Influence of tide and marine vessel activity on harbour porpoises (*Phocoena phocoena*) in Torbay, SW England.

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Abstract

The harbour porpoise (*Phocoena phocoena*) is a widely distributed species and is the most commonly sighted cetacean in the UK (Camphuysen and Siemensma, 2015; Evans et al., 2013). Despite this, harbour porpoises are influenced by a variety of anthropogenic factors including fisheries bycatch, noise pollution and marine vessel traffic (Bas et al, 2017; Oakley et al, 2017; Bjørge et al, 2013; Dawson et al, 1997). Understanding how these pressures affect this species is paramount to their protection. During a 5-month period, data was collected on harbour porpoise presence and behaviour, environmental factors and marine vessel traffic using standard visual surveys. The research was carried out at 4 sites located within the Torbay Marine Conservation Zone (Berry Head, Sharkham Point, Thatcher's Point and Hopes Nose, SW England). A total of 124 land-based observations were completed with 14 hours spent at each study location. Two of the four study sites (Thatcher's Point and Hopes Nose) resulted in zero porpoise sightings despite 28 hours of survey effort, therefore research at these sites was discontinued. Feeding was the most common behaviour recorded at both sites (Berry Head 88.9% and Sharkham Point 95%) and significantly more porpoises and occurrences of feeding behaviour were recorded during ebb and low-slack (χ^2 = 26.8, p<0.001 and χ^2 = 28, p<0.001 respectively). No statistical significance was found between marine vessel traffic and porpoise presence and behaviour (χ^2(N = 28) = 1.40 p = 0.236). Berry Head appears to serve as an important feeding ground for harbour porpoises in the Torbay area and also acts as a passing place for a high volume of marine vessels, both commercial and recreational. Although there was no statistical significance found between marine traffic and porpoise presence and behaviour during the current study, previous research has shown results to the contrary (Roberts et al., in review) indicating that this population may require further protection. Further research must be implemented on specific variables such as water salinity, tidal flow, porpoise prey species, distribution of porpoises and porpoise population numbers to understand this population of porpoises in greater detail and to add further value to the argument that harbour porpoises in the Torbay area require further protection.

1.0. Introduction

The harbour porpoise (*Phocoena phocoena*) is a widely distributed species in cold temperate to sub-arctic waters of the Northern-Hemisphere and are found in both the Atlantic and Pacific Oceans (Camphuysen and Siemensma, 2015). In UK waters, harbour porpoises are the smallest and most frequently sighted cetacean (Evans et al., 2013), and like many other cetacean species, are affected by an array of anthropogenic factors including bycatch in fishing nets, noise pollution, and marine vessel traffic (Bas et al, 2017; Oakley et al, 2017; Bjørge et al, 2013; Dawson et al, 1997). Marine mammals are often used as sentinel species when monitoring aquatic ecosystems as they are usually positioned at the top of the food chain, are relatively long-lived and are highly mobile species (Ijsseldijk et al., 2018). The overall health status of a sentinel species can reflect the health of the ecosystem they reside within, making them of great value to scientific research (Ijsseldijk et al., 2018).

In 2016, DEFRA submitted an annual report created by the Sea Mammal Research Unit/Scottish Oceans Institute and the Centre for Research into Ecological and Environmental Modelling. This report stated that a total of 10 harbour porpoises, 2 common dolphins (*Tursiops truncatus)* and 2 long-finned pilot whales (*Globicephala melas*) were observed as bycaught in static-net fishing gear during dedicated sampling periods (Northbridge et al., 2016). Various other species were also recorded including 7 grey seals (*Halichoerus grypus*), 69 seabirds, 48 blue sharks (*Prionace glauca*) and 22 porbeagle sharks (*Lamna nasus*) (Northbridge et al., 2016). A similar result was recorded in 2015 with another 10 harbour porpoises, 1 common dolphin and 1 white-beaked dolphin (*Lagenorhynchus albirostris*) caught in static net gear (Northbridge et al., 2015). Additionally, between 1,137 and 1,472 harbour porpoises were estimated to be bycaught in setnets in the Celtic and Irish seas during the period of 2006-2013 by ICES (2015). These figures may represent only a fraction of the true bycatch rate of harbour porpoises and similar species and highlight how harbour porpoises, and many other important marine species, are suffering as a result of commercial fishing practices.

The study of the impacts on cetaceans by marine vessel abundance and frequency is growing, with the clear majority providing evidence that cetaceans react poorly to this pressure. In the first study of the harbour porpoises of Berry Head (Brixham), Roberts et al. (in review) found a moderate correlation between vessel frequency and harbour porpoise presence and behaviour; as marine vessel frequency increased, harbour porpoise presence and feeding behaviour decreased. Reactions of harbour porpoises to marine vessels have also been studied in the

Bristol Channel and the Istanbul Strait (Bas et al., 2017; Oakley et al., 2017). Results from these studies showed that harbour porpoises reacted negatively to marine vessel traffic presence, type of vessel and vessel speed. Additionally, feeding and resting behaviour have been found to reduce in Black Sea harbour porpoises (*P. phocoena relicta*) (Bas et al., 2017). Furthermore, habituation to vessels resulting in collisions with porpoises were noted by Oakley et al. (2017). It is evident from the current volume of research that harbour porpoises are important species to coastal ecosystems and are especially sensitive to the array of factors which threaten their survival.

Harbour porpoises are small in size therefore they can utilize habitat that other species cannot access, such as productive shelf seas and shallow near-shore waters where food is relatively abundant (Leopold, 2015). Harbour porpoises are considered elusive and shy in nature, therefore, understanding habitat selection can be a challenge (De Boer et al., 2014; Embling et al., 2010). Habitat suitability, predation risk, prey availability, and environmental features such as sea temperatures, salinity, and underwater topography are important in influencing consistent habitat use. (Toth et al., 2011). Harbour porpoises are most often found in inshore continental shelf waters and many species of cetacean, including porpoises, are commonly found close to islands and headlands where strong tidal currents play a dominant role (De Boer et al., 2014; Booth et al., 2013). Prey species abundance (schooling fish) is frequently related to mesoscale oceanographic features such as eddies and fronts, making prey presence and aggregations predictable to predators such as porpoises (Sveegaard et al., 2012b). Other factors such as bathymetry, depth and sediment type have been linked to prey species presence (Sveegaard et al., 2012b). Harbour porpoise depth preferences tend to be within deeper waters of their range, behaviour which is likely linked to the distribution of their prey (De Boer et al., 2014); distribution of harbour porpoise is often expected to follow the distribution of its main prey species (Sveegaard et al., 2012a).

Due to their small size, harbour porpoises are unable to carry large energy stores and therefore must feed continuously to maintain fitness, highlighting the importance of the species remaining close to available prey (Leopold, 2015; Sveegaard et al., 2012a; Johnston et al., 2005). Harbour porpoises have the largest surface to volume ratio per kg of body mass, making them susceptible to reduced energy storage and high relative heat loss with respect to metabolic rate (Leopold, 2015). To ensure harbour porpoises do not succumb to hypothermia or starvation, they must forage continuously (Wisniewska et al, 2016). It is important to avoid blubber loss as this multi-functional fatty tissue is responsible for performing thermoregulatory and structural roles, and lipid storage (Khudyakov et al. 2017). If harbour porpoises are disturbed by anthropogenic factors such as marine vessel traffic they may suffer poor fitness and may succumb to starvation and/or hypothermia.

The population of harbour porpoises that utilize the waters off Berry Head are most frequently sighted off the National Nature Reserve's (NNR) main headland. This population of harbour porpoises were found to spend >88% of their time feeding in the area and very little time resting (Roberts et al., in review). These results indicate that the waters off Berry Head provide an adequate food supply for the porpoises and they may be spending time elsewhere to rest and socialize. Furthermore, it could be possible that tidal currents in addition to topography, bathymetry and prey availability are the reason for the porpoise's regular presence at Berry Head, however only one study has been conducted focusing solely on this population of porpoises and focused mainly on anthropogenic impacts on porpoise presence and behaviour (Roberts et al., in review).

Harbour porpoises are protected from disturbance and endangerment under the Wildlife and Countryside Act 1981, the Conservation of Habitats and Species Regulations 2017, and have conservation status in the European Union (EU); listed in Annexes II and IV of the EU Habitats Directive (EU, 1992). In addition to protection by UK and EU legislation, marine species can be protected by Marine Protected Areas (MPA), including Marine Conservation Zones (MCZs). Currently in the UK there are 50 existing MPAs including the Torbay MCZ (TMCZ). In 2018 the Department of Environmental, Food and Rural Affairs (DEFRA) announced its ambition to create 41 more MCZs in the UK's surrounding waters (DEFRA, 2018). The TMCZ is an inshore site and was first established in 2013. The TMCZ focuses on maintaining the favourable conditions of sediments, mud, sand, rock, peat, clay, native oysters (*Ostrea edulis*), and to aid in the recovery of the long-snouted seahorse (*Hippocampus guttulatus*) and the sea grass they reside within (Natural England, 2016). Torbay is recognized as "the jewel in South Devon's crown" due to the high level of marine biodiversity in the surrounding waters, with the TMCZ itself providing many different habitats capable of supporting an array of marine wildlife (Natural England, 2016).

Berry Head, Sharkham Point, Thatcher's Point and Hope's Nose are headlands situated within the TMCZ and provide vantage points from which to observe cetaceans in the adjacent coastal waters. Previous research by the author has validated claims that there is a population of harbour porpoise that regularly utilize the TMCZ, specifically the coastal waters below the Berry Head National Nature Reserve in Brixham (Roberts et al., in review). The harbour porpoises that frequent this area have been seen during every month of the year and calves and juveniles have been recorded. Female harbour porpoises have a gestation period of 10-11 months, calves rely on their mother's milk for 10-11 months, and mothers provide up to 18 months of maternal care to their calves, especially during their first summer season (Camphuysen and Krop, 2011), indicating the importance of the study area to this population. Other cetaceans such as common dolphins have been sighted in the waters adjacent to Thatcher's Point and Hope's Nose, however it is unknown whether they are suitable for harbour porpoises, or if they have ever been recorded using the area.

The aim of this research was to explore whether harbour porpoises require further protection within the Torbay area, specifically areas within the TMCZ. The objectives were (1) to identify areas of the TMCZ utilized by harbour porpoises, (2) to determine the contribution of environmental factors including tidal state to the presence and behaviour of harbour porpoises in the TMCZ, (3) to assess the impact of maritime traffic on the presence and behaviour of harbour porpoises in the TMCZ, and (4) to identify whether the harbour porpoise is eligible to be included within the TMCZ framework as a priority species. This study serves to improve the knowledge of harbour porpoises utilizing the TMCZ. This study will also add to the body of knowledge regarding environmental factors influencing porpoise distribution, presence and behaviours and the impacts of marine traffic on cetacean presence and behaviour. In addition, this study may also provide further evidence as to why harbour porpoise should be included within the TMCZ as a priority species. At present mobile species such as porpoises are not eligible for inclusion within MCZs however, Non-Governmental Organizations (NGOs) have been working towards changing this to allow inclusion (Embling, *pers. comm*). Any evidence which highlights the importance of MCZs to mobile species (such as the harbour porpoise) would support the NGOs aim for the inclusion of such species.

2.0. Materials and Methods

2.1. *Study area*

The Torbay Marine Conservation Zone (TMCZ) (Figure 1) was designated in 2013 and covers an area of coastline between Oddicombe Beach and Sharkham Point in South West England. The TMCZ protects a total area of approximately 20km^2 and encompasses the coastal waters of the four study sites: Berry Head, Sharkham Point, Thatcher's Point and Hopes Nose.

Berry Head

Berry Head is a National Nature Reserve (NNR) located in Brixham and is governed by the Torbay Coast and Countryside Trust (TCCT). Berry Head has a high quality of biodiversity and is designated as a Site of Special Scientific Interest (SSSI). It is known for a population of harbour porpoise that utilize the waters below the main headland.

Sharkham Point

Sharkham Point is a rocky outcrop in Brixham and is governed by the TCCT. Sharkham Point is visible from Berry Head at approximately 2,218m distance.

Thatcher's Point

Thatcher's Point is a headland situated along the coast of Torquay and sits opposite Thatcher's Rock.

Hopes Nose

Hopes Nose is a significant coastal area recognized as a Site of Specific Scientific Interest (SSSI) in Torquay. It is managed by the Torbay Coast and Countryside Trust and has a distinct headland.

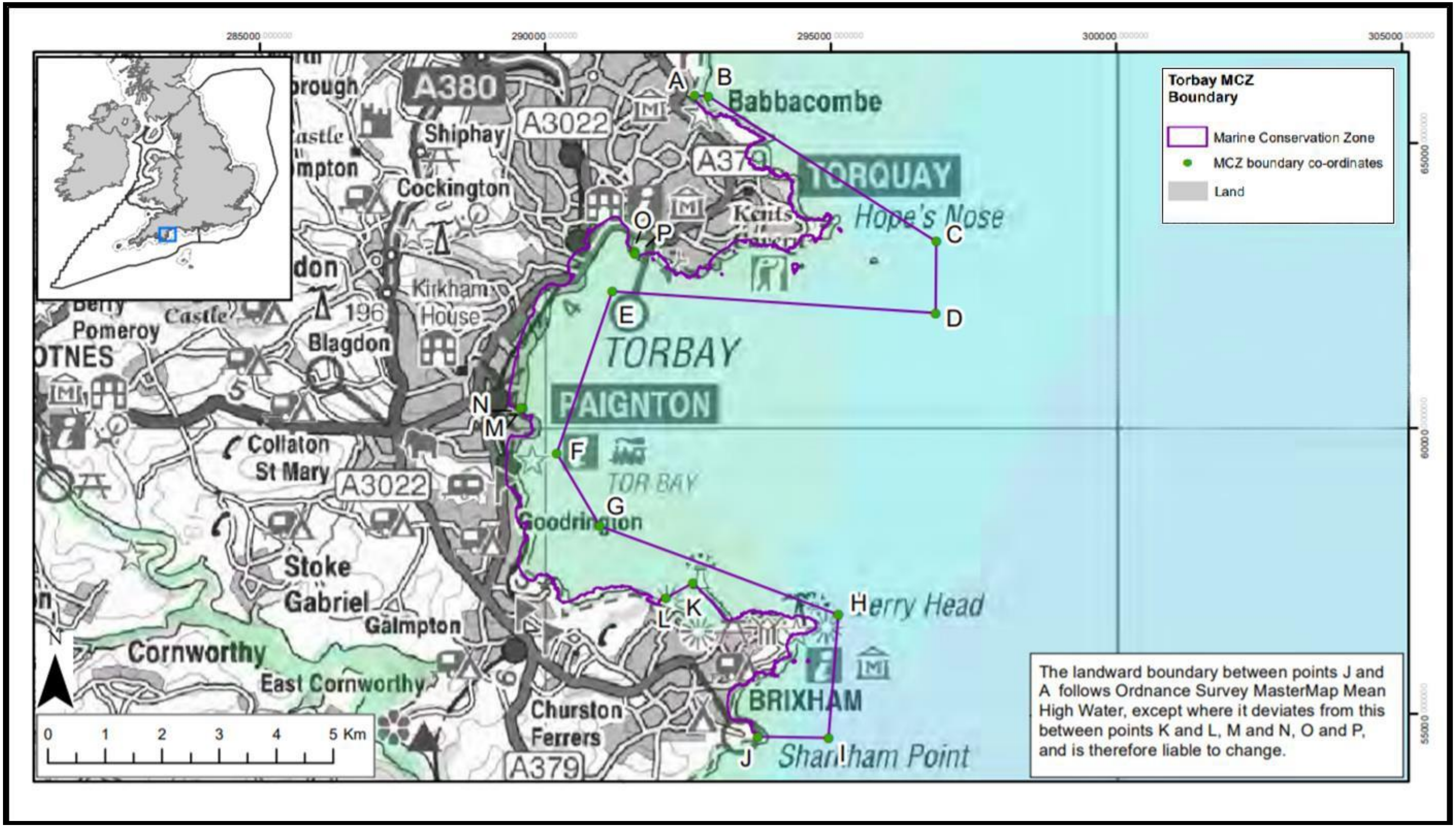

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Figure 1. Map of the Torbay Marine Conservation Zone. The purple line illustrates the boundary of the MCZ (Natural England, 2013).

2.2. *Data Collection*

Land-based observational surveys were performed using standard visual survey techniques (Oakley et al., 2017) to identify areas of coastal water used by harbour porpoises within the TMCZ, and to identify the impacts of marine traffic on their presence and behaviour. Data were collected using standard visual surveys by carrying out scan samples for durations of 15 minutes. During each 15-minute period, all occurrences of porpoise presence and frequency of behaviours were logged including presence of adults and young; each witnessed occurrence of behaviour was recorded as a tally point and minimum number of porpoises was estimated at the end of each watch. It was not possible to identify individuals. Additionally, environmental factors such as sea state, swell height and visibility (Appendix 1) were recorded as per Sea Watch Foundation (2012) and tidal states (flood, high slack, ebb, low slack) and tidal height were recorded for each watch to allow for a deeper analysis of how these factors influence harbour porpoise presence, behaviour and distribution within the TMCZ. All observations were conducted between July-November 2018 during daylight hours ensuring a wide range of time, activity periods, and tidal states were recorded. The 'between-observer reliability' method was used to avoid miscalculations during land-based efforts (Martin and Bateson, 2007). This is the measure of the agreement between different observers attempting to measure the same thing (Martin and Bateson, 2007). During a pre-data collection pilot session to test the chosen methodologies, two people collected data at the same time and compared their results to ensure they were both measuring/recording data in the same way. Observations were discontinued at Thatcher's Point and Hopes Nose in September 2018 as no positive porpoise sightings were recorded at either of these locations despite 28 hours survey effort.

The presence and behaviour of any harbour porpoises sighted during each 15 minutes watch was recorded on a survey form, adapted from the land-based effort form by the Sea Watch Foundation (2012, Appendix 2). Behaviours including travelling, feeding, resting, socializing and leap were identified and recorded (Appendix 3). Marine vessels were recorded at the beginning of each 15-minute watch. Factors included marine vessel type, moving (underlined) and non-moving vessels were logged on a map of the corresponding location and recorded for future use (Appendix 4).

Using SPSS software, a series of Kruskal-Wallis with post-hoc tests were performed to understand how tidal state (ebb, low slack, flood, high slack) influences harbour porpoise occurrences and feeding behaviour at Berry Head, to identify the location (Berry Head and Sharkham Point) porpoises were recorded at most frequently, to identify positive porpoise sightings at Berry Head during each month (July-November 2018), and to explain marine vessel frequency at Berry Head and Sharkham Point. Kruskal-Wallis tests were chosen over ANOVAs as data was not homogenous. A further Chi-square test for association was carried out to identify associations between porpoise presence/absence and marine vessel traffic presence/absence.

3.0. Results

General results

124 land-based observations took place over a five-month time-span (July to November 2018). 14 hours were spent at each study site with a total observation time of 56 hours across all four sites. A total of 175 occurrences of harbour porpoises were observed, with 3,284 behavioural-observations at Berry Head and Sharkham Point combined. There was a total frequency of 613 marine vessels across all four sites. The most common behaviour recorded at Berry Head was feeding (88.9%), followed by socializing (6%), travelling (3.6%), leap (1.4%), and resting (0.2%). At Sharkham Point, the most common behaviour recorded was feeding (95%), followed by travelling (3.1%), and leap (1.9%). Socializing and rest behaviours were not recorded at Sharkham Point. At Berry Head, 66% of porpoises were recorded on the South side of the headland and 34% on the North side. 93% of porpoises recorded at Berry Head were recorded within the allocated TMCZ.

Vessel impacts on porpoise occurrence

The most commonly sighted vessel at Berry Head, Sharkham Point and Hopes Nose were yachts (40.5%, 41.9% and 63.6% respectively), whereas kayaks were the most frequently sighted vessel at Thatcher's Point (31.84%) (Appendix 5, 6). Significantly more marine vessels were recorded at Berry Head, Thatcher's Point and Hopes Nose than Sharkham Point (Figure 2) There was no statistical difference in marine vessel frequencies between Berry Head or Thatcher's Point (p = 0.976). No significant association was found between porpoise presence or absence with marine vessel presence or absence (p = 0.236, χ^2 = 1.40, N = 28).

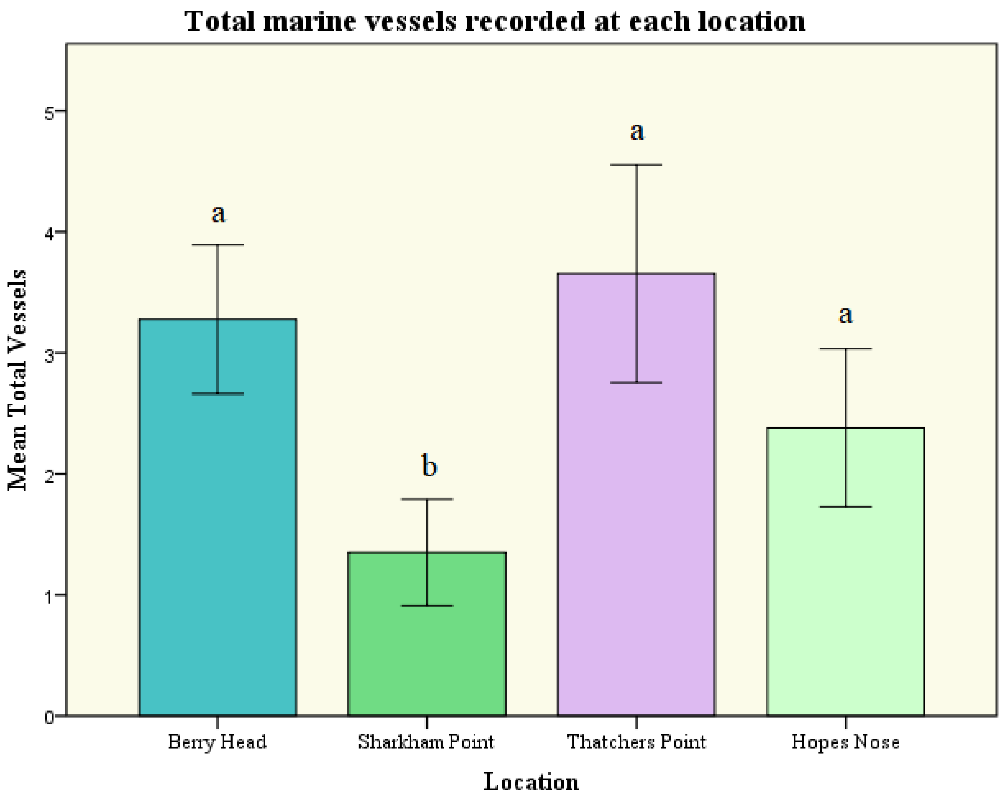

Figure 2. Total marine vessels recorded at each study location. Significantly more marine vessels were recorded at Berry Head, Thatcher's Point and Hopes Nose than at Sharkham Point as indicated by the labels (a is significantly different from b).

Environmental drivers of harbour porpoise presence and behaviour

Significantly more porpoises were observed during periods of ebb and low-slack than flood and high slack (χ^2 = 26.8, p<0.001) (Figure 3). Significantly more occurrences of feeding behaviour were recorded during periods of low-slack and ebb (χ^2 = 28, p<0.001) (Figure 4).

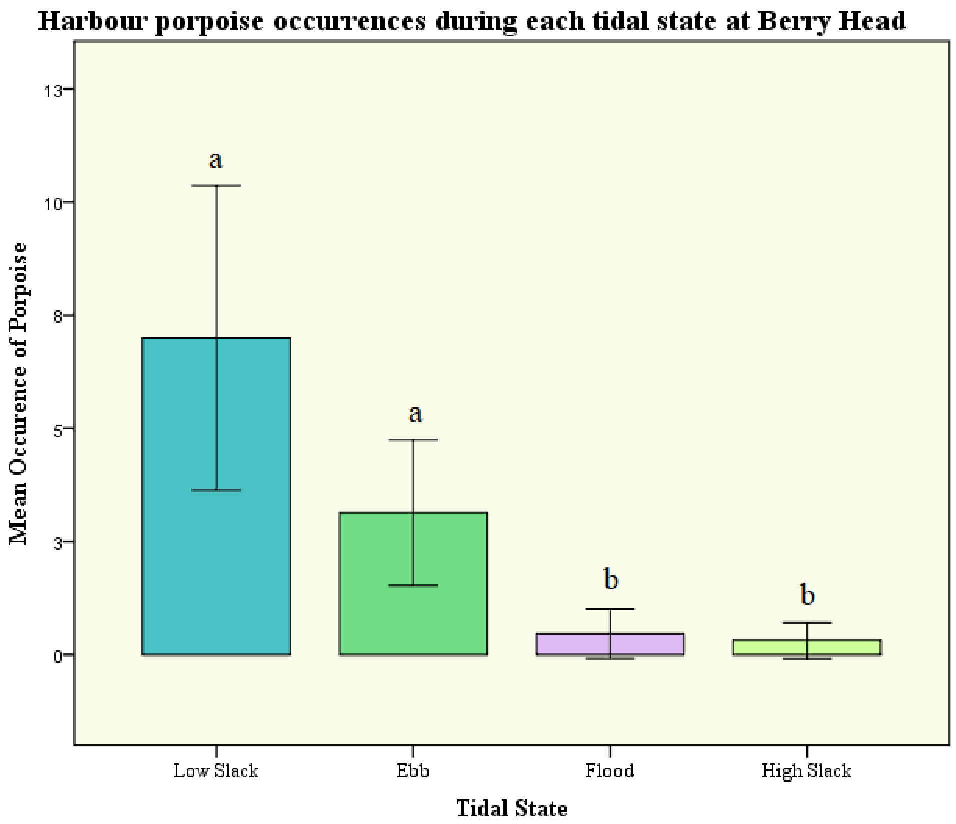

Figure 3. Mean occurrence of harbour porpoises during each tidal state at Berry Head; low slack (N =105), ebb (N = 47), flood (N = 7) and high slack (N = 5). Significantly more porpoises were recorded during low slack and ebb than flood and high slack as indicated by the labels (a is significantly different from b).

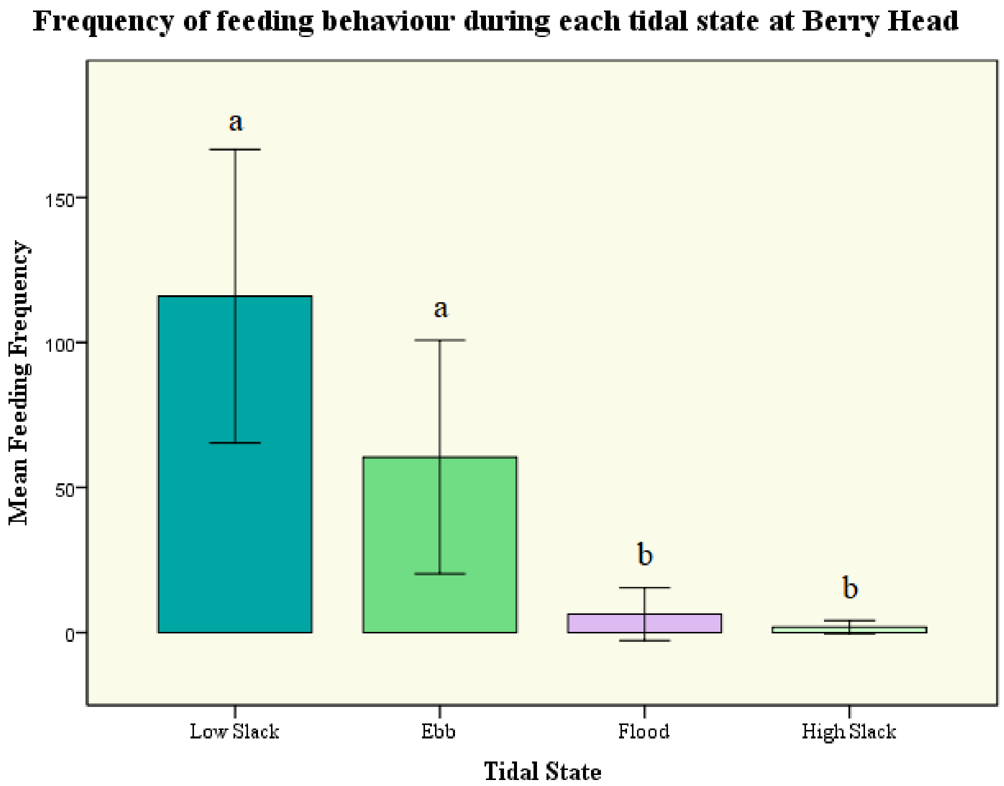

Figure 4. Mean frequency of feeding behaviour during each tidal state at Berry Head; low slack (N = 1740), ebb (N = 908), flood (N = 95) and high slack (N = 30). Significantly more occurrences of feeding behaviour were recorded during low slack and ebb than flood and high slack as indicated by the labels (a is significantly different from b).

A further Kruskal-Wallis test was conducted showing that significantly more porpoises were recorded at Berry Head (N = 164) than at Sharkham Point (N = 11; χ^2 *= 27.63, p<0.001).* As a result, the remaining analysis was only carried out on the porpoises at Berry Head. Occurrences of porpoises differed significantly according to month with more sightings recorded during August and October (Figure 5) compared to July, September and November; there were absolutely no porpoise sightings during September at Berry Head ($\chi^2 = 24.5$, $p<0.001$).

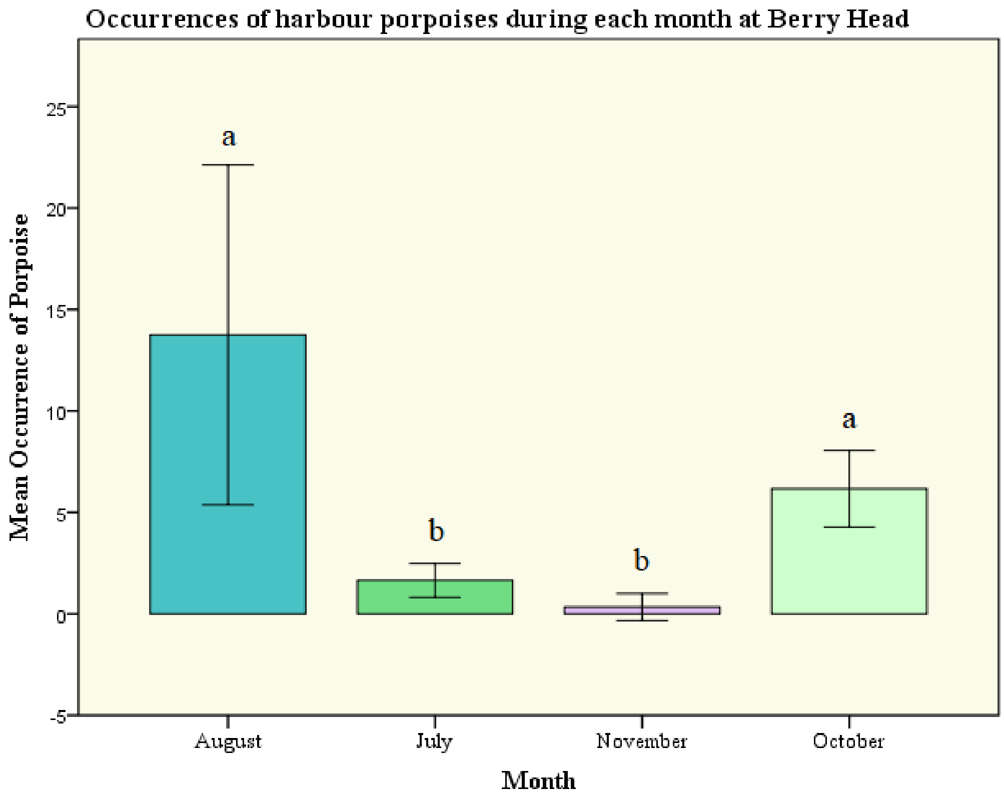

Figure 5. Mean occurrence of harbour porpoises during each month of data collection at Berry Head. Significantly more occurrences of porpoises were recorded in August and October than in July or November as indicated by the labels (a is significantly different to b). No sightings were recorded in September.

4.0. Discussion

The results of this study confirm that Berry Head is an important site for harbour porpoises within the TMCZ. Land-based efforts at both Thatcher's Point and Hopes Nose resulted in no positive sightings of porpoises, and positive sightings at Sharkham Point were few (N = 11) compared to sightings at Berry Head (N = 164). There are many factors that may be influencing harbour porpoise presence at Berry Head including the possibility that the area is a feeding ground. Harbour porpoises must remain close to food sources as high consumption rates of prey items are required daily to achieve energy needs, maintain optimum fitness, and avoid hypothermia and starvation (Leopold, 2015; Booth et al., 2013; Toth et al., 2011). Berry Head is a popular land and sea-based recreational fishing area where species such as Atlantic mackerel (*Scomber scombrus*), sea bass (Serranidae), wrasse (Labridae) and pollock (Pollachius) are regularly caught (Wooding, *pers. comm*). Harbour porpoises feed mainly on shoaling fish from pelagic and demersal habitats including Atlantic mackerel, Atlantic herring, whiting (*Merlangius merlangu*) and sand eels (Ammodytes) (Santos and Pierce, 2014; Sveegaard et al., 2012a; Sveegaard et al., 2012b). In Denmark and Norway, herring were found to contribute to 46-55% of the weight of food consumed by harbour porpoises which indicates that this species is particularly important to porpoises (Sveegaard et al., 2012b). Both herring and mackerel distributions were positively associated with depth (100 to 700m) in areas with major upwellings and strong salinity. The coastal waters off Norway and Denmark are areas of high biological productivity due to high levels of nutrients making the area very attractive for marine predators (Sveegaard et al., 2012b). Herring have been landed at Brixham Harbour, however they are unlikely to have been caught in the waters directly off Berry Head as it is not generally commercially fished with the exception for crab potting (Southward et al., 1988). However, this does not necessarily mean that herring are not found in this area. The vast majority of porpoises (93%) at Berry Head were recorded within the allocated TMCZ which ranges 500m from the headland. Depths within the study zone range between 0-40m, and seabed sediment consists of hard substrates including cobbles, boulders and rock (British Geological Survey, 2019). The substrate type within the study zone indicates that sand eels are not a commonly available prey species for the porpoises utilizing this area and instead points to pelagic species as likely prey.

Tidal activity has been found to be a strong factor influencing cetacean habitat preference and site fidelity. Significantly more porpoises were observed during periods of falling tide (ebb and low-slack, X^2 = 16.61, p<0.001). Furthermore, significantly more feeding behaviours were recorded during falling tidal states (X^2 = 17.00, p<0.001). The coastal waters off Berry Head are described to have fast running times and historic data states that tidal streams in the area flow east for approximately 9 hours and to the west for approximately 3 hours in each cycle, with a stronger east-flowing stream (Wooding, 2019; Hughes, 1975). At fine-scales, oceanographic features such as upwellings, fronts and eddies (commonly occurring at headlands) can increase primary production and aggregations of plankton can be plentiful (Bailey and Thompson, 2010; Pierpoint, 2008; Johnston et al., 2005). Aggregations of prey organisms will attract larger prey species including porpoises. Harbour porpoises studied in the southern waters off Ramsey Sound (Wales) were most commonly recorded and observed foraging during ebb tidal phases (46%) compared to flood (5%); porpoises regularly arrived and departed from the foraging area by travelling with the prevailing tide (Pierpoint, 2008). This type of behaviour is expected to reduce energetic costs incurred while searching for prey which is especially important for harbour porpoise which have high energetic requirements. These results share similarities with the current study and could indicate similar behaviour from the porpoises of Berry Head.

A study of harbour porpoise sightings in the Marsdiep area (The Netherlands) found different results. Contrary to the porpoises of Berry Head and Ramsey Sound, the porpoises of the Marsdiep area were sighted more often during high and descending tide than low and rising tide. However, effort across all four tidal states were not equal, therefore these results maynot provide a reliable example (Ijsseldijk et al., 2015). In fact, during this study, porpoise presence was more closely linked to salinity levels with more porpoises recorded during periods of higher salinity. Salinity was also found to be one of the most important drivers of the fine-scale movements of harbour porpoise in the Danish North Sea and suggested that sea-surface salinity is a reliable environmental indicator of potentially important feeding areas for porpoises (van Beest et al., 2018). Salinity was not a variable covered in the current study, however this is something to consider for future research.

Feeding is an important driver for all living organisms however, many authors have emphasised the importance of feeding to porpoise survival as paramount (Roberts et al., in review; Forney et al., 2017; Hoekenijk et al., 2017; Leopold, 2015; Booth et al., 2013; Sveegaard et al., 2012a). Harbour porpoises in particular have been described to be “living on an energetic knife-edge” (Hoekendijk et al., 2017), are intolerable to prolonged periods of fasting, and have an energetic output three times higher than terrestrial animals of the same size (Leopold, 2015). The amount of starvation-related deaths of harbour porpoises in the UK have risen significantly in the 21st Century (CSIP, 2015). According to the UK Cetacean Strandings Investigation Programme (CSIP, 2015), harbour porpoises have been the most commonly stranded cetacean in the UK every year since 1990 (excluding 1992). In 2011, 322 harbour porpoises were found stranded, and of 74 porpoises examined at post-mortem, 27% (N = 20) were found to have died due to starvation (CSIP, 2011). In addition to the threats of starvation, hypothermia is also a danger to harbour porpoises worldwide (Leopold, 2015). Like many other marine mammals, porpoises have a thick layer of blubber. Blubber is a subcutaneous fatty deposit and contributes to metabolic energy storage, hydrodynamics, buoyancy and thermal insulation (Hashimoto et al., 2015). A healthy porpoise will have a thick blubber layer, indicative of a diet rich in oily fish such as herring (Leopold, 2015). Blubber thickness will change with the seasons and is generally thinner during the summer months; this is also a period when porpoise death rates are at their highest (Leopold, 2015).

In a post-mortem summary by CSIP for the period of 2009-2010, it was stated that the cause of death for 7 of the 8 harbour porpoises examined, was starvation and/or hypothermia (CSIP, 2010). The majority of these individuals were described to be malnourished, emaciated, or in poor nutritional condition. Furthermore, of the 8 porpoises examined at post-mortem, 4 were neonatal, 2 were juvenile and 2 were adult. All neonatal and juvenile porpoises and 1 adult were victims to starvation and/or hypothermia. Younger porpoises tend to have thicker blubber layer than adults, enabling them to maintain thermoregulation, however, this may not be enough to prevent starvation and hypothermia related deaths in younglings. Smith and Read (1992) recorded an absence of milk in the stomachs of 6 by-caught calves found with their mothers in gillnets in the Bay of Fundy. This led to the suggestion that calves are unable to feed from their mothers while they are actively foraging (Smith and Read, 1992). Harbour porpoise survival is clearly dictated by a continuous food supply and with the additional strains of a high energetic output and the responsibility to feed nursing young, it is increasingly clear to see how harbour porpoises are struggling to survive even before anthropogenic factors are introduced.

Many factors pose threat to porpoises and other cetaceans on a global scale. These include fisheries bycatch, noise pollution, and marine traffic (Bas et al., 2017; Forney et al., 2017; Oakley et al., 2017; Dawson et al., 1997). Some species have been driven to near-extinction.

Vaquita porpoises (*P. sinus*) are endemic to the Sea of Cortez (Gulf of Mexico), and have suffered the pressures of illegal fishing for the entirety of their scientific history (scientifically discovered in the 1950s). The impacts of anthropogenic activities have resulted in an estimated 11 individuals left in the wild with the species unlikely to make a come-back (Bessesen, 2018). Due to delayed action, poor policing and corruption, this species is likely to become extinct in the near future, however, if the vaquitas demise was treated as an emergency sooner, they may have had a chance. In addition to direct threats from fisheries, marine vessel noise, presence, and movements have been found to disturb and cause stress to cetaceans (Roberts et al., in review; Bas et al., 2017; Oakley et al., 2017). The implementation of regular and consistent monitoring programmes will help identify factors which are impacting porpoises in a negative way and will allow for mitigation tactics to be enforced.

Effects of marine vessel traffic on cetaceans have both short-term and long-term ramifications (Pennino et al., 2016). Short-term responses to marine vessels found in literature include; changes in respiration patterns, changes in surface behaviours, and prolonged dive intervals (Stamation et al, 2009; Lusseau, 2003; Williams et al, 2002; Nowacek et al., 2001). In 2017, harbour porpoises found in the Bristol Channel were studied to determine their reactions to marine traffic (Oakley et al., 2017). Reactions of porpoises to marine vessels included positive (approaching or following vessels), neutral (no change in position or activity despite vessel presence), and negative (moving away from a vessel or undertaking prolonged dives) responses. During this study, no positive reactions of porpoises to marine vessels were recorded and 74% of observations were neutral, indicating a level of habituation to the marine traffic using the area. Habituation may lead to short-term but serious disturbances such as an increase in collisions (Nowacek et al., 2001). Additionally, 60% of negative behaviours to marine vessels were in response to vessels travelling at steady speeds, and 40% to fast speeds. Furthermore, photographic evidence was captured of a porpoise that had suffered a non-fatal injury caused by an encounter with a propeller (Oakley et al., 2017). Since Oakley et al. (2017) published their research on the harbour porpoises of the Bristol Channel, a SAC has been enforced to protect them which, if monitored correctly, will provide additional protection to this population.

Due to their close proximity to the coast and human development (Elliser et al., 2018), harbour porpoises are often impacted by human activities and must often share their chosen habitat with regular streams of marine traffic. The coastal waters surrounding Berry Head are frequented by a vast variety of marine vessels including fishing trawlers, recreational fishing boats, speed boats, ferries, jet-skis and cargo ships (Roberts et al., in review). The most dominant marine vessel types at Berry Head (in the current study) were yachts (40.5%), commercial fishing boats (21%), and recreational fishing boats (19.5%). Similar results were shown at Berry Head in 2017: yachts (63.7%), commercial fishing (15.7%), and recreational fishing (9.57%) (Roberts et al., in review). Berry Head is closely located to one of the busiest harbours in the UK (Brixham Harbour) and acts as a passing place for marine vessels of commercial and recreational purposes. There were no relationships found between marine vessels and harbour porpoise presence and behaviour in the current study. Roberts et al. (in review) conducted a study into the impacts of marine traffic on harbour porpoise presence and behaviour at Berry Head with results indicating a moderate negative correlation between marine traffic and harbour porpoise presence and feeding behaviour. Porpoises were recorded less often and feeding behaviours reduced as marine vessel frequencies increased. Less effort was spent at Berry Head during the current study compared to Roberts et al. (in review) due to an increase in study locations and reduced effort time. If effort at Berry Head matched the effort completed by Roberts et al. (in review) similar results would likely have arisen.

Berry Head is located within the TMCZ. Each MCZ objective applies to all features protected by the MCZ and must ensure that these features are in favourable condition. Research on the porpoises of Berry Head only began in 2017 (Roberts et al., in review), therefore, little is known about their distribution, their ecology, or population numbers. DEFRA (2013) states:

"*For a species the definition of favourable condition is that quality and quantity of the species' habitat, and the composition of the species' population in terms of number, age and sex ratio, are such as to ensure that the population is maintained in numbers which enable it thrive. For some highly mobile species this definition will be adapted to reflect that the species is only present in the MCZ for part of its life-cycle and/or for a particular purpose (e.g. mating, egg-laying).*"

Understanding population numbers of this species will be key to determining whether they require further protection under the TMCZ. Results from this study indicate that the porpoises utilize the southern end of the TMCZ (Berry Head) on a regular basis; the porpoises are witnessed during every month of the year (personal observation). It is therefore likely that this population of porpoises are using the area as an important feeding ground. Additionally, mothers and calves have been witnessed using the area. Further research must be carried out to understand these points in more detail and to gather demographic data of this population. Once population numbers are ascertained, “favourable conditions” (e.g. stable population numbers) can be clarified for this species and if the population is below a level which enables it to thrive, management processes can be implemented to maintain them. Furthermore, DEFRA (2013) goes on to say that:

“*Favourable condition is the condition that would be expected in the absence of significant anthropogenic pressures which have an adverse effect*”.

As highlighted by previous research on this population of porpoises, marine vessel traffic in the area appears to be impacting the porpoises in a negative way (Roberts et al., in review). With increasing marine vessel frequencies, fewer porpoises are recorded in the area and important behaviours such as feeding may be interrupted, thus reducing fitness. The general management approach for the TMCZ may be changed if:

“*there is new scientific understanding of the sensitivity of a habitat or species to a particular activity*” (DEFRA, 2013).

Due to the study areas close proximity to one of the busiest harbours in the UK, it would be unrealistic to expect marine vessel traffic to be reduced, however, Berry Head serves as a passing place rather than a fishing zone, and boat users (including commercial and recreational) could be provided with a designated route on which to take on their way to sea and a speed limit could be enforced within this zone. This route will prevent marine vessels from cutting across the waters directly below the headland and provide an area of sanctuary for the porpoises where they will suffer less disturbance as a result. Additionally, a speed restriction within the area will allow the porpoises more time to react to oncoming vessels and the boat-users will have better control over their vessel if a cetacean is within then range. For this proposal to be successful, it is important that local stakeholders (boat users) are included in the decision making of this change and are heard by MCZ management officials. According to McAuliffe et al. (2014), respondents from a survey used to understand the attitudes and perceptions of recreational boat users towards MCZs, suggested that boat users would respond more positively to education and encouragement as opposed to more legislation (byelaws). Furthermore, provision of straightforward and pragmatic information regarding proposed and enacted MCZs would gain the trust of stakeholders, thus resulting in their support of the zone in question (McAuliffe et al., 2014).

DEFRA (2013) referrers to “characteristic biological communities” within its Marine Conservation Zone Designation Explanatory Notes and states that maintenance to favourable conditions does not just account for the habitat in question (e.g. subtidal sand or subtidal mud), but for the flora and fauna which live in or on that material under prevailing conditions. It could be possible that prey species to the porpoises of Berry Head are reliant on the substrate found within the TMCZ and therefore, by association, the porpoises are eligible for the protection of the designated MCZ. Again, further research is required to ascertain categorical proof of which species the porpoises are feeding on and whether these species rely on the substrate found there.

Each MCZ is established under section 116(1) of the Marine and Coastal Access Act 2009 (MCAA). This piece of legislation places an obligation on DEFRA to publish a report every six years with an assessment of how well MCZs are achieving their objectives (DEFRA, 2013). To date there have been no monitoring surveys completed for this site or its designated features (Singfield, *pers. comm.*), however, the TMCZ was implemented in 2013, therefore, an assessment of the success of this zone is due this year (2019). This may offer an opportunity to enlighten DEFRA and the TMCZ management team to the issues regarding harbour porpoises utilizing this zone. Officials involved with the management and governing of the TMCZ include the Inshore Fisheries Conservation Authorities (IFCA), the Marine Management Organisation (MMO), the Environment Agency (EA), the Department of Energy and Climate Change (DECC), the Harbour Authorities, the Department for Transport, and Natural England (NE). The Harbour Authorities are responsible for the management and regulation of coastal recreation and tourism and IFCA are responsible for governing fisheries (0-6nm) including commercial fisheries and recreational fishing activities (GOV.uk, 2013b). As before mentioned, stakeholders are more likely to support MCZs and their management if education and information is readily available and clear for them to understand (McAuliffe et al., 2014). IFCAs website is not particularly ‘user-friendly’ and information about the TMCZ is difficult, if not impossible to locate. In contrast, the Torbay Harbour Authorities website provides clear, easy to access and user-friendly information about features of the TMCZ and why we should protect them. However, there appears to be no designated location within the website specifically for the TMCZ. Instead, features of the TMCZ mentioned here are listed under associated bodies such as ‘The Community Seagrass Initiative’ and ‘Coral Coast’ (Torbay

Harbour, 2019a). In general, information that is currently available about the TMCZ is either vague, overly scientific, difficult to find, or unavailable. Due to this reality, it can be speculated that a lay-person or stakeholders such as boat users are not aware of the TMCZ, do not know how to behave when using it, or simply find the information available too complicated to interpret. This will inevitably result in law-breaking and possibly marine wildlife interference and disturbance.

All species of cetacean and other marine fauna such as basking sharks (*Cetorhinus maximus*) are protected by various legislation in the UK such as the Wildlife and Countryside Act 1981 and the Conservation of Habitats and Species Regulations 2017. Harbour porpoises have conservation status in the European Union (EU); listed in Annexes II and IV of the EU Habitats Directive (EU, 1992). Under these commissions, harbour porpoises are eligible to be awarded a SAC if an area has continuous or regular presence of the species (although subject to seasonal variation), good population density (in relation to neighbouring areas), and high ratios of young to adults during certain periods of the year (EU, 1992). The population of porpoises in question use the coastal waters below the Berry Head headland during every month of the year and have been witnessed with calves indicating that they are eligible under at least one of these criteria. To date no population studies have been carried out on the porpoises of Berry Head and it is currently unknow where or how far they travel. Once this information if acquired, further action may be taken to protect them under a SAC or to be included as a priority species under the TMCZ framework.

Environmental, biological and anthropogenic factors have influence on the porpoises of Berry Head and may be impacting their presence and behaviour at this site. Results have shown that porpoises are witnessed at only two of the four study sites, with Berry Head acting as the main location for porpoise activity within the TMCZ. Time restrictions were a limitation during this study and due to zero sightings of porpoises at two of the study locations (Thatcher's Point and Hopes Nose), less time was spent at Berry Head and Sharkham Point. However, this has proven useful to rule out Thatcher's Point and Hopes Nose as locations utilized by harbour porpoises. It would however be beneficial to allocate more time to these locations to be able to categorically declare them as unsuitable and unused by porpoises. For a more reliable and detailed data set, this research would have benefitted greatly from more effort time at Berry Head and Sharkham Point. This would have allowed a deeper analysis of how and why the porpoises use these locations as opposed to Thatcher's Point and Hopes Nose.

Tidal state seems to play an important role in the presence of harbour porpoises which is most likely associated with prey distribution. The importance of feeding and remaining with81in close proximity to prey species has been addressed (Leopold, 2015; Sveegaard et al., 2012a; Johnston et al., 2005), therefore, it would be beneficial to carry out research specifically tailored to understanding specific species that the porpoises are consuming in the study area and their movements. Unfortunately, during the current study this was not possible, but acquiring such information would greatly benefit our understanding of the porpoises distributions and feeding behaviour along the Torbay coastline.

No statistical significance (p = 0.236, χ^2 = 1.40, N = 28) was found between marine traffic presence/absence and porpoise presence/absence, however results to the contrary have been found in a previous study indicating that the porpoises of Berry Head may be impacted negatively by marine vessel presence (Roberts et al., in review). Further research on this issue would contribute to the ever-growing literature surrounding the topic of vessel impacts on cetaceans. Results point toward Berry Head as an important site for harbour porpoises. The area may be an important feeding ground as indicated by this research and a previous study (Roberts et al., in review). Furthermore, the area may also be used as a breeding ground as mothers and calves have been witnessed and recorded in the area. Breeding and nursing grounds can only be proven using individual identification methods such as dorsal fin identification (Embling, *pers. comm*.), however such research would benefit the porpoises significantly. For this population of porpoises to be categorically eligible for further protection under the allocated TMCZ or to be awarded a SAC, further research must be implemented on specific variables such as water salinity, tidal flow, porpoise prey species, distribution of porpoises and porpoise population numbers.

5.0. Acknowledgements

I would like to thank Dr Clare Embling for all of her support and guidance during the planning process, research and write-up stages of this study. Thank you to Stuart Collier for supporting me with data collection while on site and for the original idea to study the porpoises within the Torbay Marine Conservation Zone. I would also like to thank Dr Andrea Gaion for statistical support.

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Appendices

Appendix 1. Environmental factors considered during observation periods adapted from the Sea Watch Foundation (2012).

Appendix 2. Land-Based Effort Recording Form (15-minute period) – Adapted from Sea Watch Foundation (2012)

Appendix 3. Behavioural ethogram specifying *Harbour porpoise* behaviours. Adapted from; Bas et al. (2017), Oakley et al. (2017), Feingold and Evans (2013) and Constantine, Brunton and Dennis (2004).

Appendix 4. Example of a marine vessel log taken at Berry Head. Moving vessels are identified using an underline, porpoises are identified using the letter P. The TMCZ is depicted by the green solid and perforated lines.

Appendix 5. Total marine vessels (%) recorded at each study location.

Appendix 6. All Kruskal-Wallace with post-hoc test results.

Appendix 1. Environmental factors considered during observation periods adapted from the Sea Watch Foundation (2012).

Sea State		**Swell Height**	
0	Mirror calm.	Light	< 1 metre
1	Slight ripples, no foam crests.	Moderate	1-2 metres
2	Small wavelengths. Glassy crests, no whitecaps.	Heavy	>2 metres
3	Large wavelets, crests begin to break, few whitecaps.		
4	Longer waves, many whitecaps.	**Visibility**	
5	Moderate waves of longer form, some spray.	A	< 1 kilometre
6	Larger waves, whitecaps everywhere, frequent sprays.	B	1-5 kilometres
7	Sea heads up, white foam lows in streaks.	C	6-10 kilometres
8	Long, high waves, edges breaking, foam blows in streaks.		
9	High waves, sea begins to roll, dense foam streaks.		

Appendix 2. Land-Based Effort Recording Form (15-minute period) – Adapted from Sea Watch Foundation (2012)

Day/Month/Year……………………… **Location:…………………………..**

Watch Start (GMT)	Watch End (GMT)	Sea State	Swell Height	Wind Direction	Visibility	Tide		Notes
						Height	State	

Data Definitions:

Sea State	
0	Mirror calm
1	Slight ripples, no foam crests.
2	Small wavelets, glassy crests, no whitecaps.
3	Large wavelets, crests begin to break, few whitecaps.
4	Longer waves, many whitecaps.
5	Moderate waves of longer form, some spray.
6	Large waves, whitecaps everywhere, frequent spray.
7	Sea heaps up, white foam lows in streaks.
8	Long, high waves, edges breaking, foam blows in streaks.
9	High waves, sea begins to roll, dense foam streaks.

Swell Height	
Light	< 1 metre
Moderate	1-2 metres
Heavy	>2 metres

Visibility	
A	< 1 kilometre
B	1-5 kilometres
C	6-10 kilometres

Associated Birds:

Harbour Porpoise (*Phocoena phocoena*) Sighting:

First Seen (GMT)	Group Size (Min)	Number of Young (Calves and Juvenile)

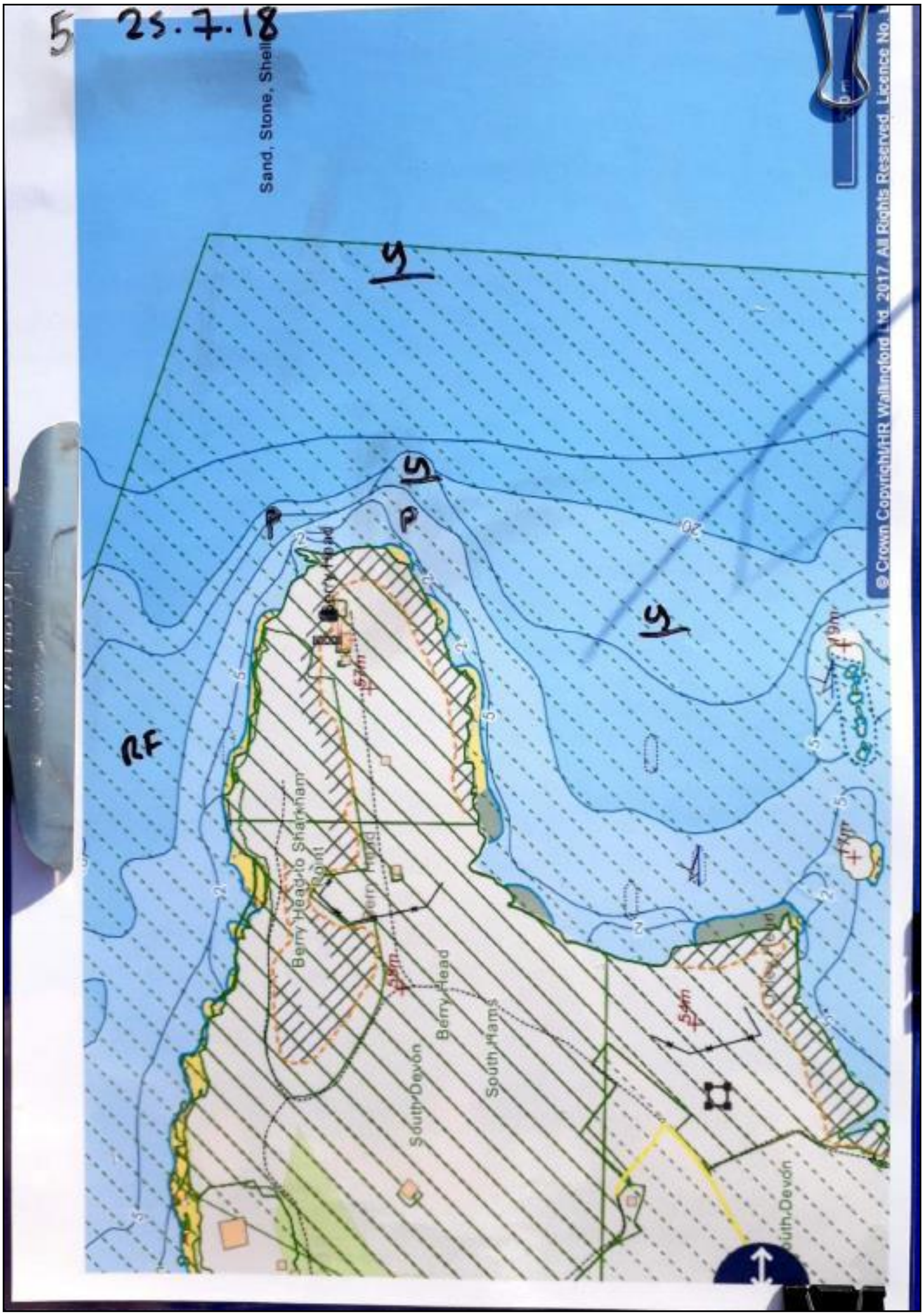
Behaviour:

Behavioural state	Tally
Travelling	
Resting	
Feeding	
Socialising	
Leap	

Appendix 3. Behavioural ethogram specifying *Harbour porpoise* behaviours. Adapted from; Bas et al. (2017), Oakley et al. (2017), Feingold and Evans (2013) and Constantine, Brunton and Dennis (2004).

Behavioural State	**Definition**
Travelling	Persistent and directional movement at speeds greater than resting, including regular surfacing. Dive intervals are relatively short (< 15 sec).
Resting	Very slow movements with no apparent direction, floating on the surface of the water or stationary at the surface of the water.
Feeding	Directional and synchronised movements in no specific direction, cooperative hunting, chasing fish, associated diving seabirds e.g. gannets.
Socialising	Frequent physical contact and swimming in close proximity. Vigorous movements and aerial behaviour such as breaching, playing, rolling at the surface.
Leap	Sudden locomotion from water to air above sea level, acrobatic movements.

Appendix 4. Example of a marine vessel log taken at Berry Head. Moving vessels are identified using an underline, porpoises are identified using the letter P. The TMCZ is depicted by the green solid and perforated lines.



Appendix 5. Total marine vessels (%) recorded at each study location.

Marine Vessel Type	**Berry Head**	**Sharkham Point**	**Thatcher's Point**	**Hopes Nose**
Yacht	40.5%	41.9%	16.4%	63.6%
Commercial Fishing	21%	24.6%	4.5%	4.6%
Recreational Fishing	19.5%	22.2%	7.41%	22.1%
Speed Boats	11%	9.8%	13.4%	18.3%
Ferry	1.5%	1.2%	1%	
Kayak			31.8%	
Stand-up-paddle-board			10%	0.8%
Jet-ski	3.5%		3%	
Rib	1.5%		2.5%	
Cargo				1.52%
Catamaran	1%			
Life boat	0.5%			

Appendix 6. All Kruskal-Wallace with post-hoc test results.

Table 1. Kruskal-Wallis and post-hoc test results explaining marine vessel frequency at each study location.

Location	**Result**
Thatcher's Point and Hopes Nose	$\chi^2(1) = 5.14, p = 0.023$
Berry Head and Hopes Nose	$\chi^2(1) = 5.70, p = 0.017$
Berry Head and Thatcher's Point	$\chi^2(1) = 0.001, p = 0.976$
Sharkham Point and Hopes Nose	$\chi^2(1) = 7.60, p = 0.006$
Berry Head and Sharkham Point	$\chi^2(1) = 24.20, p = <0.001$
Sharkham Point and Thatcher's Point	$\chi^2(1) = 22.50, p = <0.001$

Table 2. Kruskal-Wallis and post-hoc test results explaining harbour porpoise occurrences during each tidal state at Berry Head.

Tidal State	**Result**
Ebb and High Slack	$\chi^2(1) = 9.01, p = 0.003$
High Slack and Low Slack	$\chi^2(1) = 16.61, p = <0.001$
Ebb and Low Slack	$\chi^2(1) = 3.70, p = 0.054$
High Slack and Flood	$\chi^2(1) = 0.03, p = 0.863$
Ebb and Flood	$\chi^2(1) = 8.00, p = 0.005$
Flood and Low Slack	$\chi^2(1) = 14.09, p = <0.001$

Table 3. Kruskal-Wallis and post-hoc test results explaining feeding behaviour occurrences during each tidal state at Berry Head.

Tidal State	**Result**
Ebb and High Slack	$\chi^2(1) = 9.11, p = 0.003$
High Slack and Low Slack	$\chi^2(1) = 17.00, p = <0.001$
Ebb and Low Slack	$\chi^2(1) = 3.40, p = 0.066$
High Slack and Flood	$\chi^2(1) = 0.05, p = 0.829$
Ebb and Flood	$\chi^2(1) = 8.85, p = 0.003$
Flood and Low Slack	$\chi^2(1) = 16.10, p = <0.001$

Table 4. Kruskal-Wallis and post-hoc test results explaining positive porpoise sightings at Berry Head during each month (July-November 2018). There were no positive sightings of porpoises during September, therefore it is excluded.

Month	Result
July and August	$\chi^2(1) = 10.82, p = 0.001$
July and October	$\chi^2(1) = 11.04, p = 0.001$
July and November	$\chi^2(1) = 2.88, p = 0.090$
August and October	$\chi^2(1) = 3.80, p = 0.052$
August and November	$\chi^2(1) = 10.03, p = 0.002$
October and November	$\chi^2(1) = 12.01, p = 0.001$