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USING CITIZEN SCIENCE DATA TO ASSESS THE VULNERABILITY OF BOTTLENOSE DOLPHINS TO HUMAN IMPACTS ALONG ENGLAND'S SOUTH COAST

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Abstract

Coastal bottlenose dolphin populations are highly vulnerable due to their small population sizes and proximity to human activities. Long-term studies in the UK have monitored populations protected within Special Areas of Conservation (SACs) since the 1990s, but a small community of bottlenose dolphins inhabiting the coastal waters of South England has received much less attention. The English Channel is one of the most heavily impacted marine ecosystems worldwide and increasing anthropogenic pressures pose a severe threat to the long-term viability of this population. Conservation measures to protect these animals have been hindered by a lack of knowledge of population size, distribution, and ranging behaviour. This study aimed to fill these knowledge gaps.

A citizen science sighting network yielded 7,458 sighting reports of bottlenose dolphins between 2000-2020. Resightings of identified individuals were used to estimate abundance, distribution, and ranging behaviour. Social structure analysis revealed a discrete interconnected group of animals in shallow coastal waters, which did not appear to mix with conspecifics identified further offshore. A Bayesian multisite mark recapture analysis estimated that this population comprises around 48 animals (CV= 0.18, 95% HPDI= 38-66).

These dolphins ranged between North Cornwall and Sussex, with an average individual range of 530 km (68-760 km). Areas of high modelled habitat suitability were found to overlap with high levels of anthropogenic pressure, with pollution and boat traffic identified as the most pervasive threats. Although adult survival rates indicated that the population was relatively stable from 2008-2019 (0.945 (0.017±SE)), the small population size implies a significant risk to their long-term viability and resilience to environmental change. By highlighting the most deleterious anthropogenic activities and regions of conservation significance, our results will be useful for developing management policies for threat mitigation and population conservation, to protect this vulnerable group of dolphins.

Introduction

Bottlenose dolphins inhabit temperate and tropical pelagic and coastal waters worldwide. Geographic segregation, environmental change, or ecological specialisation can result in the emergence of discrete populations (Lowry, 2012; Louis *et al*., 2014a; 2021). In the North Atlantic, bottlenose dolphins have been segregated into two ecotypes, the offshore and the coastal (Natoli *et al*., 2005; Louis *et al*., 2014b; Oudejans *et al*., 2015; Nykänen *et al*., 2019a; 2019b). Unlike in US Atlantic waters, where morphological and genetic differences (Mead and Potter, 1995; Perrin *et al*., 2011) indicate that coastal and offshore populations may represent distinct species (Costa *et al*., 2022), there is limited evidence to suggest speciation in the North East Atlantic (NEA).

In the NEA, offshore communities usually occur in large groups, exhibiting large ranging movements with low site fidelity (Bearzi, 2005; Silva *et al*., 2009b) whereas, coastal dolphins often live in smaller communities with high site-fidelity over a restricted range (Grellier *et al*., 1995; Ingram and Rogan, 2002; Grellier and Wilson, 2003). These ecotypes can be differentiated through genetic analysis, social associations, and habitat preferences, with coastal communities usually restricted to shallower waters less than 50 m deep (Louis *et al*., 2014a; 2014b; Oudejans *et al*., 2015).

Genetic and social analysis has delineated localised populations within each ecotype, with coastal communities demonstrating limited dispersal and low intrapopulation diversity (Mirimin *et al*., 2011; Louis *et al*., 2014b; Nykänen *et al*., 2019b). Differences in the ranging behaviours of coastal populations in the NEA have also been shown. Some exhibit a high degree of site fidelity to small-scale localised areas (Wilson, Thompson, and Hammond, 1997; Ingram and Rogan, 2002; Gasper, 2003; Grellier and Wilson, 2003; Feingold and Evans, 2014; Andre, 2017), whilst others demonstrate wide-ranging behaviour inhabiting extended stretches of coastline (Wood, 1998; Mandleberg, 2006; Ingram *et al*., 2009; Giménez *et al*., 2017; Nykänen *et al*., 2020).

As coastal communities tend to form small, isolated populations (Mirimin *et al*., 2011; Louis *et al*., 2014b; Nykänen *et al*., 2018) they are predisposed to genetic drift due to reduced heterozygosity (Lacy, 1987). This subsequent loss of genetic resilience, exacerbated by low reproductive rates and small population sizes (Connor *et al*., 2000; Baker *et al*., 2018), increases the vulnerability of these coastal communities to anthropogenic stressors and local extinction (Hare *et al*., 2011).

Inshore environments are often exposed to higher levels of anthropogenic pressure due to their proximity to human populations (EEA, 2019; He and Silliman, 2019). Consequently, coastal dolphins are subjected to increased levels of direct threats such as entanglement (López, 2006), bycatch (Palka and Rossman, 2001) and vessel strike (Dwyer, Kozmian-Ledward, and Stocking, 2014), and indirect threats such as habitat degradation (Pirotta *et al*., 2013; Agrelo *et al*., 2019), vessel disturbance (Lusseau, 2005; Bejder *et al*., 2006; Pirotta *et al*., 2015), prey depletion (Bearzi *et al*., 2005), pollution (Schwacke *et al*., 2014; Jepson *et al*., 2016), and anthropogenic noise (Buckstaff, 2006; Rako *et al*., 2013). These pressures can negatively impact the health and behaviour of coastal populations, diminishing reproductive output and survivorship (Gulland and Hall, 2007; Bejder *et al*., 2009; McHugh *et al*., 2011). Due to increased human population sizes and subsequent habitat degradation, coastal populations are also likely to be greatly reduced from historic levels (Nichols *et al*., 2007). As such, coastal communities require focused conservation management as detrimental changes to environmental conditions can have consequences at the population level.

Many studies have focused on the impact of single anthropogenic stressors (e.g. Rako *et al*., 2012; Jepson *et al*., 2016); however, due to additive effects, the cumulative impact of multiple stressors can be greater than if exposed to stressors individually (Crain, Kroeker, and Halpern, 2008; Maxwell *et al*., 2013; Pirotta *et al*., 2022). Therefore, attempting to establish the exposure of cumulative stressors over entire population ranges should be a priority for future mitigation (Crain *et al*., 2008; Maxwell *et al*., 2013). Depicting the spatial footprint, intensity, and prevalence of harmful impacts is therefore essential to identify areas for focused conservation efforts (Myers *et al*., 2000; Salafsky and Margoluis, 2003; Tulloch *et al*., 2015).

In the NEA, bottlenose dolphins are protected under a variety of legislation including the Agreement of the Conservation of Small Cetaceans of the Baltic and North Seas, the European Union Habitats Directive (92/43/EEC) and in the UK the Wildlife and Countryside Act (1981) and Conservation of Habitats and Species Regulations (2017). Protection in the UK is usually established through Special Areas of Conservation (SACs), with three designated at sites used by the UK's two largest, resident communities in Cardigan Bay & Pen Llŷn a'r Sarnau, Wales, and the Moray Firth, Scotland. Research and funding have been focused at these sites due to monitoring obligations and although multiple distinct populations have been identified and studied at other sites around Britain and Ireland (Wilson *et al*. 1997; Bristow and Rees, 2001; Ingram and Rogan, 2002; Grellier and Wilson, 2003; Liret *et al*., 2006; Pesante *et al*., 2008; Feingold and Evans, 2014), comparatively little is known about bottlenose dolphins along England's southwest and Channel coast.

The Channel has been classified as one of the most impacted marine ecosystems worldwide (Halpern *et al*., 2008). Not only is it home to one of the busiest shipping routes globally, but multiple economically important industries operate in the region (Hardisty, 1990; McClellan *et al*., 2014; Glegg, Jefferson, and Fletcher, 2015). Growing industrial activities and demand for resources has seen a rise of anthropogenic pressures in recent years (McClellan *et al*., 2014), yet exposure and risk of these threats to coastal dolphins is currently unquantified. To ensure appropriate conservation management, the identification of this community's demographic parameters as well as the impacts of regional anthropogenic pressures is needed (Frederiksen *et al*., 2004; Votier *et al*., 2005; Bejder *et al*., 2006).

Surveys around Cornwall in the southwest UK in the early 1990s reported about 51 bottlenose dolphins (Wood, 1998) resident along a 650 km stretch of coastal water centred around Cornwall. In 2016, following decades of limited data collection and increasing conservation concern for these animals, a citizen science sighting network was initiated demonstrating the year-round presence of a small group of individuals (Dudley, 2017). Previous studies revealed that bottlenose dolphins ranged throughout the Channel coast of England (Tregenza 1992, Williams *et al*., 1997; Liret *et al*., 1998; Brereton *et al*., 2017) but there was no reliable estimate of abundance of bottlenose dolphins resident in the coastal region of the English Channel.

Limited information has constrained effective discussion on conservation and management for this small population. Hence, this study aimed to integrate citizen science data throughout England's South Coast to provide robust estimates of abundance, movement patterns, habitat use, and to identify high-risk areas for future mitigation by spatially mapping cumulative stressors throughout the population's known distribution. The aim was to produce outputs useful for planning effective future protection for this population by highlighting regions of conservation importance, informing policy, and assisting management decisions.

Methods

Study Site

The South Coast of England is characterised by a combination of exposed rocky cliffs and sandy bays with prevailing south-westerly winds (British Geological Survey, 1996; Uncles and Stephens, 2007). It accommodates some of the busiest ports and shipping lanes globally as well as coastal tourism spots. Consequently, its waters are subjected to high levels of vessel activity and an increase in recreational boating and marine tourism during summer months.

Data Collection

154 In 2016, the South West Bottlenose Dolphin Consortium was formed, creating a shared dataset of current and historical bottlenose dolphin encounters from various contributors in the UK's southwest. In response to reports of sightings outside this network, from 2019 we extended the citizen science sighting network throughout the whole southern coast of the UK. Regular boat users such as tour operators, and environmental NGOs with frequent contact with coastal observers were invited to participate. Press releases, radio interviews, webinars, and social media were then used to encourage sighting submissions from the wider public. Contributors were requested to send sightings information including time, location (GPS coordinates if available), numbers of animals, and any photographs taken, with emphasis on photographing all individuals in the group to prevent bias.

Photographic identification techniques were used to identify individuals using their unique nicks and scars (Würsig & Würsig, 1977). Individuals were then allocated one of three degrees of marking severity and matched against a catalogue of identified individuals. Permanently marked individuals (M1) possessed persistent markings which allowed long-term re-identification. Superficially marked (M2) individuals possessed markings which although not permanent were observable over a single field season and temporarily marked individuals (M3) had markings which can fade between sightings (Scott, Wells, and Irvine, 1990; Wilson, Hammond, and Thompson, 1999; Oudejans *et al*., 2015). Due to the diverse array of contributors, all photos were graded (G1-4) on factors such as lighting, distance from individual, angle, and focus following Nykänen *et al*., 2020's criteria. A total of 7458 encounters were collated from citizen science reports between 2000-2020, with identifications made from 326 photo-verified sightings from 2007–2020. To reduce bias from incorrectly identified dolphins the data was restricted to permanently marked individuals (M1, G1-G4) from 2008-2019 for the social and survival analyses; and 2018 for the abundance analysis. All sighting data from 2000-2019 was used for the cumulative impact distribution analysis.

177 **Social Structure**

178 To differentiate between the resident coastal community and other transient animals, the social
179 structure of all identified individuals between 2008-2019 (irrespective of sighting frequency) was
180 investigated using Socprog 2.9 with resultant networks depicted in Netdraw 2.158 (Borgatti and
181 Everett, 2006; Whitehead, 2009a; 2009b). Individuals were considered associated if captured within
182 the same encounter (Whitehead and Dufault, 1999; Whitehead, 2008). To minimise bias, only
183 permanently marked individuals (M1) were used to ensure individuals could be matched throughout
184 the study's duration. The Half Weight Association index was used to calculate the association
185 strength between pairs of individuals, which ranges from 0 (never associated) to 1 (always
186 associated) and reduces bias when individuals are present but not identified (Cairns and Schwager,
187 1987).

188 **Abundance**

189 Due to the wide-ranging nature of this population the broader study region was segregated into three
190 geographically distinct sites (Figure 1) and a multi-site mark-recapture framework was used to assess
191 the abundance across the entire study area (Durban *et al*., 2005). Bayesian inference was used to fit
192 hierarchical log-linear models of likelihood of permanently marked individuals across the three
193 discrete study sites (Cheney *et al*., 2013; Nykänen *et al*., 2020). This method accounts for the
194 movement of individuals between study sites and permits data to be collected opportunistically in
195 different regions (Durban *et al*., 2005). Sightings of permanently marked individuals (M1) from 2018
196 were partitioned via study site (S1) and incorporated into the model, which predicts the number of
197 permanently marked individuals not observed at each study site. Sightings data from 2018 was
198 chosen due to its high proportion of G1-G2 photos (S2) and even distribution of Network A sightings
199 across sites compared to other years. The ratio of marked/to unmarked individuals in each encounter
200 across the framework was then incorporated to estimate the total abundance of the population

(Cheney *et al*., 2013; Nykänen *et al*., 2020). Markov Chain Monte Carlo sampling in WinBUGS software was used to conduct model estimation and averaging with 100,000 burn-in followed by 100,000 iterations. Reliability and convergence were monitored through the visual inspection of three separate chains (Lunn *et al*., 2000; Durban *et al*., 2005; Nykänen *et al*., 2020).

Survival

Sighting histories of permanently marked (M1) individuals identified during the period from 2008-2019 were used to estimate survival. As mark-recapture modelling requires discrete capture periods, data were partitioned according to year to minimise potential bias from seasonal heterogeneity in sampling effort. Cormack-Jolly-Seber models using the program MARK 9.x were then constructed to estimate capture probabilities for each year (p) and survival between years (φ) (Cormack, 1964; Jolly, 1965; Seber, 1965; Lebreton *et al*., 1992; White and Burnham, 1999).

Heterogeneity of capture and survival probabilities were evaluated using goodness-of-fit tests in the program U-CARE 2.3.4, along with tests for transience and trap-dependence (Pradel *et al*., 1997; Choquet *et al*., 2005). Overdispersion of data is common in cetacean studies, as the outcomes of individuals travelling in the same school are not independent (Anderson, Burnham, and White, 1994), and was assessed through the variance inflation factor ($\hat{c}$) which can be used to correct lack of fit in models. Once a suitable general model was found, increasingly simpler models were fitted. The Akaike Information Criteria (AICc) were used to select the most parsimonious model, with the lowest AICc representing the best fit model. Normalised AICc weights were then used to assess the strength of the evidence for that model over others.

Cumulative Utilisation & Impact Distribution

To assess the impact of anthropogenic pressures on bottlenose dolphins, suitable habitat was identified using presence-only species distribution models in the program MaxEnt 3.4.0 (See Supplementary Info; Phillips, Dudík, and Schapire, 2020). This method connects background environmental data and occurrence records to predict both the probability of a species distribution across geographical space and the most influential environmental driver(s) (Phillips et al., 2006; Elith et al., 2011). All bottlenose dolphin sightings regardless of network from 2000-2019 in waters less than 61 m were incorporated into this model as this was identified as key habitat of network A individuals by depth preference analysis (GEBCO, 2020; Figure 3c). Spatial data of 16 human activities (Table 1) were used to assess the impact of current anthropogenic pressures across the South Coast. Numerous stressor levels were allocated to three sectors: fishing, pollution, and shipping activity, following procedures from Halpern *et al*., 2008 and Trew *et al*., 2019. Non-binary stressor layers, were log-transformed, summed, then rescaled (between 0 and 1) to give an intensity score for each activity (Trew *et al*., 2019). Intensity scores were then rescaled to match the resolution of the relative habitat suitability score ($1km^2$).

Cumulative impact scores were determined to identify regions of high risk, where each activity is weighted by the vulnerability of the population to the corresponding stressor. Anticipated impacts from each activity were accessed via a literature review, with vulnerability weightings ascertained via measurements from Maxwell *et al*. 2013 (S3-4). Scores were then summed and rescaled between 0-1.

Cumulative Utilisation and Impact Distribution (CUI) scores were calculated by summing all cumulative impact scores and multiplying by the relative habitat suitability score following:

$$CUI = \sum_{i=1}^{n}\sum_{j=1}^{m} D_i \times S_j \times U_{i.j}$$

Where Di is an activity's intensity score at location i, Sj the relative habitat suitability of species j, and Ui,j is the vulnerability weighting of activity i on species j. To assess which anthropogenic activity or sector exhibited the greatest risk to the population, pairwise linear regression was completed to monitor the effect of individual CUIs on the overall CUI score.

Results

Bottlenose dolphin sightings (n= 7,458) were collated from citizen science reports, with 326 photographic sightings from 2007–2020 (S5-6). 18% of identifiable dolphins (M1) were resighted (sighting range: 2-90), with 30 individuals (11%) logged in multiple years. School size ranged from 1-60 with an average of 9.7 ±8.1 (±SD). The number of individuals (M1-M3) photo-identified per group ranged from 1-25 with an average of 4.0 ±4.01 (±SD).

Social Structure

Social structure analysis identified 25 clusters of 217 permanently marked (M1) individuals (Figure 2). Network A consisted of 32 individuals identified during 90% of encounters (mean group size = 9.39 ±5.69 (±SD)). 94% of individuals from network A were re-sighted on more than one occasion (range: 1-87), with 78% seen in multiple years (Figure 2). Networks B-Y consisted of 185 permanently marked individuals seen on 10% of encounters, 97% of which were seen only once. Analysis of depth preferences and residency levels (Figures 2b & 3c) confirmed network A as a discrete resident population, therefore, subsequent analysis included individuals from network A only.

Range Analysis and Abundance

Most of the identified animals ranged between North Cornwall and Dorset. However, 10 individuals, ranged more widely between North Cornwall and East Sussex (Figure 3b). Analysis of individual ranging behaviour revealed a mean minimum distance of 530 km (range: 68 km – 760 km). Occasionally, individuals were also seen to make extended journeys, with ≈460 km travelled within three days.

Permanently marked (M1) individuals were recorded more frequently in Site 1 (30 individuals) compared to Site 2 (23 individuals) and Site 3 (14 individuals), with 14 individuals (45%), sighted across all three regions. However, whilst sightings in Site 2 have remained relatively stable, sightings in Site 3 have gradually increased in recent years, which could be linked to decreases in sightings in Site 1 since 2015 (S7). In 2018, 18 permanently marked dolphins (M1) were included in the abundance analysis, with a ratio of marked to unmarked individuals of 0.48 (CV = 0.55), and a Bayesian multi-site population abundance estimate of 48 (CV =0.18, 95% HPDI = 38-66).

Survival

Sighting data of network A (M1) individuals (n=27) from 2008-2019 exhibited a good overall fit of the underlying model assumptions (($\chi2$ = 13.335, p = 0.42228, df = 13). UCare results indicated no adjustments were required as the data exhibited only minor over-dispersion ($\hat{c}$= 1.03), with no significant evidence for trap dependence (z=-1.69, P = 0.091022) or transience (z=1.8656, P = 0.062099) within the population. Model 1 ($\phi(.)p(.)$) was the most parsimonious with an AICc of 153.54 (Table 2). According to this model the estimated parameters were constant over time with an interannual survival probability of 0.945 (0.017 ± SE, 0.899-0.971 95% CI) and a capture probability of 0.938 (0.020 ± SE, 0.888-0.967 95% CI).

Cumulative Utilisation & Impact Distribution

MaxEnt modelling identified the whole of the community's range along nearshore coastal habitat as suitable (raster values >0.5). The most parsimonious model included distance from shore and water depth, with distance from shore (86%) having the greatest influence on the population's distribution. The highest anthropogenic impact scores were around major urban areas, ports, and river mouths, with preferred habitat of coastal dolphins in waters <61m having a significantly higher mean anthropogenic footprint than those of deeper waters (Welch's t-test, t50.22 = 114868, $p < 0.001$). When anthropogenic activities were weighted by vulnerability (cumulative impact scores), the highest impacted areas were found to be adjacent to the coast, with hotspots identified around regions of high urbanisation, such as Plymouth, the Solent, and the Sussex coastline (Figure 3a). Waters directly adjacent to the coast experienced the highest CUI scores, highlighting high risk areas around the Cornish coast, Plymouth Sound, Poole Bay, the Solent and the Sussex coastline (Figure 4). Pollution was the most influential anthropogenic layer on the overall CUI score ($R^2 = 0.83$), followed by shipping ($R^2 = 0.55$), indicating that these activities confer the greatest threat to the population.

Discussion

This study confirms the residency of a small, socially distinct population of approximately 48 wide-ranging bottlenose dolphins inhabiting the coastal waters of South England. Whilst these animals have been sighted repeatedly over a number of years, site preference and distribution appears fluid. Areas of high cumulative threats were seen to significantly overlap with areas of high habitat suitability, highlighting the vulnerability of this small population. Due to their low abundance and exposure to increased levels of anthropogenic stressors throughout their range, effective management is greatly needed to ensure their long-term viability.

Increased sighting reports around Sussex combined with a coincidental decrease in Cornwall may indicate a possible home range shift over the course of the study between 2008 and 2019. However, it is unclear at present whether this is a range shift, a range expansion, or an artefact due to increased citizen science reporting in the Eastern Channel. An increase in sightings during summer and autumn months (April-September) was also observed; however, this is likely due to increased observer effort during this period when coastal regions are more frequently traversed due to typically calmer weather in the North Atlantic rather than temporal variation in distribution. Future data will be required to understand long-term habitat use patterns within the Channel coast region.

Individuals were shown to travel large distances in relatively short periods, a finding reflected in other studies of coastal bottlenose dolphins in the UK (Wood, 1998; Robinson *et al*., 2012; O'Brien *et al*., 2009a; 2009b; Ryan, Rogan, and Cross, 2011). Although this population appears to be socially isolated, it remains unknown whether it is also genetically distinct, especially as the study area is also utilised by other populations (Network B-Y). If these coastally resident animals constitute an isolated breeding population, an abundance of 48 (CV =0.18, 95% HPDI = 38-66) individuals is significantly lower than most coastal populations in Britain and Ireland (Ingram and Rogan, 2002; Ingram *et al*., 2009; Cheney *et al*., 2013; 2018; Arso Civil *et al.*, 2019), and puts them at great risk of local extinction.

Survival of permanently marked (M1) individuals was found to be within known ranges of other bottlenose dolphin populations (0.83-0.97: Wells and Scott, 1990; Gaspar, 2003; Fortuna, 2006; Corkrey *et al*., 2008; Currey *et al*., 2009; Silva *et al*., 2009a; Daura-Jorge, Ingram, and Simoes-Lopes, 2013; Ludwig *et al*., 2021). However, due to the opportunistic nature of sighting data, this survival and abundance estimate may be negatively biased as encounter history was dependent on the quality and quantity of data submitted. Owing to this, some individuals may not have been photographed within the study area at capture sessions, or photographs submitted were of too low quality for positive identification. The incorporation of lower quality data could also cause potential biases in which individuals with more distinctive marks could be identified more frequently and thus having higher survival probabilities. Due to the limitations of using incidental photos, analysis by age group or sex was also not possible, restricting insights into the dynamics and stability of this population. Future research should, therefore, include investigations of sex, age class, and reproductive rates to clarify any potential demographic changes.

Although the southwest UK has previously been identified as a biodiversity hotspot for UK marine megafauna (McClellan *et al*., 2014), it is also exposed to high levels of anthropogenic activity (Halpern *et al*., 2008), with significant declines in sightings and pod size of bottlenose dolphins noted within the area (Pikesley *et al*., 2012). Coastal waters were found to have significantly higher levels of human activity compared to offshore regions, mirroring that of previous studies (Coll *et al*., 2012; Batista *et al*., 2014; Trew *et al*., 2019). Areas prone to the highest levels were concentrated around urbanised areas, which host industries such as shipping, fisheries, and recreation (McClellan *et al*., 2014; Halpern *et al*., 2015). We found areas of high CUI intersected with areas of high habitat suitability (≥ 75%) likely due to the population's dependency on the inshore environment (Figure 3c) and intense anthropogenic activity in the region. Boat traffic, pollution and fishing are all significant threats to this population, and mitigation of these drivers in localised regions of high habitat suitability could have a great effect on decreasing the overall cumulative impact of human activities on this resident population.

In recent years, the effect of recreational vessel activity has become a growing concern. In summer months, the South and West Coasts experience a rise in vessel traffic (RYA and British Marine, 2018), which increases threats such as underwater noise, vessel disturbance, and collision. Persistent vessel disturbance can also cause declines in abundance (Bejder *et al*., 2006) and displacement from preferential habitat (Gerrodette and Gilmartin, 1990). In 2013, the death of a calf in the Camel

360 Estuary, Padstow was attributed to the persistent disturbance and collision with recreational vessels
361 (Morris, 2013). Due to the small size of this population losing a single dolphin confers an important
362 cost, especially if female. Greater education of coastal users and enforcement of protective legislation
363 would contribute to the preservation of this population and other vulnerable wildlife in the area.
364
365 Entanglement and bycatch represent serious threats to small cetaceans worldwide (Read, Drinker,
366 and Northridge, 2006). Since only demersal fisheries had a significant impact on the overall CUI,
367 habitat degradation, vessel disturbance, and prey depletion may instead confer greater threats to this
368 population, with overfishing already linked to reduced bottlenose dolphin abundance in the Ionian
369 and Adriatic Seas (Bearzi *et al*., 1999; 2005). Overfishing in the Channel has previously been
370 highlighted as a major factor affecting biodiversity in the area, with decreases in higher trophic-level
371 fish observed (Molfese, Beare, and Hall-Spencer, 2014). As bottlenose dolphins can survive in
372 regions of intense human activity when prey is plentiful (Bearzi, Fortuna, and Reeves, 2008b), prey
373 depletion may have a significant effect on this population. Closures of some fisheries in the
374 Amvrakikos Gulf have corresponded to increases in bottlenose dolphin abundance in comparison to
375 adjacent prey depleted areas (Bearzi *et al*., 2006; 2008a). Therefore, successful management of the
376 fishing sector may assist ecosystem recovery and confer great benefits to this vulnerable population.
377
378 Pollution had the greatest effect on CUI scores, which is of specific concern since persistent
379 polychlorinated biphenyls in bottlenose dolphins in the NEA have been amongst the highest observed
380 in cetaceans worldwide, with a hotspot identified around Cornwall (Jepson *et al*., 2016).
381 Environmental pollutants are widely known to detrimentally affect the health of marine mammals
382 (Kalinowska, 1991; Baulch and Perry, 2012). Various ubiquitous environmental compounds have
383 been linked to the harm of fundamental reproductive and endocrine processes and immune
384 suppression, resulting in mass mortalities and population declines (Cummins, 1988; Borrell and

Aguilar, 1991; Kannan *et al*., 2000; Schwacke *et al*., 2002; Law *et al*., 2012). As apex predators, bottlenose dolphins can bioaccumulate these chemical pollutants that if persistent may have a significant effect at the population level (Aguilar, Borrell, and Reijnders, 2002). As depletion of prey resources can also increase toxicity in cetaceans, as emaciated individuals metabolise lipophilic contaminants (Kannan *et al*., 2000; Houde *et al*., 2005), increased pollution and fishing pressures in the region may confer a significant synergistic effect on both reproductive success and survival of the population.

Efforts to reduce contaminants in riparian and sewage outputs as well as reductions in ocean-based debris should be increased, in combination with the identification and mitigation of pollutant sources. Future investigations should identify and monitor individual toxic compounds present in the region, which together with assessing the likely impact on this small community could assist with the creation of remediation strategies (Schwacke *et al*., 2002; Porte *et al*., 2006; Bearzi *et al*., 2008b).

The designation of Marine Protected Areas (MPAs) is commonly used in the protection of vulnerable cetacean species to aid population recovery (Taylor, Suckling, and Rachlinski, 2005). However, the success of a fixed-area conservation zone depends on the inclusion of a high proportion of the range and ecologically relevant habitat of the population of interest (Hooker and Gerber, 2004; Cañadas *et al*., 2005; White *et al*., 2017). Conservation management is therefore increasingly challenging for highly mobile populations, due to the lack of knowledge on temporal and spatial distributions, which is exacerbated by the relatively small coverage of coastal MPAs (Wilson, 2016). Consequently, fixed MPAs may be ineffective for highly mobile populations as they do not encompass sufficient habitat. Nevertheless, SACs are the principal form of bottlenose dolphin protection within Europe. Although SACs may be effective for populations exhibiting high-site fidelity such as the Shannon Estuary

(Ingram and Rogan 2002) their utility for highly mobile populations has been questioned (Wilson, 2016) following the range shift of the Moray Firth population outside its designated SAC (Wilson *et al*., 2004). Although members of the Moray Firth population identified outside the SAC are still afforded the same protection as within the boundaries it has yet to be determined if this approach is appropriate for other highly mobile populations (Arso Civil *et al*., 2019).

Distributions can exhibit changes due to prey availability, environmental processes, anthropogenic disturbance, climate change, and habitat degradation (Parmesan and Yohe, 2003; MacLeod *et al*., 2005; Bejder *et al*., 2006; Friedlaender *et al*., 2006, Harley *et al*., 2006; Karczmarski *et al*., 2017). Thus, a conservation strategy at a regional scale with an integrated management plan that accounts for the threats throughout the population's range may be suitable, alongside long-term population monitoring. Dynamic ecosystem-based management has already successfully reduced incidental bycatch of other wide-ranging species such as loggerhead and leatherback turtles, where real-time preferred habitat information was provided to fisheries to avoid detrimental interactions (Howell *et al*., 2015). Therefore, flexible tracking of the population and management of nearby human activities could also provide an effective management approach.

Although a thorough understanding of population ecology is required to assess cumulative impacts throughout a population's range, for wide-ranging bottlenose dolphin populations, dedicated surveys covering the entirety of their range are often impracticable. Instead, collaborations between researchers and citizen science networks may be the key to long-term, cost-effective monitoring, alongside dedicated surveys in targeted areas of high importance.

Due to the broad nature of threats and temporal shifts in range identified in this study, it is likely that the designation of a traditional static conservation zone would not be effective. Mitigation of all anthropogenic pressures may also prove to be problematic due to the expansive overlap between high-risk areas and suitable habitat. Therefore, using dynamic conservation zones in areas of high-risk spanning the South and West Coasts may be more beneficial, where long-term monitoring and real-time mitigation of relevant pressures could be achieved.

Conclusions

Although previous studies have demonstrated the occurrence of a resident population of bottlenose dolphins around southwest England (Williams *et al*., 1997; Liret *et al*., 1998; Wood, 1998; Dudley, 2017), this is the first integrated study to assess the impact of anthropogenic activities and highlight regions of conservation concern. Thus, it can be used to inform policy and highlight possible protective measures for this population and wider biodiversity in the region. Small, coastal populations are inherently more vulnerable to anthropogenic pressures and environmental disturbance due to their limited genetic variation and high site fidelity (Harzen and Brunnick, 1997; Bejder *et al*., 2006; Torres and Read, 2009). The small size of this population is of particular concern due to the pervasive levels of anthropogenic impact observed throughout their habitat. With anthropogenic activities and climate change pressures likely to increase in the future, the viability of this population is at significant risk, as any further degradation of habitat would likely have consequences at the population level. This study has highlighted the need for swift integrated conservation management, tailored to the ecological needs of this wide-ranging population, with the mitigation of threats throughout the region essential to ensure its survival. Our results have highlighted significant knowledge gaps and greater understanding of population ecology and demographics is clearly needed to support more effective management, with further work into the population's reproductive rate and calf survival required to evaluate current population trends and the impact of direct pressures.

This study demonstrates the advantages of wide-scale collaborations and the value of citizen science data in monitoring highly mobile populations. Indeed, public data can have great value for informing conservation management when analysed appropriately. Although the quality of photos available for analysis in this study was lower than would be expected in dedicated scientific surveys, biases related to poor image quality were mitigated by restricting analysis to permanently marked (M1) animals. The submission of opportunistic sightings in data-sparse regions has helped to identify new key areas, in which possible dedicated research can be undertaken. As this method is more sustainable over broader temporal and spatial scales than traditional surveys (Dickinson *et al*., 2012), it could be part of the solution to long-term monitoring. Therefore, to elucidate the full extent and temporal variation of the population's range, future targeted effort should be directed into expanding the sighting network to mitigate the current spatial bias and increase the quality of submissions.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Author Contributions

SC expanded the citizen science network, analysed the data, and wrote the manuscript. RD created the initial sighting database and photo ID catalogue. RW, AC, NC, DJ, TB, TH, PE, SS, NT, and MW conceived the consortium and contributed sighting data. SD compared the catalogue with catalogues from the Moray Firth and the Channel Isles. SI conceived analytical ideas, reviewed and edited the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

Data Accessibility

As the sighting database is an amalgamation of privately owned databases under a TOR agreement the raw data file is not publicly available, however extracted data used for this analysis has been submitted to a public repository available here: Data repository. Electronic supplementary information is also available at this location.

Tables

Table 1- Anthropogenic driver data used in analysis with sources. Activities may include multiple individual stressor datasets and are grouped into 3 sectors: Fishing (F), Pollution (P) and Shipping (S).

Anthropogenic Activity	Activity Sector	Source
Fishing	F	Falco et al., 2019
Sum of PCBs ((CB28 CB52 CB101 CB118 CB138 CB153 CB180): Water Column	 P	 ICES, 2010

Sediment	P	ICES, 2010
Biota	P	ICES, 2010
Shipping:		
Dredging & Underwater Ops	S	Falco et al., 2019
Sailing	S	Falco et al., 2019
Pleasure Craft	S	Falco et al., 2019
High Speed Craft	S	Falco et al., 2019
Tug and Towing	S	Falco et al., 2019
Passenger	S	Falco et al., 2019
Sevice	S	Falco et al., 2019
Cargo	S	Falco et al., 2019
Tanker	S	Falco et al., 2019
Military and Law Enforcement	S	Falco et al., 2019
Unknown	S	Falco et al., 2019
Oher	S	Falco et al., 2019

Table 2 - Selection criteria of candidate Cormack-Jolly-Seber models of survival (ϕ) and capture (p) probabilities. Models were produced in program MARK 9.x with (t) = survival/capture probability varies over time and (.) = survival/capture probabilities are constant over time.

#	Model	AICc	Δ AICc	AICc Weight	Likelihood	No. Parameters	Deviance
1	ϕ(.)p(.)	153.5395	0.0000	0.99906	1.0000	2	87.2780
2	ϕ(t)p(.)	168.2693	14.7298	0.00063	0.0006	12	80.1046
3	ϕ(.)p(t)	169.7427	16.2032	0.00030	0.0003	12	81.5780
4	ϕ(t)p(t)	185.0016	31.4621	0.00000	0.0000	21	74.6102

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500 **Figure 1** - Map of study area with areas of interest indicated (Projection: GCS_WGS_1984). The
501 study area is segregated into three discrete regions: Site 1 (North Devon and Cornwall) in blue, Site 2
502 (South Devon and Dorset) in red and Site 3 (Hampshire and Sussex) in black. Blue diamonds
503 represent photo verified encounters of network A (the resident population) and other networks B-Y in
504 grey.

505 **Figure 2** - Sociogram displaying the social network analysis of all permanently marked individuals
506 encountered between 2008-2019. 25 clusters were identified (A-Y). Square nodes represent
507 individuals, the size of which correspond to the frequency of sightings (range 1-87). Grey squares
508 depict individuals seen only once and blue squares individuals seen on multiple occasions, with the
509 black lines representing associations between individuals.

510 **Figure 2b** - Bar graph depicting the number of sightings of individuals with members of network A
511 in blue and other networks in grey.

Figure 3A - Cumulative impact distribution (anthropogenic activity weighted by vulnerability) depicting areas of threat hotspots, scaled between 1 (highest cumulative impact distribution) and 0 (lowest). Locations of interested are noted with initials, N = Newquay, PE = Penzance, P = Plymouth, BH = Berry Head, DH = Durlston Head and B = Brighton

Figure 3B - Range (longitudinal distance) of permanently marked individuals from network A from North Cornwall to East Sussex.

Figure 3C - Depth (m) of encounters of network A (blue) and networks B-Y (diagonal black).

Figure 4 - Cumulative utilisation impact distributions (cumulative impact scores combined with relative habitat suitability) of coastal bottlenose dolphins in the region, scaled between 1 (highest) and 0 (lowest).

References

Agrelo, M., Daura-Jorge, F. G., Bezamat, C., Silveira,T. C. L., Volkmer de Castilho, P., Pires, J. S. R., & Simões-Lopes, P. S. (2019). Spatial behavioural response of coastal bottlenose dolphins to habitat disturbance in southern Brazil. *Aquat. Conserv.: Mar. Freshw. Ecosyst*. 29:11, 1949-1958. doi:10.1002/aqc.3188

Aguilar, A., Borrell, A., & Reijnders, P. (2002). Geographical and temporal variation in levels of organochlorine contaminants in marine mammals. *Mar. Environ. Res*. 53:5, 425–452. doi:10.1016/S0141-1136(01)00128-3

Anderson, D. R., Burnham, K. P., & White, G. C. (1994). AIC model selection in overdispersed capture–recapture data. *Ecology*. 75:6, 1780-1793. doi:10.2307/1939637

Andre, V. (2017). *Bottlenose dolphins (Tursiops truncatus) from the Chaussée de Sein and of the Molène archipelago: Parameter estimation demographics from Capture-Mark-Recapture models and* *recommendations for optimization of monitoring protocol*. Master's Thesis, Centre for Functional and Evolutionary Ecology, Montpellier, France.

Arso Civil, M., Quick, N. J., Cheney, B., Pirotta, E., Thompson, P. M., & Hammond, P. S. (2019). Changing distribution of the east coast of Scotland bottlenose dolphin population and the challenges of area-based management. *Aquat. Conserv.: Mar.*29(S1), 178-196. doi:10.1002/aqc.3102

Baker, I., O'Brien, J., McHugh, K., & Berrow, S. (2018). Female reproductive parameters and population demographics of bottlenose dolphins (*Tursiops truncatus*) in the Shannon Estuary, Ireland. *Mar. Biol.* 165:15. doi:10.1007/s00227-017-3265-z

Batista, M. I., Henriques, S., Pais, M. P., & Cabral, H. N. (2014). Assessment of cumulative human pressures on a coastal area: Integrating information for MPA planning and management. *Ocean Coast. Manag.* 102:A, 248- 257. doi:10.1016/j.ocecoaman.2014.09.020

Baulch, S. & Perry, C. (2012). A sea of plastic: Evaluating the impacts of marine debris on cetaceans. *Environmental Investigation Agency (EIA), report SC/64/E10, London, UK.*

Bearzi, G., Agazzi, S., Bonizzoni, S., Costa, M., & Azzellino, A. (2008a), Dolphins in a bottle: abundance, residency patterns and conservation of common bottlenose dolphins *Tursiops truncatus* in the semi-closed eutrophic Amvrakikos Gulf, Greece. *Aquat. Conserv.: Mar. Freshw. Ecosyst.* 18:2, 130–146. doi:10.1002/aqc.843

Bearzi, G., Fortuna, C. M., & Reeves, R. R. (2008b). Ecology and conservation of common bottlenose dolphins *Tursiops truncatus* in the Mediterranean Sea. *Mamm. Rev.* 39:2, 92-123. doi:10.1111/j.1365-2907.2008.00133.x

Bearzi, G., Politi, E., Agazzi, S., & Azzellino, A. (2006). Prey depletion caused by overfishing and the decline of marine megafauna in eastern Ionian Sea coastal waters (central Mediterranean). *Biol. Conserv.* 127:4, 373–382. doi:10.1016/j.biocon.2005.08.017

Bearzi, G., Politi, E., Agazzi, S., Bruno, S., Costa, M., & Bonizzoni, S. (2005). Occurrence and present status of coastal dolphins (*Delphinus delphis* and *Tursiops truncatus*) in the eastern Ionian Sea. *Aquat. Conserv.: Mar. Freshw. Ecosyst.* 15, 243–257.

Bearzi, G., Politi, E., & Notarbartolo di Sciara, G. (1999). Diurnal behavior of free-ranging bottlenose dolphinsin the Kvarneric (northern Adriatic Sea*). Mar. Mamm. Sci.* 15:3, 1065–1097. doi:10.1111/j.1748-7692.1999.tb00878.x

Bearzi, M. (2005). Aspects of the ecology and behaviour of bottlenose dolphins (*Tursiops truncatus*) in Santa Monica Bay, California. *J. Cetacean Res. Manag.* 7:1, 75–83.

Bejder, L., Samuels, A., Whitehead, H., Finn, H,. & Allen, S. (2009). Impact assessment research: use and misuse of habituation, sensitisation and tolerance in describing wildlife responses to anthropogenic stimuli. *Mar. Ecol. Prog. Ser.* 395, 177-185. doi:10.3354/meps07979

Bejder, L., Samuels, A., Whitehead, H., Gales, N., Mann, J., Connor, R., Heithaus, M., Watson-Capps, J., Flaherty, C., & Krützen, M. (2006). Decline in relative abundance of bottlenose dolphins exposed to long-term disturbance. *Conserv. Biol.* 20:6, 1791–1798. doi:10.1111/j.1523-1739.2006.00540.x

Borrell, A. & Aguilar, A. (1991). Pollution by PCBs in striped dolphins affected by western Mediterranean epizootic. *Proceedings of the Mediterranean Striped Dolphin Mortality International Workshop*, X. Pastor and M. Simmonds (Ed.). Madrid, Spain: Greenpeace International Mediterranean Sea Project, 121-127.

Borgatti, S. P. & Everett, M. G. (2006). A Graph-theoretic perspective on centrality, *Soc. Netw.* 28:4, 466–484. doi:10.1016/j.socnet.2005.11.005

Brereton, T., Jones, D., Leeves, K., Lewis, K., Davies, R., & Russel, T. (2017). Population Structure, Mobility and Conservation of Common Bottlenose Dolphin off South-west England from Photo-Identification Studies. *J. Mar. Biolog. Assoc. U.K.,* 98:05, 1-9. doi:10.1017/S0025315417000121

British Geological Survey (1996). Chapter 2.3. Wind and Water. *In Coasts and Seas of the United Kingdom. Region 10. South-west England: Seaton to Falmouth Bay,* J. H. Barne, C. F. Robson, S. S. Kaznowska, & J. P. Doody (Ed.). Peterborough, IK: Joint Nature Conservation Committee, 23-25.

Bristow, T. & Rees, E. I. S. (2001). Site fidelity and behaviour of bottlenose dolphins (*Tursiops truncatus*) in Cardigan Bay, Wales. *Aquat. Mamm.* 27:1, 1–10.

Buckstaff, K. C. (2006). Effects of watercraft noise on the acoustic behavior of bottlenose dolphins, *Tursiops truncatus*, in Sarasota Bay, Florida. *Mar. Mamm. Sci.* 20:4, 709-725. doi:10.1111/j.1748-7692.2004.tb01189.x

Cairns, S. J. & Schwager, S. J. (1987). A comparison of association indices. *Anim. Behav.* 35:5, 1454-1469. doi:10.1016/S0003-3472(87)80018-0

Cañadas, A., Sagarminaga, R., de Stephanis, R., Urquiola, E., & Hammond, P. S. (2005). Habitat preference modelling as a conservation tool: proposals for marine protected areas for cetaceans in southern Spanish waters. *Aquat. Conserv.: Mar. Freshw. Ecosyst.* 15, 495-521. doi:10.1002/aqc.689

Cheney, B., Thompson, P. M., Ingram, S. N., Hammond, P. S., Stevick, P. T., Durban, J. W., Culloch, R. M., Elwen, S. H., Mandleberg, L., Janik, V. M., Quick, N. J., ISLAS-Villanueva, V., Robinson, K. P., Costa, M., Eisfeld, S. M., Walters, A., Phillips, C., Weir, C. R., Evans, P. G. H., Anderwald, P., Reid, R. J., Reid, J. B., & Wilson, B. (2013). Integrating multiple data sources to assess the distribution and abundance of bottlenose dolphins Tursiops truncatus in Scottish waters. *Mamm. Rev.* 43:1, 71-88. doi:10.1111/j.1365-2907.2011.00208.x

Cheney, B., Graham, I. M., Barton, T. R., Hammond, P. S., & Thompson, P.M. (2018). Site Condition Monitoring of bottlenose dolphins within the Moray Firth Special Area of Conservation: 2014-2016. *Scottish Natural Heritage Research Report No. 1021*.

Choquet, R., Reboulet, A. M., Lebreton, J. D., Gimenez, O., & Pradel, R. (2005). *UCARE 2.2 User's Manual*. Montpellier, France: CEFE.

Coll, M., Piroddi, C., Albouy, C., Lasram, F. B. R., Cheung, W. W. L., Christensen, V., Karpouzi, V. S., Guilhaumon, F., Mouillot, D., Paleczny, M., Palomares, M. L., Steenbeek, J., Trujillo, P., Watson, R., & Pauly, D. (2012). The Mediterranean Sea under siege: spatial overlap between marine biodiversity, cumulative threats and marine reserves. *Glob. Ecol. Biogeogr.* 21, 465- 480. doi:10.1111/j.1466-8238.2011.00697.x

Connor, R. C., Wells, R. S., Mann, J., & Read, A. J. (2000). The bottlenose dolphin: social relationships in a fission-fusion society. *In Cetacean societies: field studies of whales and dolphins,* Mann, J., Connor, R. C., Tyack, P., & Whitehead, H. (Ed.). Chicago, USA: University of Chicago Press, 91–126.

Corkrey, R., Brooks, S., Lusseau, D., Parsons, K., Durban, J. W., Hammond, P. S., & Thompson, P. M. (2008). A Bayesian capture-recapture population model with simultaneous estimation of heterogeneity. *J. Am. Stat. Assoc.* 103:483, 948-960. doi:10.1198/016214507000001256

Cormack, R. M. (1964). Estimates of survival from the sighting of marked animals. *Biometrika*, 51:3/4, 429– 438.

619 Costa, A. P. B., Mcfee, W., Wilcox, L. A., Archer, F. I., & Rosel, P. E. (2022).The common bottlenose dolphin (*Tursiops truncatus*) ecotypes of the western North Atlantic revisited: an integrative taxonomic investigation supports the presence of distinct species, *Zool. J. Linn. Soc.* zlac025. doi:10.1093/zoolinnean/zlac025

623 Crain, C. M., Kroeker, K., & Halpern, B. S. (2008). Interactive and cumulative effects of multiple human stressors in marine systems. *Ecol. Lett.* 11:12, 1304–1315. doi:10.1111/j.1461-0248.2008.01253.x

626 Cummins, J. E. (1988). Extinction: the PCB threat to marine mammals, *The Ecologist*, 18, 193-195.

627 Currey, R. J., Dawson, S. M., Slooten, A., Schneider, K., Lusseau, D., Boisseau, O. J., Haase, P., & Williams, J. A. (2009). Survival rates for a declining population of bottlenose dolphins in Doubtful Sound, New Zealand: an information theoretic approach to assessing the role of human impacts. *Aquat. Conserv.: Mar. Freshw. Ecosyst.* 19, 658-670. doi:10.1002/aqc.1015

631 Daura-Jorge, F. G., Ingram, S. N., & Simoes-Lopes, P. C. (2013). Seasonal abundance and adult survival of bottlenose dolphins (*Tursiops truncatus*) in a community that cooperatively forages with fishermen in southern Brazil. *Mar. Mamm. Sci.* 29:2, 293-311. doi:10.1111/j.1748-7692.2012.00571.x

635 Dickinson, J. L., Shirk, J., Bonter, D., Bonney, R., Crain, R. L., Martin, J., Phillips, T., & Purcell, K. (2012). The current state of citizen science as a tool for ecological research and public engagement. *Front. Ecol. Environ.* 10:6, 291-297. doi:10.1890/110236

Dudley, R. H. (2017). *Using citizen science data to assess the social structure, residency and distribution of bottlenose dolphins (Tursiops truncatus) in Southwest England*. Master's Thesis, University of Plymouth, Plymouth, UK.

Durban, J. W., Elston, D. A., Ellifrit, D. K., Dickson, E., Hammond, P. S., & Thompson, P. M. (2005). Multisite mark-recapture for cetaceans: Population estimates with Bayesian model averaging. *Mar. Mamm. Sci.* 21:1, 80–92. doi:10.1111/j.1748-7692.2005.tb01209.x

Dwyer, S. L., Kozmian-Ledward, L., & Stocking, K. A. (2014). Short-term survival of severe propeller strike injuries and observations on wonder progression in a bottlenose dolphin. *N. Z. J. Mar. Freshwater Res.* 48:2, 294-302. doi:10.1080/00288330.2013.866578

Elith, J., Phillips, S. J., Hastie, T., Dudík, M., En Chee, Y., & Yates, C. J. (2011). A statistical explanation of MaxEnt for ecologists. *Divers. Distrib*., 17:1, 43–57. doi:10.1111/j.1472-4642.2010.00725.x

European Environment Agency. (2019). Marine messages II, *EEA Report No 17/2019*.

Falco, L., Pititto, A., Adnams, W., Earwaker, N., & Greidanus, H. (2019). EMODnet Human Activities: Vessel Density Map. [revision date: 16/12/2019], EMODnet Human Activities Data Repository.

Feingold, D. & Evans, P. G. H. (2014). Bottlenose Dolphin and Harbour Porpoise Monitoring in Cardigan Bay and Pen Llyn a'r Sarnau Special Areas of Conservation 2011-2013. *Natural Resources Wales Evidence Report Series No. 4,* 124.

Fortuna, C. M. (2006). *Ecology and conservation of bottlenose dolphins (Tursiops truncatus) in the north-eastern Adriatic Sea*. PhD Thesis, University of St. Andrews, St. Andrews, Scotland.

Frederiksen, M., Wanless, S., Harris, M. P., Rothery, P., & Wilson, L. J. (2004). The role of industrial fisheries and oceanographic change in the decline of North Sea black-legged kittiwakes. *J. Appl. Ecol.* 41:6, 1129–1139. doi:10.1111/j.0021-8901.2004.00966.x

Friedlaender, A., Halpin, P., Qian, S., Lawson, G., Wiebe, P., Thiele, D., & Read, A. J. (2006). Whale distribution in relation to prey abundance and oceanographic processes in shelf waters of the Western Antarctic Peninsula. *Mar. Ecol. Prog. Ser. 317*, 297–310. doi:10.3354/meps317297

Gasper, R. (2003). *Status of the resident bottlenose dolphin population in the Sado Estuary: Past, Present and Future*. PhD Thesis, University of St. Andrews, St. Andrews, Scotland.

GEBCO Compilation Group. (2020). GEBCO 2020 Grid. Available from https://www.gebco.net/ [accessed 04 August 2020].

Gerrodette, T. & Gilmartin, W. G. (1990). Demographic consequences of changes pupping and hauling sites of the Hawaiian monk seal. *Conserv. Biol.* 4:4, 423-430. doi:10.1111/j.1523-1739.1990.tb00317.x

Giménez, J., Louis, M., Barón, E., Ramírez, F., Verborgh, P., Gauffier, P., Esteban, R., Eljarrat, E., Barceló, D., Forero, M. G., & de Stephanis, R. (2017). Towards the identification of ecological management units: A multidisciplinary approach for the effective management of bottlenose dolphins in the southern Iberian Peninsula. *Aquat. Conserv.: Mar. Freshw. Ecosyst.* 28, 205-215. doi:10.1002/aqc.2814

Glegg, G., Jefferson, R., & Fletcher, S. (2015). Marine Governance in the English Channel (La Manche): Linking science and management. *Mar. Pollut. Bull.* 95:2, 707-718. doi:10.1016/j.marpolbul.2015.02.020

Grellier, K., Arnold, H., Thompson, P., Wilson, B. & Curran, S. (1995). Management recommendations for the Cardigan Bay bottlenose dolphin population. *Wales, UK: Report (134) to Countryside Council for Wales.*

Grellier, K. & Wilson, B. (2003). Bottlenose dolphins using the Sound of Barra Scotland. *Aquat. Mamm.* 29:3, 378–382.

Gulland, F. M. D., & Hall, A. J. (2007) Is marine mammal health deteriorating? Trends in the global reporting of marine mammal disease. *EcoHealth*, 4:2, 135–150. doi:10.1007/s10393-007-0097-1

Halpern, B. S., Frazier, M., Potapenko, J., Casey, K. S., Koenig, K., Longo, C., Stewart Lowndes, J., Cotton Rockwood, R., Selig, E. R., Selkoe, K. A., & Walbridge, S. (2015). Spatial and temporal changes in cumulative human impacts on the world's ocean. *Nat. Commun.* 6:1, 1-7. doi:10.1038/ncomms8615

Halpern, B. S., Walbridge, S., Selkoe, K. A., Kappel, C. V., Micheli, F., D'Agrosa, C., Bruno, J. F., Casey, K. S., Ebert, C., Fox, H. E., Fujita, R., Heinemann, D., Lenihan, H. S., Madin, E. M. P., Perry, M. T., Selig, E. R., Spalding, M., Steneck, R., & Watson, R. (2008). A global map of human impact on marine ecosystems. *Science*, 319, 948–952. doi:10.1126/science.1149345

Hardisty, J. (1990). *The British Seas: An Introduction to the Oceanography and Resources of the North-west European Continental Shelf*. London, UK: Routledge.

Hare, M. P., Nunney, L., Schwartz, M. K., Ruzzante, D. E., Burford, M., Waples, R. S., Ruegg, K., & Palstra, F. (2011). Understanding and estimating effective population size for practical application in marine species management. *Conserv. Biol.* 25:3, 438-449. doi:10.1111/j.1523-1739.2010.01637.x

Harley, C. D. G., Randall Hughes, A., Hultgren, K. M., Miner, B. G., Sorte, C. J. B., Thornber, C. S., Rodriguez, L. F., Tomanek, L., & Williams, S. L. (2006). The impacts of climate change in coastal marine systems. *Ecol. Lett. 9:*2, 228–241. doi:10.1111/j.1461-0248.2005.00871.x

Harzen, S., & Brunnick, J. (1997). Skin disorders in bottlenose dolphins (*Tursiops truncatus*), resident in the Sado estuary, Portugal. *Aquat. Mamm.* 23:1, 59-68.

He, Q., & Silliman, B. R., (2019). Climate change, human impacts, and coastal ecosystems in the Anthropocene. *Current Biology*, 29 (19), R1021-R1035.

Hooker, S., & Gerber, R. L. (2004). Marine reserves as a tool for ecosystem-based management: The potential importance of megafauna. *BioScience*, 54:1, 2739. doi:10.1641/0006-3568(2004)054[0027:MRAATF]2.0.CO;2

Houde, M., Hoekstra, P. F., Solomon, K. R., & Muir, D. C. G. (2005). Organohalogen contaminants in delphinoid cetaceans. *Rev. Environ. Contam. Toxicol.* 184, 1–57. doi: 10.1007/0-387-27565-7_1

Howell, E. A., Hoover, A., Benson, S. R., Bailey, H., Polovina, J. J., Seminoff, J. A., & Dutton, P. H. (2015). Enhancing the TurtleWatch product for leatherback sea turtles, a dynamic habitat model for ecosystem-based management. *Fish. Oceanogr.* 24:1, 57-68. doi:10.1111/fog.12092

ICES (2010). *Contaminants and Biological Effects dataset*. ICES, Copenhagen.

Ingram, S. N., Kavanagh, A., Englund, A., & Rogan, R. (2009). Site assessment of the waters of northwest Connemara. A survey of bottlenose dolphins (*Tursiops truncatus*). *University College Cork, Ireland: Report for the National Parks and Wildlife Service of Ireland.*

Ingram, S. N. & Rogan, E. (2002). Identifying critical areas and habitat preferences of bottlenose dolphins Tursiops truncatus. *Mar. Ecol. Prog. Ser.* 244, 247-255. doi:10.3354/meps244247

Jepson, P. D., Deaville, R., Barber, J. L., Aguilar, À., Borrell, A., Murphy, S., Barry, J., Brownlow, A., Barnett, J., Berrow, S., Cunningham, A. A., Davison, N. J., ten Doeschate, M., Esteban, R., Ferreira, M., Foote, A. D., Genov, T., Giménez, J., Loveridge, J., Llavona, A., Martin, V., Maxwell, D. L., Papachlimitzou, A., Penrose, R., Perkins, M. W., Smith, B., de Stephanis, R., Tregenza, N., Verborgh, P., Fernandez, A., & Law, R. J. (2016). PCB pollution continues to impact populations of orcas and other dolphins in European waters. *Sci. Rep.* 6:18573. doi:10.1038/srep18573

Jolly, G. M. (1965). Explicit estimates from capture–recapture data with both death and immigration-stochastic models. *Biometrika*, 52 (1/2), 225–247. doi:10.2307/2333826

Kalinowska, M. (1991). *Dolphins, Porpoises and Whales of the World,* The IUCN Red Data Book. Gland, Switzerland and Cambridge, UK: IUCN Publ.

Kannan, K., Blankenship, A., Jones, P., & Giesy, J. (2000). Toxicity reference values for the toxic effects of polychlorinated biphenyls to aquatic mammals. *Hum. Ecol. Risk Assess.* 6:1, 181–201. doi:10.1080/10807030091124491

Karczmarski, L., Huang, S., Wong, W., Chang, W., Chan, S. C. Y., & Keith, M. (2017). Distribution of a coastal delphinid under the impact of long-term habitat loss: Indo-pacific humpback dolphins off Taiwan's west coast. *Estuaries Coast.* 40:2, 594- 603. doi:10.1007/s12237-016-0146-5

Lacy, R. C. (1987). Loss of Genetic Diversity from Managed Populations: Interacting Effects of Drift, Mutation, Immigration, Selection, and Population Subdivision. *Conserv. Biol.* 1:2, 143–158. doi:10.1111/j.1523-1739.1987.tb00023.x

Law, R. J., Barry, J., Barber, J. L., Bersuder, P., Deaville, R., Reid, R. J., Brownlow, A., Penrose, R., Barnette, J., Loveridge, J., Smith, B., & Jepson, P. D. (2012). Contaminants in cetaceans from UK waters: Status as assessed within the Cetacean Strandings Investigation Programme from 1990 to 2008. *Mar. Pollut. Bull.* 64:7, 1485–1494. doi:10.1016/j.marpolbul.2012.05.024

Lebreton, J. D., Burnham, K. P., Clobert, J., & Anderson, D. R. (1992). Modelling survival and testing biological hypotheses using marked animals: a unified approach with case studies. *Ecol. Monogr.* 62:1, 67–118. doi:10.2307/2937171

Liret, C., Baines, M. E., Evans, P. G. H., Hammond, P. S., & Wilson, B. (2006). Atlantic bottlenose dolphins: conservation and management. Oceanopolis, Brest, France, 56

Liret, C., Creton, P., Evans, P. G. H., Heimlich-Boran, J. R., & Ridoux, V. (1998). English and French coastal Tursiops from Cornwall to the Bay of Biscay, 1996. *Photo-Identification Catalogue*, 100.

López, B. D. (2006). Interactions between Mediterranean bottlenose dolphins (*Tursiops truncatus*) and gillnets off Sardinia, Italy. *ICES J. Mar. Sci.* 63, 946-951. doi:10.1016/j.icesjms.2005.06.012

Louis, M., Fontaine, M. C., Spitz, J., Schlund, E., Dabin, W., Deaville, R., Caurant, F., Cherel, Y., Guinet, C. & Simon-Bouhet, B. (2014a). Ecological opportunities and specializations shaped genetic divergence in a highly mobile marine top predator. *Proc. Royal Soc. B.* 281:1795, 20141558. doi:10.1098/rspb.2014.1558

Louis, M., Galimberti, M., Archer, F., Berrow, S., Brownlow, A., Fallon, R., Nykänen, M., O'Brien, J., Roberston, K. M., Rosel, P. E., Simon-Bouhet, B., Wegmann, D., Fontaine, M. C., Foote, A. D., & Gaggiotti, O. E. (2021). Selection on ancestral genetic variation fuels repeated ecotype formation in bottlenose dolphins. *Sci. Adv.*, 7:44. doi: 10.1126/sciadv.abg1245

Louis, M., Viricel, A., Lucas, T., Peltier, H., Alfonsi, E., Berrow, S., Brownlow, E., Covelo, P., Dabin, W., Deaville, R., de Stephanis, R., Gally, F., Gauffier, P., Penrose, R., Silva, M. A., Guinet, C., & Simon-Bouhet, B. (2014b). Habitat-driven population structure of bottlenose dolphins, *Tursiops truncatus*, in the North-East Atlantic. *Mol. Ecol.* 23:4, 857-874. doi:10.1111/mec.12653

Lowry, D. B. (2012). Ecotypes and the controversy over stages in the formation of new species. *Biol. J. Linn. Soc.* 106, 241–257. doi:10.1111/j.1095-8312.2012.01867.x

Ludwig, K. E., Daly, M., Levesque, S., & Berrow, S. D. (2021) Survival Rates and Capture Heterogeneity of Bottlenose Dolphins (*Tursiops truncatus*) in the Shannon Estuary, Ireland. *Front. Mar. Sci.* 8: 611219. doi: 10.3389/fmars.2021.611219

Lunn, D. J., Thomas, A., Best, N., & Spiegelhalter, D. (2000). WinBUGS-a Bayesian modelling framework: Concepts, structure, and extensibility. *Stat. Comput.* 10:4, 325–337. doi:10.1023/A:1008929526011

Lusseau, D. (2005). Residency pattern of bottlenose dolphins *Tursiops* spp. In Milford Sound, New Zealand, is related to boat traffic. *Mar. Ecol. Prog. Ser.* 295, 265-272. doi:10.3354/meps295265

MacLeod, C. D., Bannon, S. M., Pierce, G. J., Schweder, C., Learmonth, J. A., Herman, J. S., & Reid, R. J. (2005). Climate change and the cetacean community of north-west Scotland. *Biol. Conserv.* 124:4, 477–483. doi:10.1016/j.biocon.2005.02.004

Mandleberg, L. (2006). Bottlenose dolphins of the Hebrides. *Hebridean Whale and Dolphin Trust, Scotland: A summary report from five years of research (2001-2005).*

Maxwell, S. M., Hazen, E. L., Bograd, S. J., Halpern, B. S., Breed, G. A., Nickel, B., Teutschel, N. M., Crowder, L. B., Benson, S., Dutton, P. H., Bailey, H., Kappes, M. A., Kuhn, C. E., Weise, M. J., Mate, B., Shaffer, S. A., Hassrick, J. L., Henry, R. W., Irvine, L., McDonald, B. I., Robinson, P. W., Block, B. A., & Costa, D. P. (2013). Cumulative human impacts on marine predators. *Nat. Commun.* 4:2688. doi:10.1038/ncomms3688

McClellan, C. M., Brereton, T., Dell'Amico, F., Johns, D. G., Cucknell, A., Patrick, S. C., Penrose, R., Ridoux, V., Solandt, J., Stephan, E., Votier, S. C., Williams, R., & Godley, B. J. (2014). Understanding the distribution of marine megafauna in the English Channel region: Identifying key habitats for conservation within the busiest seaway on Earth. *PLoS One*, 9:2, e89720. doi:10.1371/journal.pone.0089720

McHugh, K. A., Allen, J. B., Barleycorn, A. A., & Wells, R. S. (2011). Natal philopatry, ranging behavior, and habitat selection of juvenile bottlenose dolphins in Sarasota Bay, Florida. *J. Mammal.* 92:6, 1298-1313. doi:10.1644/11-MAMM-A-026.1

Mead, J. G. & Potter, C. W. (1995). Recognizing two populations of the bottlenose dolphin (*Tursiops truncatus*) of the Atlantic coast of North America: Morphologic and ecologic considerations. *Int. Biol. Res. Institute Rep.* 5:5, 31–44.

Mirimin, L., Miller, R., Dillane, E., Berrow, S. D., Ingram, S., Cross, T. F., & Rogan, E. (2011). Fine-scale population genetic structuring of bottlenose dolphins in Irish coastal waters. *Anim. Conserv.* 14:4, 342-353. doi:10.1111/j.1469-1795.2010.00432.x

Molfese, C., Beare, D., & Hall-Spencer, J. M. (2014). Overfishing and the Replacement of Demersal Finfish by Shellfish: An Example from the English Channel. *PLoS One*, 9:7, e101506. doi:10.1371/journal.pone.0101506

Morris, S., (2013). Rare dolphin killed in 'boat hit-and-run'. *The Guardian*, [online] Available at: https://www.theguardian.com/environment/2013/jul/22/rare-dolphine-killed-boat-hit-run [Accessed 11 August 2020].

Myers, N., Mittermeier, R. A., Mittermeier, C. G., Da Fonseca, G. A. B., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, 403, 853-858. doi:10.1038/35002501

Natoli, A., Birkun, A., Aguilar, A., Lopez, A., & Hoelzel, A. R. (2005). Habitat structure and the dispersal of male and female bottlenose dolphins (*Tursiops truncatus*). *Proc. Royal Soc. B.* 272:1569, 1217-1226. doi:10.1098/rspb.2005.3076

Nichols, C., Herman, J., Gaggiotti, O.E., Dobney, K.M., Parsons, K., & Hoelzel, A.R. (2007). Genetic isolation of a now extinct population of bottlenose dolphins (Tursiops truncatus). *Proc. Royal Soc. B.* 274:1618, 1611-1616. doi:10.1098/rspb.2007.0176

Nykänen, M., Dillane, E., Englund, A., Foote, A. D., Ingram, S. N., Louis, M., Mirimin, L., Oudejans, M., & Rogan, E. (2018). Quantifying dispersal between marine protected areas by a highly mobile species, the bottlenose dolphin, *Tursiops truncatus*. *Ecol. Evol.*, 8, 9241-9258. doi:10.1002/ece3.4343

Nykänen, M., Kaschner, K., Dabin, W., Brownlow, A., Davison, N. J., Deaville, R., Garilao, C., Kesner-Reyes, K., Gilbert, M. T. P., Penrose, R., Islas-Villanueva, V., Wales, N., Ingram, S. N., Rogan, E., Louis, M., & Foote, A. D. (2019a). Postglacial Colonization of Northern Coastal Habitat by Bottlenose Dolphins: A Marine Leading-Edge Expansion? *J. Hered.* 110:6, 662-674. doi:10.1093/jhered/esz039

Nykänen, M., Louis, M., Dillane, E., Alfonsi, E., Berrow, S., O'Brien, J., Brownlow, A., Covelo, P., Dabin, W., Deaville, R., de Stephanis, R., Gally, F., Gauffier, P., Ingram, S. N., Lucas, T.,Mirimin, L., Penrose, R., Rogan, E., Silva, M. A., Simon-Bouhet, B., & Gaggiotti, O. E. (2019b). Fine-scale population structure and connectivity of bottlenose dolphins, Tursiops truncatus, in European waters and implications for conservation. *Aquat. Conserv.: Mar. Freshw. Ecosyst.* 29:1, 197-211. doi:10.1002/aqc.3139

Nykänen, M., Oudejans, M., Rogan, E., Durban, J., & Ingram, S. (2020). Challenges in monitoring mobile populations: Applying bayesian multi-site mark-recapture abundance estimation to the monitoring of a highly mobile coastal population of bottlenose dolphins. *Aquat. Conserv.: Mar. Freshw. Ecosyst*. 30:8, 1674-1688. doi:10.1002/aqc.3355

O'Brien, J. M., Berrow, S. D., Ryan, C., McGrath, D., O'Connor, I., Pesante, G., Burrows, G., Massett, N., & Klotzer, W. P. (2009a). A note on long-distance matches of bottlenose dolphins (*Tursiops truncatus*) around the Irish coast using photo-identification. *J. Cetacean Res. Manag.* 11:1, 71-76.

O'Brien, J. M., Berrow, S. D., Ryan, C., McGrath, D., O'Connor, I., & Whooley, P. (2009b). Evidence of long-distance movements of bottlenose dolphins (*Tursiops truncatus*) around the Irish coast using photo-identification. 23rd Conference of the European Cetacean Society, UK: Unpublished poster.

Oudejans, M. G., Visser, F., Englund, A., Rogan, E., & Ingram, S. N. (2015). Evidence for Distinct Coastal and Offshore Communities of Bottlenose Dolphins in the North East Atlantic. *PLoS One*, 10:4, e0122668. doi:10.1371/journal.pone.0122668

Palka, D. L. & Rossman, M. C. (2001). Bycatch Estimates of Coastal Bottlenose Dolphin (*Tursiops truncatus*) in *U.S. Mid-Atlantic Gillnet Fisheries for 1996 to 2000*. National Marine Fisheries Science Center , USA: Northeast Fisheries Science Center Reference Document 01-15.

Parmesan, C. & Yohe, G. (2003). A globally coherent fingerprint of climate change impacts across natural systems. *Nature*, 421:6918, 37–42. doi:10.1038/nature01286

Perrin, W. F., Thieleking, J. L., Walker, W. A., Archer, F. I., & Robertson, K. M. (2011). Common bottlenose dolphins (*Tursiops truncatus*) in California waters: Cranial differentiation of coastal and offshore ecotypes. *Mar. Mamm. Sci.* 27:4, 769–792. doi:10.1111/j.1748-7692.2010.00442.x

Pesante, G., Evans, P. G. H., Baines, M. E., & McMath, M. (2008). Abundance and Life History Parameters of Bottlenose Dolphin in Cardigan Bay: Monitoring 2005–2007. C*ountryside Council for Wales, UK: CCW Marine Monitoring Report No. 61, 1–75.*

Phillips, S. J., Anderson, R. P., & Schapire, R. E. (2006). Maximum entropy modeling of species geographic distributions. *Ecol. Model*., 190, 231–259. doi:10.1016/j.ecolmodel.2005.03.026

Phillips, S. J., Dudík, M., & Schapire, R. E. (2020). Maxent software for modeling species niches and distributions (Version 3.4.1). Available from: http://biodiversityinformatics.amnh.org/open_source/maxent/, [Accessed on 10 July 2020].

Pikesley, S. K., Witt, M. J., Hardy, T., Loveridge, J., Loveridge, J., Williams, R., & Godley, B. J. (2012). Cetacean sightings and strandings: evidence for spatial and temporal trends? *J. Mar. Biolog. Assoc. U.K.* 92:8, 1809-1820. doi:10.1017/S0025315411000464

Pirotta, E., Laesser, B. E., Hardaker, A., Riddoch, N., Marcoux, M., & Lusseau, D. (2013). Dredging displaces bottlenose dolphins from an urbanised foraging patch. *Mar. Pollut. Bull.* 74:1, 396-402. doi:10.1016/j.marpolbul.2013.06.020

Pirotta, E., Merchant, N. D., Thompson, P. M., Barton, T. R., & Lusseau, D. (2015). Quantifying the effect of boat disturbance on bottlenose dolphin foraging activity. *Biol. Conserv. 181*, 82–89. doi:10.1016/j.biocon.2014.11.003

Pirotta, E., Thomas, L., Costa, D. P., Hall, A. J., Harris, C. M., Harwood, J., Kraus, S. D., Miller, P. J. O., Moore, M. J., Photopoulou, T., Rolland, R. M., Schwacke, L., Simmons, S. E., Southall, B. L., & Tyack, P. L. (2022). Understanding the combined effects of multiple stressors: A new perspective on a longstanding challenge. *Sci. Total Environ.,* 821, 153322. doi:10.1016/j.scitotenv.2022.153322

Porte, C., Janer, G., Lorusso, L.C., Ortiz-Zarragoitia, M., Cajaraville, M.P., Fossi, M.C., & Canesi, L. (2006). Endocrine disruptors in marine organisms: approaches and perspectives. *Comp. Biochem. Physiol. CBP*. 143:3, 303–315. doi:10.1016/j.cbpc.2006.03.004

Pradel, R., Hines, J. E., Lebreton, J. D., & Nichols, J. D. (1997). Capture–recapture survival models taking account of transients. *Biometrics*, 53, 60–72. doi:10.2307/2533097

Rako, N., Fortuna, C. M., Holcer, D., Mackelworth, P., Nimak-Wood, M., Pleslić, G., Sebastianutto, L., Vilibić, I., Wiemann, A., & Picciulin, M. (2013). Leisure boating noise as a trigger for the displacement of the bottlenose dolphins of the Cres-Lošinj archipelago (northern Adriatic Sea, Croatia). *Mar. Pollut. Bull.* 68:1-2, 77-84. doi:10.1016/j.marpolbul.2012.12.019

Rako, N., Picciulin, M., Mackelworth, P., Holcer, D., & Fortuna, C. M. (2012). "Long-Term Monitoring of Anthropogenic Noise and Its Relationship to Bottlenose Dolphin (*Tursiops truncatus*) Distribution in the Cres–Lošinj Archipelago, Northern Adriatic, Croatia", i*n*: *The Effects of Noise on Aquatic Life. Advances in Experimental Medicine and Biology, vol 730*, Popper, A. N. & Hawkins, A. (Ed.). New York, USA: Springer, 323-325.

Read, A. J., Drinker, P., & Northridge, S. (2006). Bycatch of Marine Mammals in U.S. and Global Fisheries. *Conserv. Biol.* 20:1, 163–169. doi:10.1111/j.1523-1739.2006.00338.x

888 Robinson, K. P., O'Brien, J., Berrow, S., Cheney, B., Costa, M., Elsfield-Pierantonio, S. M.,
889 Haberlin, D., Mandleberg, L., O'Donovan, M., Oudejans, M., Ryan, C., Stevick, P., Thompson, P.
890 M., & Whooley, P. (2012). Discrete or not so discrete: Long distance movements by coastal
891 bottlenose dolphins in UK and Irish waters. *J. Cetacean Res. Manag.* 12:3, 365-371.

892 RYA & British Marine. (2018). *Watersports Participation Survey 2017 Summary Report*, 27

893 Ryan, C., Rogan, E., & Cross, T. (2011). The use of Cork Harbour by bottlenose dolphins (*Tursiops*
894 *truncatus* (Montague, 1821)). *Ir. Nat.' J.* 30:2, 1-9.

895 Salafsky, N. & Margoluis, R. (2003). What conservation can learn from other fields about monitoring
896 and evaluation. *BioScience.* 53:2, 120–122. doi:10.1641/0006-
897 3568(2003)053[0120:WCCLFO]2.0.CO;2

898 Schwacke, L. H., Smith, C. R., Townsend, F. I., Wells, R. S., Hart, L. B., Balmer, B. C., Collier, T.
899 K., De Guise, S., Fry, M. M., Guillette Jr, L. J., Lamb, S.V., Lane, S. M., McFee, W. E., Place, N. J.,
900 Tumlin, M. C., Ylitalo, G. M., Zolman, E. S., & Rowleset, T. K. (2014). Health of common
901 bottlenose dolphins (*Tursiops truncatus*) in Barataria Bay, Louisiana, following the *Deepwater*
902 *Horizon* oil spill. *Environ. Sci. Technol.* 48:1, 93-103. doi:10.1021/es403610f

903 Schwacke, L. H., Voit, E. O., Hansen, L. J., Wells, R. S., Mitchum, G. B., Hohn, A. A., & Fair, P. A.
904 (2002). Probabilistic risk assessment of reproductive effects of polychlorinated biphenyls on
905 bottlenose dolphins (*Tursiops truncatus*) from the Southeast United States Coast. *Environ. Toxicol.*
906 *Chem.* 21:12, 2752–2764. doi:10.1002/etc.5620211232

907 Scott, M. D., Wells, R. S., & Irvine, A. B. (1990). A Long-Term Study of Bottlenose Dolphins on the
908 West Coast of Florida. *In The bottlenose dolphin*, Leatherwood, S. & Reeves, R. (Ed.). San Diego,
909 USA: Academic Press, 235–244.

Seber, G. A. F. (1965). A note on the multiple – recapture census. *Biometrika*. 52:1/2, 249–259. doi:10.2307/2333827

Silva, M. A., Magalhães, S., Prieto, R., Santos, R. S., & Hammond, P. S. (2009a). Estimating survival and abundance in a bottlenose dolphin population taking into account transience and temporary emigration. *Mar. Ecol. Prog. Ser.* 392, 263-276. doi:10.3354/meps08233

Silva, M. A., Prieto, R., Magalhães, S., Seabra, M. I., Santos, R. S., & Hammond, P. S. (2009b). Ranging patterns of bottlenose dolphins living in oceanic waters: implications for population structure. *Mar. Biol.* 156:2, 179-192. doi:10.1007/s00227-008-1075-z

Taylor, M. F. J., Suckling, K. F., & Rachlinski, J. J. (2005). The effectiveness of the Endangered Species Act: a quantitative analysis. *BioScience*. 55:4, 360–367. doi:10.1641/0006-3568(2005)055[0360:TEOTES]2.0.CO;2

Torres, L. G. & Read, A. J. (2009). Where to catch a fish? the influence of foraging tactics on the ecology of bottlenose dolphins (*Tursiops truncatus*) in Florida Bay, Florida. *Mar. Mamm. Sci.* 25:4, 797–815. doi:10.1111/j.1748-7692.2009.00297.x

Tregenza, N. J. C. (1992). Fifty years of cetacean sightings from the Cornish coast, SW England. *Biol. Conserv.* 59:1, 65–70. doi:10.1016/0006-3207(92)90714-X

Trew, B. T., Grantham, H. S., Barrientos, C., Collins, T., Doherty. P. D., Formia, A., Godley, B. J., Maxwell, S. M., Parnell, R. J., Pikesley, S. K., Tilley, D., Witt, M. J., & Metcalfe, K. (2019). Using Cumulative Impact Mapping to Prioritize Marine Conservation Efforts in Equatorial Guinea. *Front. Mar. Sci.* 6, 717. doi:10.3389/fmars.2019.00717

Tulloch, V. J., Tulloch, A. I., Visconti, P., Halpern, B. S., Watson, J. E., Evans, M. C., Auerbach, N., Barnes, M., Beger, M., Chades, I., Giakoumi, S., McDonald-Madden, E., Murray, N., Ringma, J., & Possingham, H. (2015). Why do we map threats? linking threat mapping with actions to make better conservation decisions. *Front. Ecol. Environ.* 13:2, 91–99. doi:10.1890/140022

Uncles, R. J. & Stephens, J. A. (2007). SEA 8 Technical Report – Hydrography. *UK Department of Trade and Industry's offshore energy Strategic Environmental Assessment programme*.

Votier, S. C., Hatchwell, B. J., Beckerman, A., McCleery, R. H., Hunter, F. M., Pellatt, J., Trinder, M., & Birkhead, T. R. (2005). Oil pollution and climate have wide-scale impacts on seabird demographics. *Ecol. Lett.* 8:11, 1157–1164. doi:10.1111/j.1461-0248.2005.00818.x

Wells, R. S. & Scott, M. D. 1990. “Estimating bottlenose dolphin population parameters from individual identification and capture-release techniques*.”, in*: *Individual recognition of cetaceans: use of photo-identification and other techniques to estimate population parameters. Incorporating the Proceedings of the symposium and workshop on individual recognition and the estimation of cetacean population parameters,* Hammond, P. S., Mizroch, S. A., & Donovan, G. P. (Ed.). Cambridge, UK: Report of the International Whaling Commission, Special Issue (12), 407-415.

White, G. C. & Burnham, K. P. (1999). Program MARK: survival estimation from populations of marked animals. *Bird Study*. 46:Supplement, 120–138. doi:10.1080/00063659909477239

White, T. D., Carlisle, A. B., Kroodsma, D. A., Block, B. A., Casagrandi, R., De Leo, G. A., Gatto, M., Micheli, F., & McCauley, D. J. (2017). Assessing the effectiveness of a large marine protected area for reef shark conservation. *Biol. Conserv. 207*, 64–71. doi:10.1016/j.biocon.2017.01.009

Whitehead, H. (2008). *Analyzing animal societies: quantitative methods for vertebrate social analysis*. Chicago, USA and London, UK: University of Chicago Press.

Whitehead, H. (2009a). Programs for analyzing social structure. SOCPROG 2.9 (for MATLAB 9.5.0, release 2018b). Available from http://whitelab.biology.dal.ca/SOCPROG/social.htm, [assessed 15-02-2020].

Whitehead, H. (2009b). SOCPROG programs: Analysing animal social structures. *Behav. Ecol. Sociobiol. 63:*5, 765–778. doi:10.1007/s00265-008-0697-y

Whitehead, H. & Dufault, S. (1999). Techniques for Analyzing Vertebrate Social Structure Using Identified Individuals: Review and Recommendations. *Adv. Study Behav.* 28, 33-74.

Williams, A. D., Williams, R., Heimlich-Boran., J. R., Evans, P. G. H., Tregenza, N. J. C., Ridoux, V., Liret, C., & Savage, S. (1997). A preliminary report on an investigation into bottlenose dolphins (*Tursiops truncatus*) of the English Channel: a collaborative approach. *European Research on Cetaceans*, 10, 217-220.

Wilson, B. (2016). Might marine protected areas for mobile megafauna suit their proponents more than the animals*? Aquat. Conserv.: Mar. Freshw. Ecosyst.* 26:1, 3–8. doi:10.1002/aqc.2619

Wilson, B., Hammond, P. S., & Thompson, P.M. (1999). Estimating size and assessing trends in a coastal bottlenose dolphin population. *Ecol. Appl.* 9:1, 288-300. doi:10.1890/1051-0761(1999)009[0288:ESAATI]2.0.CO;2

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. *Anim. Conserv.* 7:4, 331–338. doi:10.1017/S1367943004001581

Wilson, B., Thompson, P. M., & Hammond, P. S. (1997). Habitat use by bottlenose dolphins: seasonal distribution and stratified movement patterns in the Moray Firth, Scotland. *J. Appl. Ecol.* 34:6, 1365-1374. doi:10.2307/2405254

Wood, C. J. (1998). Movement of bottlenose dolphins around the south-west coast of Britain. *J. Zool.* 246:2, 155–163. doi:10.1111/j.1469-7998.1998.tb00144.x

Würsig, B. & Würsig, M. (1977). The Photographic Determination of Group Size, Composition, and Stability of Coastal Porpoises (*Tursiops truncatus*). *Science*. 198:4318, 755-756. doi:10.1126/science.198.4318.755

Supplementary Tables, Figures & Information

Supplementary Table (S1) – Multi-site contingency table depicting the number of permanently marked (M1) individuals identified within each study site in 2018. Y indicates the presence of the individual in the study site and N the absence.

Site 1	Site 2	Site 3	Number of M1 Individuals
Y	Y	Y	2
Y	Y	N	3
N	Y	N	0
Y	N	N	11
N	Y	Y	0
Y	N	Y	2
N	N	Y	0
N	N	N	N/A

Supplementary Table (S2) – Quality grade of photos used in 2018 abundance estimate.

Grade	Proportion (%)
1	20.87
2	26.96
3	20.87
4	31.30

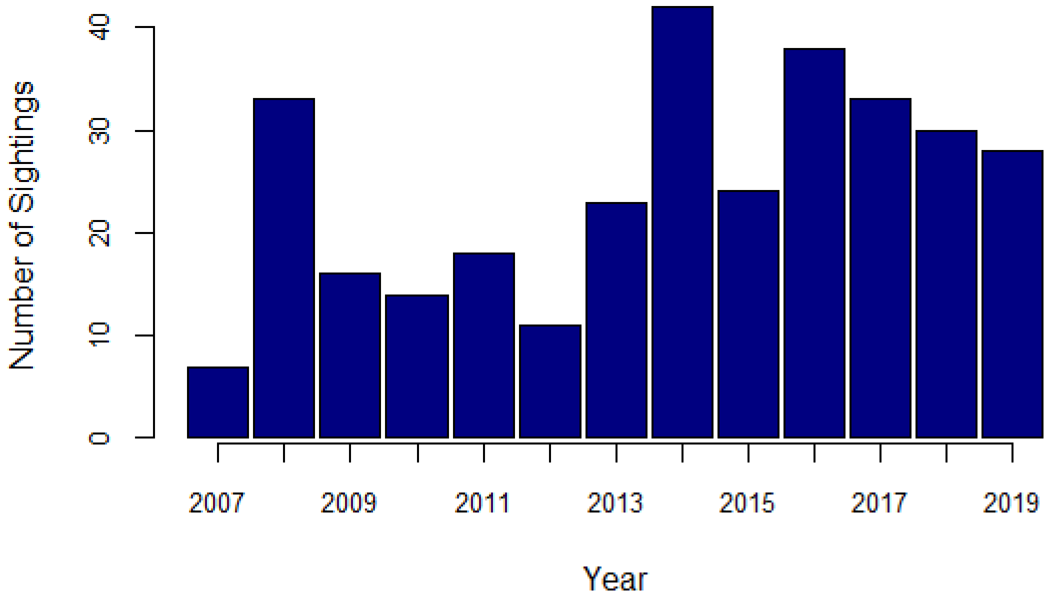
Supplementary Table (S3) – Metric to determine vulnerability weightings for anthropogenic activity impact scores, derived from Maxwell *et al*., 2013.

Vulnerability Measure	Category	Grade	Description
Impact Frequency	Never	0	
	Rare	1	Infrequent enough to affect population or long-term population (e.g. oil spill)
	Occasional	2	Frequent but Irregular
	Annual or regular	3	Common/Seasonal
	Persistent	4	Frequently constant year-round, may last multiple years
Does it impact the individual directly?	No impact	0	
	Distant indirect impact	1	Effects are one degree removed (e.g. habitat degradation, impacts prey species)
	Indirect impact	2	Causes effect due to indirect connection (e.g. effects of heavy metals which don't cause death directly)
	Direct impact	3	Mortality
Chance of Mortality	No impact	0	
	Low	1	Mortality unlikely (0-33%)
	Medium	2	Mortality moderate likelihood (34-66%)
	High	3	High chance of mortality (67-100%)
Impact Recovery Time (years)	No impact	0	
	<1	1	
	1-10	2	
	10-100	3	
	>100	4	
Reproductive Impact	No impact	0	
	Low	1	Can alter some aspect (behaviour) but not reproductive capacity
	Moderate	2	Reproductive capacity decreased
	High	3	Direct mortality
Effect on Population	No impact	0	
	Low	1	Impacts one individual
	Moderate	2	Impacts large of specific section of population (e.g. sex specific)
	High	3	Impacts the whole population

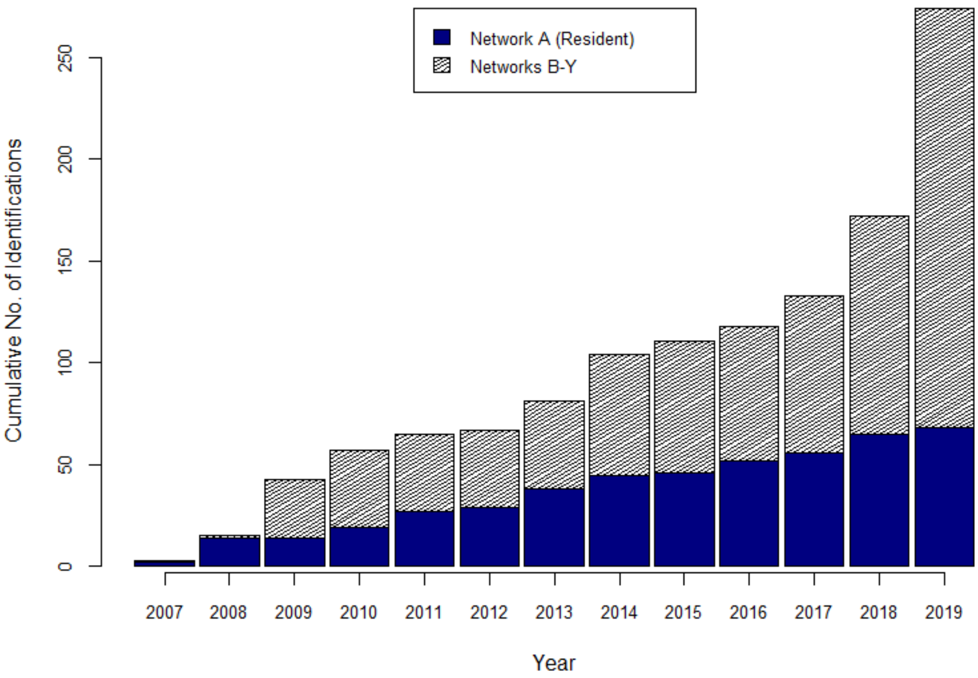
Supplementary Table (S4) – Individual vulnerability scores for all 16 anthropogenic activities grouped into 3 different categories: fishing, pollution, and shipping activity.

Vulnerability Measure	Fishing	Shipping	Pollution
Impact Frequency	4	4	4
Impact on Individual	1	3	2
Change of Mortality	1	2	2
Impact Recovery Time	1	2	2
Reproductive Impact	1	3	2
Effect on Population	3	1	3
Total	11	15	15

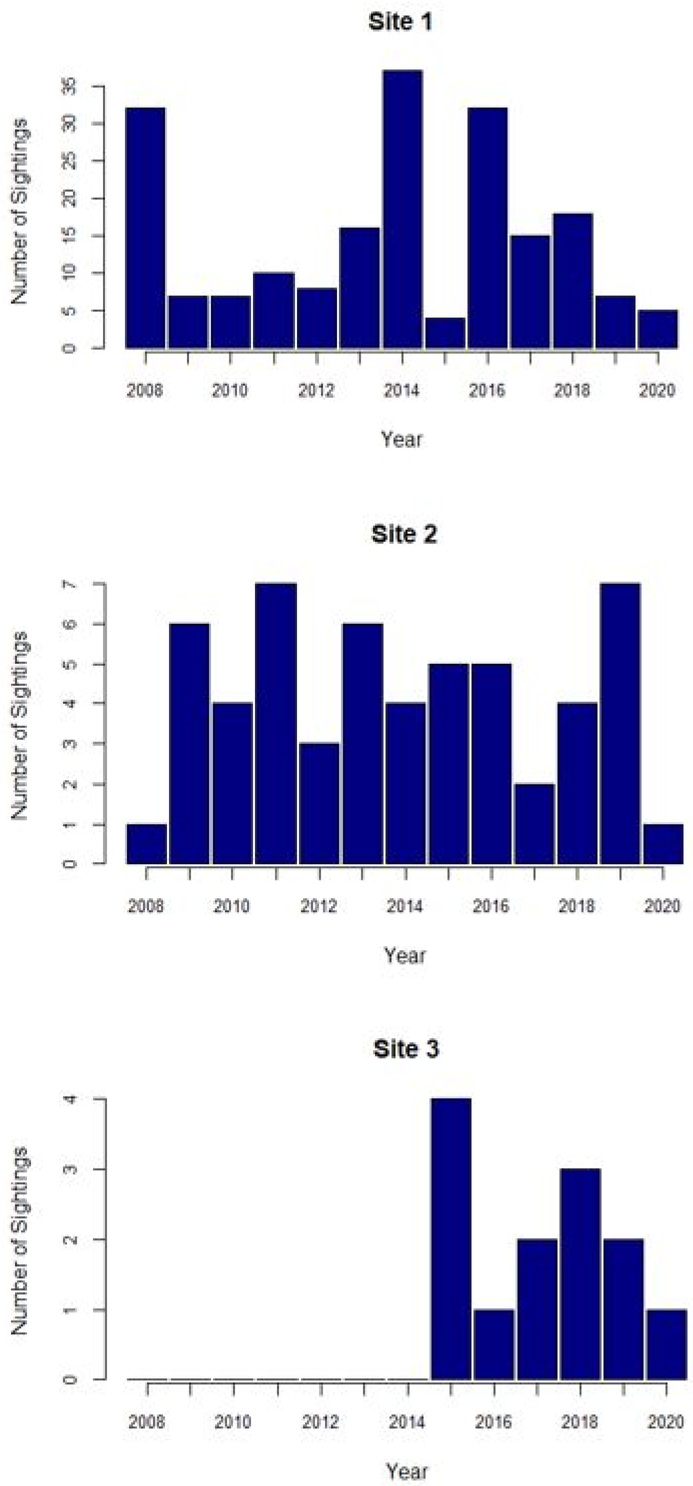
Supplementary Figure (S5) – Bar plot depicting photographic effort from years 2007-2019



Supplementary Figure (S6) – Bar plot depicting cumulative individuals identified from 2007-2019, Network A the resident population discovered through the social analysis is shown in blue, transient Networks B-Y are shown in grey.



Supplementary Figure (S7) – Bar plots depicting sightings of Network A between geographic sites from 2008-2020.



Supplementary Information Section 2.7.1

To assess the impact of anthropogenic pressures on dolphins using coastal waters the entirety of suitable habitat needed to be identified. To reduce effort bias within the sighting data, relative habitat suitability was modeled through maximum entropy techniques using presence-only species distribution models in the program MaxEnt 3.4.0 (Phillips et al., 2020). This method uses a fitted cloglog link function which connects background environmental data and occurrence records to predict both the probability of a species distribution across geographical space and the most influential environmental driver(s) (Phillips et al., 2006; Elith et al., 2011).

To ensure correlated environmental variables did not confound model results pair-wise Pearson's correlations were conducted. Those found to be significant (> 0.70) were removed from further analysis. All bottlenose dolphin sightings from 2000-2019 in regions less than 61m deep were used to test and train the model. Environmental variables including averaged water depth, distance from shore, slope and longitude were obtained from GEBCO (GEBCO Compilation Group, 2020), whilst salinity data was obtained from EMODNET (EMODNET, 2020). Due to the presence-only nature of this data a bias file was incorporated to account for sampling bias. The bias file is a grid layer which cell values indicate sampling effort, giving weight to random background data. Essentially, the bias file is a sampling probability surface obtained by a Gaussian kernel density map of occurrence locations using the kde2d function from the MASS package in RStudio.

To tune the model, R studio was interfaced with Maxent through the dismo package using the 'randomkfold' method with 10,000 background points from the bias file and 10 cross validation folds. To obtain the optimum values for the beta regularization multiplier (βM) and permitted features, models were ran testing 6 arrays of permitted features: (linear), (linear, quadratic), (hinge), (linear, quadratic, hinge), (linear, quadratic, hinge, product) and (linear, quadratic, hinge, product, threshold). Each array ran with 10 βM values ranging from 0.5 to 5, from there the final model was selected from 60 models of various settings. Model hyperparameters were selected through the lowest delta AICc score and were as follows: linear features, 0.5 βM.

Jackknife analysis was used to acquire estimates of variable significance, this was conducted by investigating the contribution (gain) of each variable to the model independently and in a stepwise backwards selection. The model's discriminatory power was assessed via the area under the receiver operating characteristic curve (AUC), with values closer to 1 indicating an accurate fit (Phillips et al., 2006; McClellan et al., 2014).

Raw data is unable to be provided to third parties under the data sharing agreement in place by the South West Bottlenose Dolphin Consortium, please see following documentation for details.

Supplementary Document D1 – South West Bottlenose Dolphin Consortium Terms of Reference and Data Sharing Agreement

Part 1 - Terms of Reference

Bottlenose dolphins in the coastal waters of SW England are under threat and likely in decline. Despite this, these animals have no specific protected area or special protection measures other than via general statutory protection of wildlife and cetaceans in UK waters. In order to ensure the best protection for these vulnerable animals we need to present the best scientific evidence to support and promote conservation action.

What is the SW Bottlenose Dolphin Consortium?

The consortium is a partnership of various stakeholders throughout the southwest of England sharing a common interest in developing understanding and conservation of the region's bottlenose dolphins. The consortium aims to develop an open and collaborative agreement between various private and public contributors who may own and/or collect photos or sightings information which may make a useful contribution to a larger shared data set for evidence gathering and scientific analysis.

All partners within the consortium will be joint and equal, representing individuals and organisations working collaboratively to provide data to enable better scientific assessment of the SW bottlenose dolphin population. All outputs will be to meet the agreed objectives of the consortium and not for the individual needs of partners' own respective organisations.

The actions and use of data shared with the consortium are agreed and managed by a consortium Steering Group. This Steering Group will meet regularly to coordinate the progress and strategy of the consortium and is currently chaired by Cornwall Wildlife Trust, as independent co-ordinator for the project.

Is my data relevant or useful?

Any data on SW bottlenose dolphins is useful and relevant. It is clear that we need to capture all available data to make the best assessment of the status of these animals to promote their conservation. Concentrated volumes of high quality data are vital for estimating abundance but the number of such data sets is limited. Incidental records, photos and sightings data are also important for exploring distribution, occupancy and ranging behaviour. Historic data that may have been collected several (or many) years ago are also useful for reconstructing the status of this 'population' through time to fill the gaps between dedicated survey effort.

Any and all data is therefore useful to this work. All contributed data will only be used for non- commercial conservation use, and should include information on what, where, when and who recorded it.

Suggestions of current and historic data that would be useful would include:

- Ad-hoc / incidental sightings
- Time and location referenced photos suitable for fin identification
- Land based effort related sightings data
- Boat based effort related sightings data

How will my data be used and will I be acknowledged?

Wherever possible your data will be used in scientific analysis of the abundance, distribution, range and occupancy of the coastal waters of SW by bottlenose dolphins. The level of integration of your data will be dependent on their quality and quantity and your contribution will be acknowledged accordingly in all analyses and outputs. Significant contributors to this collaboration may also be included as a co-author in any relevant outputs.

Data shared to the project will only be used for work led by the consortium steering group, will not be passed to any third parties outside the consortium and will not be used for any analyses outside those agreed by the Steering Group, without prior consent of contributors. Any copies of the datasets will be stored securely and access restricted to permitted individuals, administered by the Steering Group.

What about intellectual property?

By agreeing to this Terms of Reference your data will be made available for inclusion in data presentation and analysis according to the strategy agreed by the Steering Group.

There are two options for data contributors:

1) a blanket agreement for the inclusion of your data for all analysis and for use at the discretion of the consortium

2) specific agreement for the inclusion of your data on a case by case basis.

Contributors will retain the intellectual property of their data and information supplied, and are free to withdraw their input and data at any future time. If you hold data supplied to you by third parties you should secure permission for their data to be included in this data sharing agreement.

How do I become a contributor?

To become a contributor to the consortium simply fill out the attached form and email or post this to the address given. On receipt of your form you will be contacted regarding transfer of your data and included in a list of contributors.

Part 2 - Data sharing agreement form

1. Personal details

Title	
Surname	
First name	
Affiliation (company/organisation)	
Address	
Postcode	
Contact email	
Contact telephone	

2. Data type:

I have the following data (please select)

- Ad-hoc / incidental sightings ☐
- Time and location referenced photos ☐
- Land based effort related sightings data ☐
- Boat based effort related sightings data ☐

3. Detail of data to be shared:

Data Description (eg: historic sightings, year range, format, etc.)

4. Data sharing status (please select one):

a) I agree for my data to be included and used for non-commercial conservation purposes without further specific consent. ☐

b) I would like my data to be included and used for non-commercial conservation purposes dependent on case by case consent. ☐

To be signed by Data contributor:

I agree to supply the data as specified for the SW Bottlenose Dolphin Consortium. Signed: ………………………………………………..

Date: …………………

Name: …………………………………..

Position: ………………..………………

To be signed by SW Bottlenose Dolphin Consortium:

I agree that the information supplied by the above named data provider will not be put to any other use than that stated in the agreed Terms of Reference above, nor communicated to any third party without prior consent.

Signed: ……………………………………………….. Date: ……………………

Name: ……..………………………………..

Position: …..…………………..…………

Please return this form to:

Nicola Clear, ERCCIS Data Officer

Email: Niki.Clear@cornwallwildlifetrust.org.uk

Cornwall Wildlife Trust

Address: Environmental Records Centre for Cornwall and the Isles of Scilly, Five Acres, Allet, Truro, Cornwall TR4 9DJ

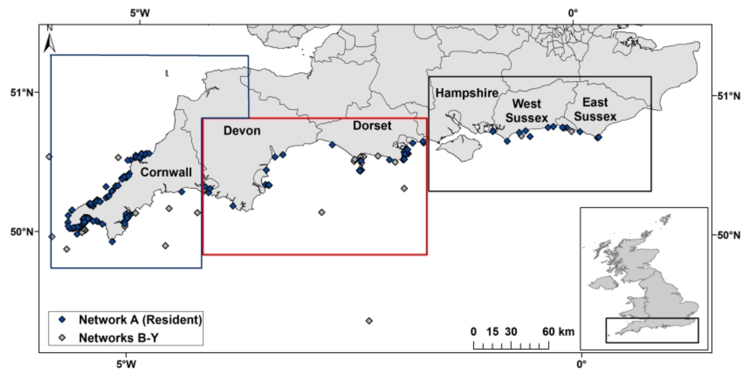


Figure 1 - Map of study area with areas of interest indicated (Projection: GCS_WGS_1984). The study area is segregated into three discrete regions: Site 1 (North Devon and Cornwall) in blue, Site 2 (South Devon and Dorset) in red and Site 3 (Hampshire and Sussex) in black. Blue diamonds represent photo verified encounters of network A (the resident population) and other networks B-Y in grey.

400x209mm (600 x 600 DPI)

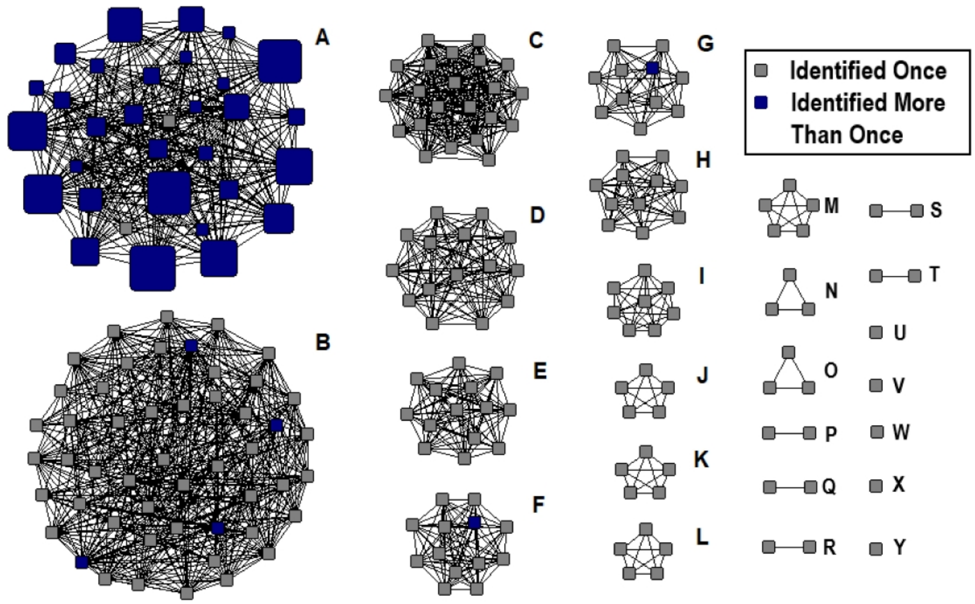


Figure 2 - Sociogram displaying the social network analysis of all permanently marked individuals encountered between 2008-2019. 25 clusters were identified (A-Y). Square nodes represent individuals, the size of which correspond to the frequency of sightings (range 1-87). Grey squares depict individuals seen only once and blue squares individuals seen on multiple occasions, with the black lines representing associations between individuals.

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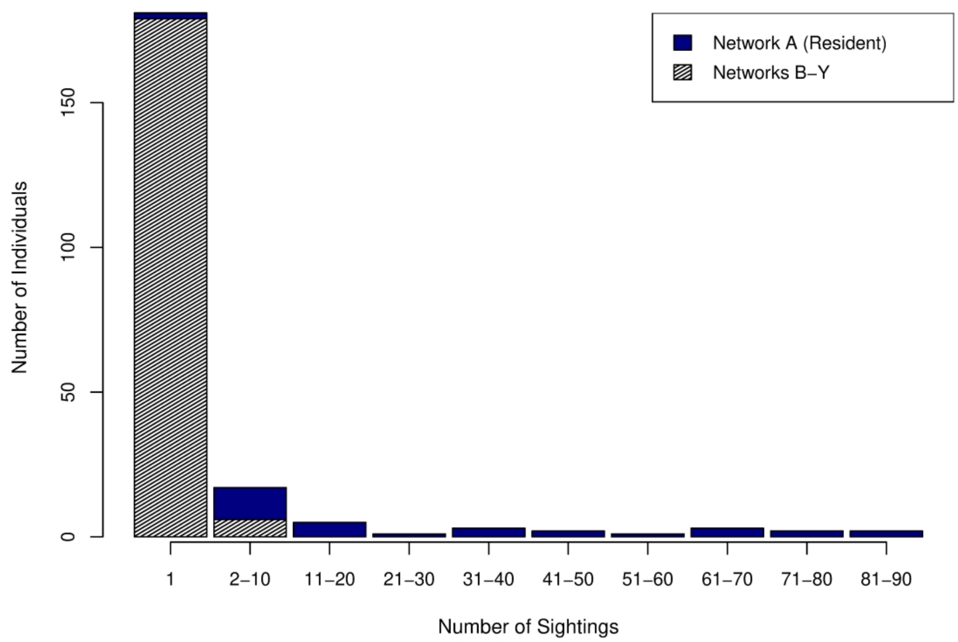

Figure 2b - Bar graph depicting the number of sightings of individuals with members of network A in blue and other networks in grey.

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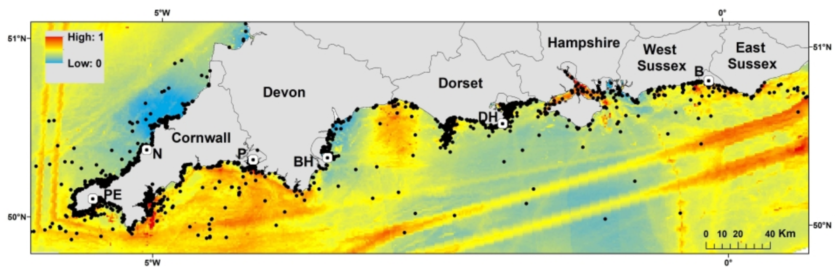

Figure 3A - Cumulative impact distribution (anthropogenic activity weighted by vulnerability) depicting areas of threat hotspots, scaled between 1 (highest cumulative impact distribution) and 0 (lowest). Locations of interested are noted with initials, N = Newquay, PE = Penzance, P = Plymouth, BH = Berry Head, DH = Durlston Head and B = Brighton

499x210mm (600 x 600 DPI)

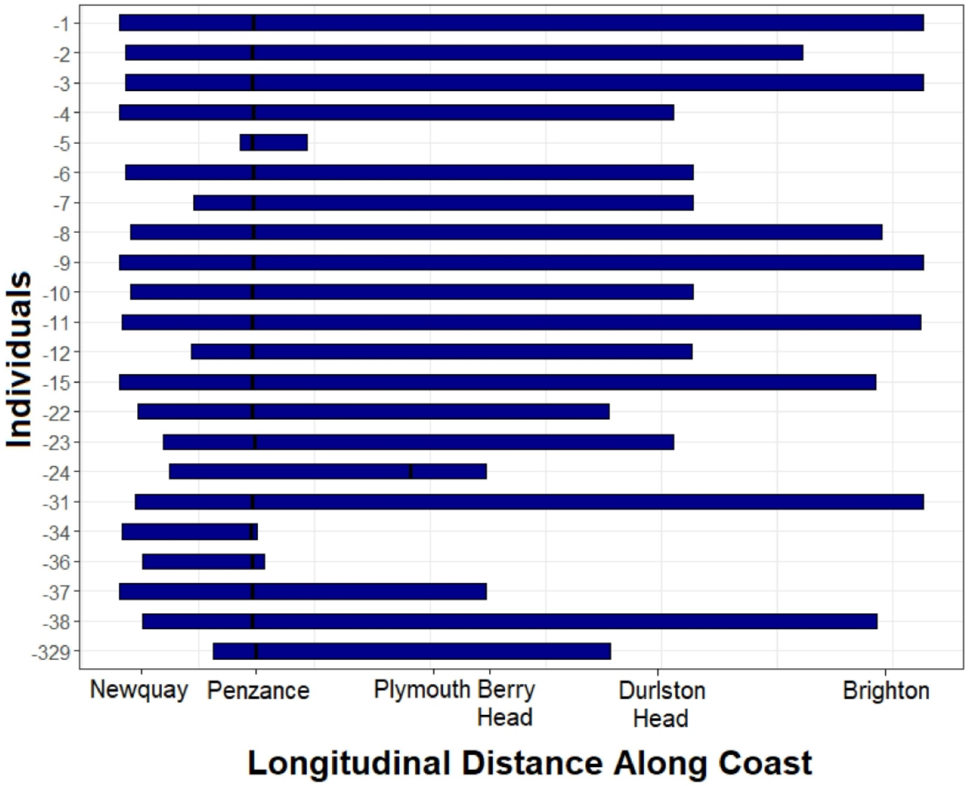

Figure 3B - Range (longitudinal distance) of permanently marked individuals from network A from North Cornwall to East Sussex

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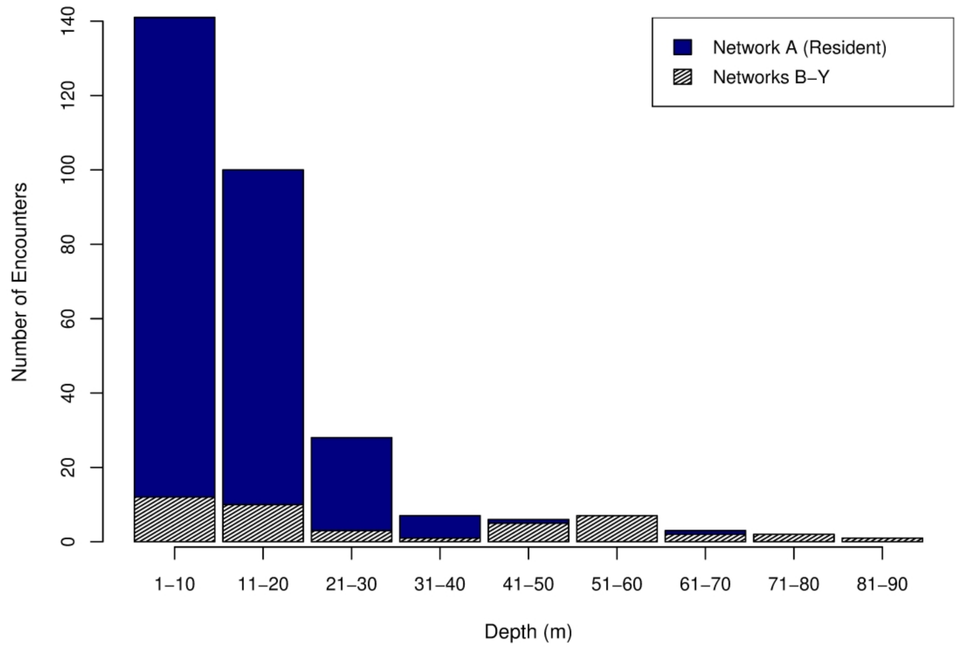

Figure 3C - Depth (m) of encounters of network A (blue) and networks B-Y (diagonal black).

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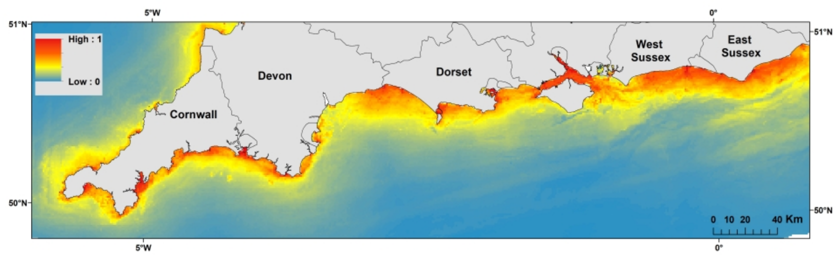

Figure 4 - Cumulative utilisation impact distributions (cumulative impact scores combined with relative habitat suitability) of coastal bottlenose dolphins in the region, scaled between 1 (highest) and 0 (lowest).

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