2002) Influence of the tidal cycle and a tidal intrusion front on the spatio-temporal distribution of coastal bottlenose dolphins. *Marine Ecology Progress Series* 239, p 221-229.

Molina-Schiller, D., Rosales, S.A. & De Freitas, T.R.O. (2005) Oceanographic conditions off coastal South America in relation to the distribution of Burmeister's Porpoise, *Phocoena spinipinnis. LAJAM* 4(2), p 141-156.

Natural History Museum (NHM) (2005) *Out of the Blue, The UK Whale & Dolphin Stranding Scheme.* Natural History Museum, London.

Neave, D.J. and Wright, B.S. (1968) Seasonal Migrations of the Harbour Porpoise and Other Cetacea in the Bay of Fundy. *Journal of Mammalogy* 49(2), p 259-264.

Newborough, D., Goodson, A.D. & Woodward, B. (2000) An acoustic beacon to reduce the bycatch of cetaceans in fishing nets. *Journal of Society for Underwater Technology* 24(3), p 102-114.

Northridge, S. & Pilleri, G. (1986) A Review of Human Impact on Small Cetaceans. Prepared for Greenpeace. *Investigations on Cetacea*, Vol XVIII.

Northridge, S.P., Rogan, E., Tregenza, N. & Hammond, P. (2001) *Approaches to minimising porpoise entanglement in the Celtic Sea gillnet fishery.* 10pp.

Notarbartolo di Sciara, G., Jahoda, M., Biassoni, N. & Lafortuna, C. (1996) Reactions of fin whales to approaching vessels assessed by means of a laser range finder. In P.G.H. Evans (ed.) European Research on Cetaceans 10. Proceedings of the European Cetacean Society, Lisbon, Portugal, p 38-43.

Otani, S., Naito, Y., Kawamura, A., Kawasaki, M., Nishiwaki, S. & Kato, A. (1998) Diving behavior and performance of harbor porpoises, *Phocoena phocoena*, in Funka Bay, Hokkaido, Japan. *Marine Mammal Science* 14(2), p 209-220.

Palka, D. (1995) Influences on spatial patterns of Gulf Of Maine harbour porpoises. In *Whales, Seals, Fish & Man* (A.S. Blix, L.Walløe & Ø.Ultang, eds.). Elsevier Science.

Palka, D.L. & Hammond, P.S. (2001) Accounting for responsive movement in line transect estimates of abundance. *Canadian Journal of Fisheries and Aquatic Sciences* 58 (4), p 777-787.

Parsons, E.C.M., Warburton, C.A., Woods-Ballard, A., Hughes, A. and Johnston, P. (2003) The value of conserving whales: the impacts of whale-watching on the economy of rural West Scotland. *Aquatic Conservation* 13, 23-36.

Pierpoint, C., Earl, S. & Baines, M. (1994) Observations of Harbour Porpoise in West Wales, 1993. European Research on Cetaceans - 8. (P.G.H. Evans, ed.) Proceedings of the 8th Annual Conference of the European Cetacean Society, Montpellier, France. European Cetacean Society, Cambridge.

Pryor, K. (1990) Non-Acoustic Communication in Small Cetaceans: Glance, Touch, Position, Gesture and Bubbles. In. *Sensory Abilities of Cetaceans Laboratory & Field Evidence* (J.A. Thomas & R.A. Kastelein, eds.) NATO ASI Series A: Life Sciences Vol 196. Plenum Press, New York & London.

Purves, P.E. & Pilleri, G.E. (1983) *Echolocation in Whales & Dolphins*, Academic Press, London.

Purves, M.G., Agnew, D.J., Balguerias, E., Moreno, C.A. & Watkins, B. (2004) Killer whale (*Orcinus orca*) and sperm whale (*Physeter macrocephalus*) interactions with longline vessels in the patagonian toothfish fishery at South Georgia, South Atlantic. *CCAMLR Science* 11, p 111-126.

RMNC (2004) Review of Marine Nature Conservation Working Group report to Government, UK. Published by the Department for Environment, Food and Rural Affairs.

Rae, B.B. (1965) The food of the common porpoise (*Phocoena phocoena*). *Journal of Zoology* 146, p 114-122.

Rae, B.B. (1973) Additional Notes on Food of Common Porpoise (*Phocoena phocoena*). *Journal of Zoology* 169, p 127-131.

Read, A.J. (1990) Age of sexual maturity and pregnancy rates of harbour porpoises *Phocoena phocoena* from the Bay of Fundy. *Canadian Journal of Fisheries & Aquatic Sciences* 47(3), p561-565.

Read, A. (1999a) *Porpoises.* Colin Baxter Photography, Grantown-on-Spey, Scotland.

Read, A. J. (1999b) Harbour Porpoise *Phocoena phocoena* (Linnaeus, 1758) In. *Handbook of Marine mammals, Volume 6: The Second Book of Dolphins* (S.H. Ridgeway & R. Harrison, eds.) The Academic Press.

Read, A.J. and Westgate, A.J. (1997) Monitoring the movements of harbour porpoises (*Phocoena phocoena*) with satellite telemetry. *Marine Biology* 130, p 315-322.

Read, A.J., Waples, D.M., Urian, K.W. & Swanner, D. (2003) Fine-scale behaviour of bottlenose dolphins around gillnets. *Proceedings of the Royal Society of London Series B* – Biological Sciences 270, S90-S92.

Recchia, C.A. and Read, A.J. (1989) Stomach contents of harbour porpoises *Phocoena phocoena* (L.) from the Bay of Fundy. *Canadian Journal of Zoology* 67, p 2140-2146.

Redfern, J.V., Ferguson, M.C., Becker, E.A., Hyrenbach, K.D., Good, C., Barlow, J., Kaschner, K., Baumgartner, M.F., Forney, K.A., Balance, L.T., Fauchald, P., Halpin, P., Hamazaki, T., Pershing, A.J., Qian, S.S., Read, A., Reilly, S.B., Torres, L. & Werner, F. (2006) Techniques for cetacean-habitat modeling. *Marine Ecology Progress Series* 310, p 271-295.

Reeves, R.R. & Leatherwood, S. (1994) *Dolphins, Porpoises and Whales: 1994-1998 Action Plan for the Conservation of Cetaceans.* 92. IUCN, Gland, Switzerland.

Reid, J.B., Evans, P.G.H. & Northridge, S. (2003) *Atlas of Cetacean distribution in north-west European waters.* Joint Nature Conservation Committee, Peterborough.

Richardson, W.J. (1995) Documented disturbance reactions. In J.W. Richardson, C.R. Greene, C.I. Malme and D.H. Thompson (eds.) *Marine Mammals and Noise.* Academic Press, San Diego, p 241-324.

Rindorf, A. (2003) Diel feeding pattern of whiting in the North Sea. *Marine Ecology Progress Series* 249, p 265-276.

Rogan, E. & Berrow, S. (1996) A Review of Harbour Porpoises, *Phocoena phocoena* in Irish Waters. *Report to the International Whaling Commission* 46, p 595-605.

Ross, G.J.B, Heinsohn, G.E. & Cockcroft, V.G. (1994) Humpback Dolphins *Sousa chiensis*, *Sousa plumbea* and *Sousa teuszii*. In *Handbook of Marine Mammals Vol. 5: The First Book of Dolphins* (S.H. Ridgeway & R. Harrison eds.) Academic Press, London, p 23-42.

Saayman, G.S. , Taylor, C.K. & Bower, D. (1973) Diurnal Activity Cycles in Captive and Free-Ranging Indian Ocean Bottlenose Dolphins (*Tursiops aduncus* Ehrenburg). - *Behaviour* 44, p 212-233.

Santos, M.B. and Pierce, G.J. (2003) The Diet of harbour Porpoise (*Phocoena phocoena*) in the Northeast Atlantic. *Oceanography & Marine Biology: an Annual Review* 41, p 355-390.

Santos, M.B., Pierce, G.J., Learmonth, J.A., Reid, R.J., Ross, H.M., Patterson, I.A.P., Reid, D.G.& Beare, D. (2004) Variability in the diet of harbor porpoises (*Phocoena phocoena*) in Scottish waters 1992-2003. *Marine Mammal Science* 20(1), p 1-27.

Scott, N.J. & Parsons, E.C.M. (2004) A survey of public awareness of the occurrence and diversity of cetaceans in south-west Scotland. *Journal of the Marine Biological Association of the UK* 84 (5), p 1101-1104.

Seafish (2005) Trial of acoustic deterrents (porpoise pingers) for prevention of porpoise (*Phocoena phocoena*) bycatch. Phase 2 and 3 and Tangle net Endurance Trial. *Seafish Report No. CR207.* Sea Fish Industry Authority.

Shane, S.H. (1990) Behaviour and Ecology of the Bottlenose Dolphin at Sanibel Island, Florida. In. *The Bottlenose Dolphin* (S. Leatherwood & R.R. Reeves eds.) Academic Press Inc.

Shane, S.H., Wells, R.S. and Wursig, B. (1986) Ecology, Behavior & Social Organization of the Bottlenose Dolphin: A Review. *Marine Mammal Science* 2(1), p 34-63.

Sheidat, M. & Palka, D. (1996) The Effect of a Survey Vessel on the Movement of Harbour Porpoises (*Phocoena phocoena*). European Research on Cetaceans - 10. (P.G.H. Evans, ed.) Proceedings of the 10th Annual Conference of the European Cetacean Society, Lisbon, Portugal. European Cetacean Society, Cambridge.

Slooten, E. (1994) Behaviour of Hector's Dolphin: Classifying Behaviour by Sequence Analysis. *Journal of Mammalogy*, 75(4), p 956-964.

Smith, R.J. & Read, A.J. (1992) Consumption of euphausids by Harbour Porpoise (*Phocoena phocoena*) calves in the Bay of Fundy. *Canadian Journal of Zoology* 70(8), p 1629-1632.

Sørensen, T.B. & Kinze, C.C. (1994) Reproduction and Reproductive Seasonality in Danish Harbour Porpoises *Phocoena phocoena*. *Ophelia* 39(3), p 159-176.

Stevick, P.T., McConnell, B.J. 7 Hammond, P.S. (2002) Patterns of Movement. In *Marine Mammal Biology: An Evolutionary Approach* (R. Hoelzel ed.) Blackwell Publishing.

Stockin, K.A., Fairbairns, R.S., Parsons, E.C.M. and Sims, D.W. (2001). Effects of diel and seasonal cycles on the dive duration of the minke whale (*Balaenoptera acutorostrata*). *Journal of the Marine Biological Association* 81, p 189-190.

Swihart, S. K. & Slade, N.A. (1985) Influence of sampling interval on estimates of home range size. *Journal of Wildlife Management* 49(4), p 1019-1025.

Thompson, P.M., Wilson, B., Grellier, K. & Hammond, P.S. (2000) Combining power analysis and population viability analysis to compare traditional and precautionary approaches to the conservation of coastal cetaceans. *Conservation Biology* 14, p 1253-1263.

Tolley, K. A., Rosel, P. E., Walton, M., Bjørge, A. & Øien, N. (1999) Genetic population structure of harbour porpoises (*Phocoena phocoena*) in the North Sea and Norwegian waters. *Journal of Cetacean Research and Management* 1, p 265–274.

Tougaard, J., Carstensen, J., Henriksen, O.D., Skov, H. & Teilamann, J. (2003) *Short-term effects of the construction of wind turbines on harbour porpoises at Horns Reef.* Technical report to TechWise A/S HME/362-02662, Hedeselskabet, Roskilde.

Tregenza, N.J.C. (1992) Fifty years of cetacean sightings from the Cornish coast, SW England. *Biological Conservation* 59, p 65-70.

Tregenza, N.J.C. (2000) Fishing and Cetacean Bycatches. In. *Effects of Fishing on non-Target Species and Habitats. Biological, Conservation and Socio-economic Issues.* (M.J. Kaiser & S.J. de Groot eds.) Blackwell Science.

Tregenza, N. & Northridge, S. (1999) Development of an automatic porpoise detector. *International Whaling Commission Scientific Committee Report* SC/51/SM44 (unpublished). 6pp.

Tregenza, N.J.C., Berrow, S.D., Hammond, P.S. & Leaper, R. (1997) Harbour porpoise (*Phocoena phocoena*) bycatch in set gillnets in the Celtic Sea. *ICES Journal of Marine Science* 54, p 896-904.

Trippel, E.A., Strong, M.B., Terhune, J.M. & Conway, J.D. (1998) Mitigation of harbour porpoise (*Phocoena phocoena*) bycatch in the gillnet fishery in the lower Bay of Fundy. *Canadian Journal of Fisheries and Aquatic Science* 56, p 113-123.

Tynan, C.T., Ainley, D.G., Barth, J.A. Cowles, T.J., Pierce, S.D. & Spear, L.B. (2005) Cetacean distributions relative to ocean processes in the northern California Current

System. *Deep-Sea Research Part II-Tropical Studies in Oceanography* 52 (1-2), p 145-167.

Villadsgaard, A., Wahlber, M. & Tougaard, J. (2007) Echolocation signals of wild harbour porpoises *Phocoena phocoena. The Journal of Experimental Biology* 210, p 56-64.

Walton, M.J. (1997) Population structure of harbour porpoises *Phocoena phocoena* in the seas around the UK and adjacent waters. *Proceedings of the Royal Society of London Series B – Biological Sciences* 264, p 89-94.

Wang, J.Y., Gaskin, D.E. & White, B.N. (1996) Mitochondrial DNA analysis of harbour porpoise, *Phocoena phocoena*, subpopulations in North American waters. *Canadian Journal of Fisheries and Aquatic Sciences* 53(7), p 1632-1645.

Watkins, W.A. (1980) Acoustics and the behavior of sperm whales. *In: Animal Sonar Systems* (Busnel, R.G. and Fish, J.F. eds), pp. 283-290. Plenum Press, New York. 1125 pp.

Whale & Dolphin Conservation Society (WDCS) (2004) *Cetaceans and Pelagic Trawl Fisheries in the Western Approaches of the English Channel.* A WDCS Scientific Report: The Report of the 2004 WDCS/Greenpeace Winter Survey.

Weir, C.R., Pollack, C., Cronin, C. and Taylor, S. (2001) Cetaceans of the Atlantic Frontier, north and west of Scotland. *Continental Shelf Research* 21(8-10), p 1047-1071.

Wells, R. S. (1993) The marine mammals of Sarasota Bay. *In: Sarasota Bay: 1992 Framework for Action.* Sarasota Bay National Estuary Program, Sarasota, Florida, p 9.1 – 9.23.

Wells, R.S., Rhinehart, H.L., Whaley, J., Baran, M., Koberna, C. & Costa, D.P. (1999) Long Distance Offshore Movements of Bottlenose Dolphins. *Marine Mammal Science* 15(4), p 1098 - 1114.

Westgate, A.J. & Read, A.J. (1998) Applications of new technology to the conservation of porpoises. *Marine Technology Society Journal* 38(1), p 70-81.

Westgate, A.J., Read, A.J., Per Berggren, Koopman, H.N. and Gaskin, D.E. (1995) Diving behaviour of harbour porpoises, *Phocoena phocoena. Canadian Journal of Fisheries & Aquatic Science* 52, p 1064-1073.

Wilson, B., Hammond, P.S. & Thompson, P.M. (1999) Estimating size and assessing trends in a coastal bottlenose dolphin population. *Ecological Applications* 9(1), p 288-300.

Wilson, B., Reid, R.J., Grellier, K., Thompson, P.M. & Hammond, P.S. (2004) Considering the temporal when managing the spatial: a population range expansion

impacts protected areas-based management for bottlenose dolphins. *Animal Conservation* 7, p 331-338.

Wood, S.N. (2004) Stable and efficient multiple smoothing parameter estimation for generalized additive models. *Journal of the American Statistical Association* 99, p 673-686.

Wood, F.G. & Evans, W.E. (1980) Adaptiveness and ecology of echolocation in toothed whales. In. *Animal Sonar Systems* (R.G. Busnel & J.F. Fish eds.) Plenum Press, New York, p 381-425.

Woodley, T.H. & Read, A.J. (1991) Potential rates of increase of a harbour porpoise *Phocoena phocoena* population subjected to incidental mortality in commercial fisheries. *Canadian Journal of Fisheries and Aquatic Science* 48, p 2429-35.

Wursig, B. & Wursig, M. (1980) Behaviour and ecology of the dusky dolphin, *Lagenorhynchus obscurus* in the South Atlantic. *Fishery Bulletin* 77, p871-890.

Zamon, J.E. (2003) Mixed species aggregations feeding upon herring and sandlance schools in a nearshore archipelago depend on flooding tidal currents. *Marine Ecology Progress Series* 261, p 243-255.

Zollet, E.A. & Read, A.J. (2006) Depredation of catch by bottlenose dolphins (*Tursiops truncatus*) in the Florida king mackerel (*Scomberomorus cavalla*) troll fishery. *Fishery Bulletin* 104, p 343-349.