Harbour porpoise (Phocoena phocoena) behavioural responses to recreational craft

*Elliot Charles Grundy | **500482202***

osub22@bangor.ac.uk

Supervisor(s):

Dr Peter G.H. Evans (SWF Bangor/SOS), and Dr James Waggitt (SOS)

Collaborating Institutions:

Sea Watch Foundation (SWF)

For Submission to: **Marine Ecology Progress Series**

Key Words:

Noise, Anthropogenic, Behaviour, Vessel, Motorized, Avoidance

ABSTRACT

Following expansions in shipping worldwide, there's been growing amounts of literature highlighting that increases in recreational shipping is driving adverse behavioural alterations in numerous marine mammal species. Any activities which alter the energy budget of an organism while causing increased energy expenditure, has the potential to pose long-term negative impacts on the individual, and populations health as a whole. This study aims to examine the short-term responses elicited by harbour porpoise (*Phocoena phocoena*) following the passage of different vessel types and to explore long-term impacts which may arise as a result of changes to their behaviour. To address these aims, 15 land-based surveys were conducted at Point Lynas, between 3rd June to 15th August 2021. The surfacing rate, behaviour, and abundance of *P. phocoena* was recorded in the absence and presence of differing vessels which use the area. This was supported through the use of theodolite tracking and digital video recordings to provide further insight into vessel-organism interactions. Results highlighted the number and type of marine crafts within the area significantly influenced the number of individuals using the site (ANOVA: F= 5.968, p= 0.003, d.f.= 2), along with the behaviour of organisms (X^2 (2) = 10.067, p= 0.007). The surfacing rate of porpoise was found to significantly decline in the presence of motorized speed crafts (ANOVA: F= 3.735, p= 0.025, d.f.= 2). Finally, theodolite tracking highlighted the changing response elicited by *P. phocoena* in the presence of differing maritime crafts. Findings will guide management initiatives to retain the favourable conservation status of *P. phocoena* within the area.

1. INTRODUCTION

The increasing dependence on the world's oceans by humans, for resource extraction, trade and recreation poses a number of challenges regarding the sustainable use of natural resources. Worldwide, the number and size of marine vessels is ever increasing, particularly within coastal regions. Furthermore, the urbanization of coastal environments partnered with population growth is found to be directly linked to increases in commercial and recreational shipping (Becker et al. 2013) stemming primarily as a result of overall economic growth and trade globalization (Zhou et al. 2019). Shipping has now been identified as the dominant marine anthropogenic underwater noise source in the world's oceans (Hildebrand, 2009; Wisniewska et al. 2018) and is found to be increasing at a rate of 3dB per decade (Andrew et al. 2002, 2011; Chapman & Price, 2011; Miksis-Olds et al. 2013; Miksis-Olds & Nichols, 2016). However, within the world's oceans, there are high levels of heterogeneity in the types of sounds produced by differing vessels, from jet skis producing sound in the range of 130–160 dB re 1 µPa m, to large ferries and container vessels producing source levels of 200 dB re 1 µPa m and more which may propagate over large distances. For smaller vessels travelling at speed the primary source of vessel noise originates from propeller cavitation, which involves the violent collapsing of bubbles, producing a broadband noise spectrum ranging from low frequency noise (<100 Hz) to extremely high frequencies (>100 kHz) (Ross, 1976). For larger vessels, the major contributor to underwater noise is from engine noise which is propagated over large distances through the water from the ship's hull (Arveson & Vendittis, 2000; Urick, 1983).

Anthropogenic underwater noise from commercial and recreational shipping is now recognized as a worldwide problem, causing a variety of negative effects on marine taxa (NRC, 2003; Richardson et al. 1995; Williams et al. 2015), impacting organisms physiologically and/or behaviourally (Tougaard et al. 2014). Yet due to these differences in source level noise and differing propagation differences, several long-lived marine species with complex social structures may respond to varying degrees to increases in commercial and recreational shipping (Mann et al. 2000). Following the expansion and diversification of human activities in recent years; there is increasing amounts of literature highlighting the influence of maritime shipping on the marine environment and marine organisms (Tyack, 2008; Williams et al. 2015). In particular, marine mammals such as cetaceans which use sound in the form of echolocation for feeding, navigation and communication are particularly vulnerable to negative impacts posed by anthropogenic underwater noise (Tyack, 2008; Wisniewska et al. 2018). Increases in maritime traffic is found to impact cetaceans directly through collision, or indirectly through anthropogenic noise pollution (Simmonds & Brown, 2011; Evans, 2020). Anthropogenic noise pollution can cause physiological damage to auditory systems and/or alter the behaviour of affected organisms (Tougaard et al. 2014), having the capacity to cause long-term changes to the marine ecosystem as a whole (Clark et al. 2009; Pirotta et al. 2015b).

1.1 | Previous Studies

Previous research undertaken by Wisniewska et al. (2018, highlighted that harbour porpoise (Phocoena phocoena) not only alter and/or reduce echolocating behaviour in the presence of vessels, but also display avoidance behaviour, swimming rapidly horizontally or vertically away from the noise source. Individuals were reported to return to the surface and continue foraging ~15 minutes after first being exposed to increased noise levels. Investigations on Atlantic bottlenose dolphins (*Tursiops truncatus*) using a combination of both passive acoustic and visual observation techniques found that individuals appear to temporarily halt foraging activity, switching to avoidance behaviours in the presence of motorized boats (Pirotta et al. 2015), leading to increases in energy demands as individuals changed direction rapidly and began swimming away from the noise source, a common response to approaching vessels (Au & Perryman, 1982; Nowacek et al. 2001; Mattson et al. 2005; Lemon et al. 2006; Lusseau, 2006; Christiansen et al. 2010; Marley et al. 2017). Individuals have been reported to dive quickly (Palka & Hammond, 2001) or increase porpoising in an attempt to swim away from vessels (Dyndo et al. 2015).

The observed responses may be due to marine mammals such as *P. phocoena* utilizing sound for predator detection, having evolved antipredator responses to generalized threatening stimuli such as loud noises and rapidly approaching objects. Observed avoidance reactions by marine mammals may occur as a result of individuals perceiving vessels as a predation risk, or collision risk (Frid & Dill, 2002), as prey are known to invoke a response when stimuli exceed a given threshold. Underwater noise produced from vessel traffic may exceed this threshold when within proximity of the organism, thus eliciting anti-predatory techniques in the form of avoidance behaviour (Frid & Dill, 2002). However, various factors have been identified to influence the onset and intensity of a response, such as quality of a foraging patch, social characteristics, health of individual, and extent of previous encounters (Blumstein, 2006).

1.2 | Conservation Issue

Around Point Lynas, North Anglesey, there are a range of different vessel types which frequent the area for commercial and recreational purposes. Some of these include the use of small, motorized vessels for sea angling or for commercial pot fisheries, along with sail boats, and recreational speed crafts such as jet skis, ribs, and powerboats. In recent years, there has been a gradual increase in the use of waters surrounding Point Lynas for recreational purposes, particularly at weekends and throughout public holidays (P.G.H Evans, pers. comm.). These increases in maritime traffic raise concerns regarding the effect on marine mammals such as *P. phocoena* which frequent the area for important activities such as feeding and mating, as vessel noise can mask acoustic cues (Clark et al. 2009), alter the behaviour of porpoise and their prey (Pirotta et al. 2012) and/or cause increased stress levels in affected individuals (Wright et al. 2007). Other sublethal effects may include changes in activity budgets through the disruption of foraging activity (Lusseau, 2003; Pirotta et al. 2014), whereas physical damage includes hearing loss as a result of powerful transient noise and avoidance reactions as a result of persistent low-level noise (Tougaard et al. 2014). The increased use and accessibility to recreational speed crafts (such as jet skis and speed boats) is of particular concern as their high speed partnered with their high frequency noise means that crafts may move rapidly and erratically while remaining relatively undetectable to porpoises until within close range of the organism.

Disturbance caused by maritime vessels may alter the energy budgets of disturbed organisms, as less time will be spent resting or foraging and more time will be spent travelling or avoiding vessels. Repeated exposure to human activities which disrupt natural foraging behaviours while increasing energy expenditure have the potential to reduce energy intake (New et al. 2013), and thus pose long-term negative impacts on an individual's health (Wisniewska et al. 2018). This is of high concern for *P. phocoena* due to their high metabolic rate (Rojano-Doñate et al. 2018), high feeding rates (Wisniewska et al. 2016) and dependency on a year-round proximity to food sources. Therefore, repeated disturbance from human activities may lead to individuals decreasing their residency in an area or avoiding areas completely (Lusseau, 2005; Bejder et al. 2006; Rako et al. 2013; Pirotta et al. 2015; Pérez-Jorge et al. 2016).

1.3 | Knowledge Gaps

Existing research regarding the effects of commercial and recreational boat traffic on marine mammals is highly patchy with regards to species coverage, vessel type, and geographic area. There is a significant species bias in terms of research effort, with bottlenose dolphin and humpback whale (*Megaptera novaeangliae*) being studied significantly more than other species. Specific vessel-types tend to be more commonly investigated than others, with tourism vessels being most commonly studied on bottlenose dolphins, due to vessels directly seeking interaction with individuals. By comparison, small recreational craft such as jet skis have received little research attention, despite repeated exposure potentially interfering with natural behaviours. Smaller vessels are also considerably more difficult to study due to their unpredictable nature. However, the continued increase in small vessel ownership is driving concerns over their contribution to anthropogenic underwater noise and erratic movements. Finally, previous studies have emphasized the highly contextual nature of responses. Since Point Lynas has been identified as an important feeding ground for porpoises (Shucksmith et al. 2009), the increase in recreational boat traffic in recent years may cause more detrimental impacts on individuals' behaviour and should be studied thoroughly to inform management initiatives. A localized assessment of how *P. phocoena* are responding to increases in recreational boat traffic would build further on identifying how local factors may influence the type and severity of response that marine mammals display to maritime vessels. Research will ensure effective management initiatives can be established within the North Anglesey Marine SAC to reduce any negative effects on the porpoise population and further efforts to maintain its favourable conservation status in the region.

1.4 | Aims, Objectives and Hypothesis –

To address the current knowledge gaps regarding how recreational vessels at Point Lynas may influence the behaviour of harbour porpoise, this study aims to: 1) Examine short-term responses of *P. phocoena* to the passage of different types of vessels passing Point Lynas; and 2) Assess longer-term impacts that could arise as a result of changes to natural behaviours which may influence the energy budgets for other biologically important processes. It is hypothesised that, in the presence of vessels and other watercraft, porpoises will display a reduction in foraging behaviour due to individuals being disturbed and there will be a reduction in the surfacing rates of individuals during vessel passes as individuals dive to deeper depths to avoid contact with vessels. It is also hypothesised that in the presence of more boats, there will be a decreased abundance of *P. phocoena* using the area.

2. MATERIALS & METHODS

2.1 | Study Species

Harbour porpoise (Phocoena phocoena) are the smallest of the oceanic cetaceans within the suborder Odontoceti. The species is <1.8 meters length on average, with females generally slightly larger than males, whereas weights range between 45 – 70 kg for adults (Jefferson et al. 2006). Individuals possess a very robust body shape, a blunt snout, and do not possess any external rostrum. The identifying feature of this species from the surface is its small triangular dorsal fin, and a prominent dorsal ridge extending down the back to the fluke (Gaskin et al. 1976; Jefferson et al. 2006). *P. phocoena* are widely distributed throughout temperate and subarctic regions of both the Atlantic and Pacific in the Northern hemisphere (Evans & Waggitt, 2020), and are the most common and widely distributed cetacean species in British waters (Hammond et al. 2017; Evans & Waggitt, 2020). *P. phocoena* are mainly found in continental shelf waters and are most common in depths of 50 – 150 metres (Marubini et al. 2009), regularly seen as solitary individuals or less commonly forming loose aggregations (Evans et al. 2008; Blanchard, 2018).

In the coastal waters of North Anglesey, common prey items include small pelagic schooling species such as sprat (*Sprattus sprattus*), sand eel (*Ammodytes americanus*), and whiting (*Merlangius merlangus*) plus demersal species such as dab (*Limanda limanda*), plaice (*Pleuronectes platessa*) and cod (*Gadus morhua*)

(Reijnders, 1992; Santos and Pierce, 2003). Several studies have identified both spatial and temporal variation in diet (Santos et al. 2003; 2004; Sveegard et al. 2011) dependent on the availability of different prey species. Due to *P. phocoena*'s small size, and inability to store substantial amounts of energy (Santos et al. 2004), individuals must feed regularly to meet high energy demands (Heide-Jørgensen et al. 2012; Wisniewska et al. 2018), therefore it is assumed much of their time is spent foraging.

To mitigate human-wildlife interactions and conflicts, *P. phocoena* are protected under several management initiatives, such as the UK Biodiversity Action Plan (HM Government, 1994), and EU Habitats Directive (UK BAP - JNCC, 2021), to determine any activities which may threaten their conservation status within UK waters. Under the Habitats Directive (Annex IV, Article 12), all cetaceans are designated as European Protected Species, restricted from deliberate killing, capture and disturbance within their range (JNCC, 2019). Harbour porpoise are also listed under Annex II, resulting in the North Anglesey Marine SAC being designated as a Special Area of Conservation by Ministers on 26th February 2019, along with four other SACs distributed around the UK as part of the Natura 2000 network. Within the North Anglesey Marine SAC, conservation objectives are set out to ensure that the site contributes in the best way possible to achieving Favourable Conservation Status (FCS) of harbour porpoise. If a proposed development or activity within the site is likely to significantly affect the FCS of harbour porpoise, the Habitats Directive (Article 6(3)) mandates an Appropriate Assessment be undertaken. The purpose of the assessment is to determine whether a plan will affect the site's integrity to achieve its conservation objectives to contribute towards FCS (JNCC, 2019).

2.2 | Study Area

Systematic surveys were undertaken at Point Lynas, (53˚ 25' 0.59" N 004˚ 17' 19.21" W), a headland located on the north-east coast of Anglesey. The area is classified as a high-energy environment with current speeds reaching as high as 1.5ms^{-1} and depth ranging between 0 - 34 meters (Figure 1) (Robins et al. 2014). Point Lynas has been identified as an important area for *P. phocoena*, with individuals frequenting the area throughout the year for activities such as feeding, socializing, and potentially mating (Baines & Evans, 2012; Evans et al. 2015). Around Point Lynas, the strong currents produced by areas of upwelling and eddies, are known to aggregate prey species and represent important foraging areas for porpoises (Waggitt et al. 2017). In the wake of the headland, current speeds are also increased as features generate complex 3D secondary flows, creating physical and biological fronts (Wolanski & Hamner, 1988). These fronts aggregate weak nektons and plankton which in turn affects the distribution and density of small consumers, resulting in patches of concentrated prey that harbour porpoise can exploit (Borges & Evans, 1997; Evans & Waggitt, 2020). The high degree of turbulence around Point Lynas also increases the vulnerability of prey as they become disorientated, causing a decreased school cohesion (Benjamins et al. 2015). Therefore, as *P. phocoena* must feed regularly, such high energy environments as Point Lynas are of high importance, allowing individuals to find a regular high quality food source (Marubini et al. 2009; Heide-JØrgensen et al. 2012; Isojunno et al. 2012). Point Lynas was selected due to the high abundance of *P. phocoena* throughout the year, along with the biological importance of the area as a foraging ground.

2.3 | Field Methods

2.3.1 | Land-Based Watches

Land-based watches were undertaken between 3rd June and 15th August 2021 from a raised vantage point 26 meters above sea-level to ensure a suitable viewing point for accurate determination of boat presence in the area along with accurate determination of harbour porpoise behaviour. Surveys aimed to span a range of tidal states and times of day to gain a representative coverage throughout each time of day, while ensuring that the behaviour and number of individuals is monitored throughout each tidal phase. Surveys were undertaken in 90-minute blocks, separated by 30-minute intervals to allow observers time to rest between surveys and to reduce the effects of observer fatigue on the sightings data collected.

2.3.2 | Effort and Environmental Conditions

Throughout surveys, surrounding environmental conditions and effort were recorded at 15-minute intervals, including information such as Beaufort scale sea state (Table 1), swell height (Light = <1 meter, Moderate = 1-2 meters and Heavy = >2 meters), visibility (<1km, 1-5km, 6-10km and >10km), Glare/Lighting (Table 2) and boat activity in the area (Table 5). As locating porpoises can be difficult in sea states ≥3, surveys were only undertaken in sea states ≤2 to reduce the likelihood of missing individuals (Barco et al. 1999).

2.3.3 | Sightings Data

Any porpoise sightings within the study area were recorded on forms provided by the Sea Watch Foundation (Figure 11), recording information on the time the animal(s) were first and last seen, the group size, number of juveniles/calves, vertical/horizontal angle to the animal(s), direction of movement of the animal, and observed behaviour (Table) along with whether there were any associated seabirds. A sighting was classified to end once the individual or group was not sighted for 5 minutes. Should individuals be then sighted within the same area after this 5-minute time frame, this was then recorded as a new observation.

2.3.4 | Theodolite Tracking

During porpoise sightings, theodolite tracking was undertaken to determine the dive tracks and movements of individuals during different behaviours and to monitor the movement of target individuals throughout interactions with vessels. The theodolite was first set up and calibrated before the vertical and horizontal angle to the individual were recorded and tabulated each time the animal resurfaced. The theodolite was placed at the same location and height above sea-level for each survey, thus ensuring there was no bias in recordings. Should any vessels pass through or use the area during theodolite tracking, the vertical and horizontal angles to the vessel were also recorded at regular intervals throughout the interaction so that the boat's movements could be tracked in relation to the animal.

2.3.5 | Surfacing Rate

The surfacing rate of an individual was measured by counting the number of times the same porpoise resurfaced within 60-seconds. The surfacing rate was then tabulated, along with information on the time of the recording, the type/number of crafts in the area, and suspected behaviour of the target individual. The type of vessel was categorized in the same way as mentioned in section 2.3.2 (Table 5).

2.3.6 | Video Recordings

Both theodolite tracking and surfacing rate data were supported by the use of digital video recordings taken from a tripod-mounted camcorder (Sony HDR-CX240E Handy Cam, 54x Zoom). During surveys, the camera was used to record any individuals using the area and any vessel-organism interactions, with recordings initiated once an animal was detected. Digital video recordings provide a greater insight into the behaviour and direction of both porpoises and vessels, while also allowing for later comparison with in-situ visual observations, to help validate information such as surfacing rates.

2.4 | Data Analysis

All data collected were inputted to Microsoft Excel ready for statistical analysis; all statistical analysis was then undertaken in IBM SPSS Statistics (version 27) while figures and maps were created in ArcMap (version 10.7.1).

2.4.1 | Number of Individuals

To determine whether there was a significant difference in the number of *P. phocoena* sighted in the presence vs absence of vessel activity, sightings were separated into those with ≥1 vessel in the area and those with 0 vessels within 5 km. To check that data met the assumptions of equal variances and normal distribution, initially a Levene's and Shapiro-Wilks test were used, respectively. Following this, a parametric ANOVA or non-parametric Kruskal-Wallis test was utilized to determine whether there was a significant difference in the number of individuals sighted between the two groups. Furthering this, to compare whether the vessel type influenced the number of individuals spotted during land-based watches, initially sightings were categorized as those in the absence of vessels, those in the presence of motorized crafts (fishing/research vessels, speedboats, and jet skis) and those in the presence of un-motorized crafts (sailing boats and kayaks). A Shapiro-Wilks and Levene's test were undertaken to determine whether the data met the assumptions of equal variances and normal-distribution respectively. Following this a parametric ANOVA or non-parametric Kruskal-Wallis test was undertaken to determine whether the groups differed significantly. A post-hoc Tukey test then uncovered which groups differed significantly.

To evaluate whether the number of active vessels within 5 km of the site influenced the number of individuals observed during land-based watches, the number of individuals and number of active vessels were first plotted graphically to identify patterns between the two variables. A regression analysis was then undertaken to understand the strength and significance of this relationship.

2.4.2 | Surfacing Rate

To identify a change in the surfacing rate of harbour porpoise dependent on their behaviour, initially the average surfacing rate for each behavioural state was calculated. To establish whether there was a significant difference between the surfacing rates between each of the behavioural states, initially a Levene's and Shapiro-Wilks test were used to check for equality of variances and normal distribution, respectively. Following this, either a parametric ANOVA or non-parametric Kruskal-Wallis test was used to check for significant differences between the groups. A post-hoc Tukey test was then used to determine which groups differed significantly.

To determine whether there was a significant change in the surfacing rate of *P. phocoena* in the absence and presence of both non-speed and speed crafts, sightings were first differentiated into 3 groups, those in the absence of vessel activity, those in the presence of non-speed crafts (fishing vessels, research vessels, kayaks and sail boats) and those in the presence of speed crafts (speedboats and jet skis). Initially, a Shapiro-Wilks and Levene's test were used to assess whether data were normally distributed and had equal variances. Following this, either a parametric ANOVA or non-parametric Kruskal-Wallis test was utilized to determine whether groups differed significantly. A post-hoc Tukey test then identified where the significant differences lay.

To assess whether the number of active vessels within 5 km of the site influenced the surfacing rate of the individual, initially the surfacing rate was plotted against, the number of active vessels within the area to detect any patterns within the data. Following this, a linear regression analysis was undertaken to test the relationship between these two variables and to determine whether this was a significant relationship.

2.4.3 | Behavioural State

When determining if there was a change in the dominant behavioural state displayed by harbour porpoise in the presence of marine vessels, initially the frequency of feeding, travelling and avoidance was first calculated for sightings both in the presence and absence of marine vessels. Following this, a Chi Squared analysis was completed to determine whether there was a significant change in the frequency of feeding, travelling and avoidance behaviour between the two groups.

2.4.4 | Theodolite Processing

Using the vertical and horizontal angles (radians) obtained during land-based watches, along with the known height (corrected for the known tidal height) and the exact location of the electronic theodolite (Figure 12), angles were later converted into specific coordinates (Formula 1) for subsequent plotting and analysis. A regression analysis was completed to determine whether there was a significant relationship between, the distance between the porpoise individual and the craft and the distance travelled underwater by the porpoise.

3. RESULTS

A total of 424 harbour porpoise (*Phocoena phocoena*) sightings were recorded at Point Lynas from a total of 15 surveys, with an average of 3 individuals seen in each sighting. However, at Point Lynas, *P. phocoena* were most commonly seen in pairs. The most common behaviour displayed by individuals during observations was 'Suspected Feeding' which was recorded in 67% of all encounters, further supporting the notion that Point Lynas is an important feeding ground for the species. Most sightings occurred in the absence of any calves or juveniles, however, in 52 out of 140 observations, ≥1 Juvenile/Calf was observed.

3.1 | Number of Individuals

The number of *P. phocoena* sighted was found to be significantly related to the vessel activity within 5 km of the site (ANOVA: F = 9.105, p = 0.003, d.f. = 1). In the absence of vessel activity, there were significantly more individuals seen on average compared to sightings with 1 or more active vessels within 5 km of the area. When no vessels were within 5 km, the mean number of individuals sighted was 3.6 (+/- 0.265), whereas when vessels were present, the mean number of individuals declined to 2.66 (+/- 0.18). Assessing this relationship further, there was a significant reduction in the number of individuals sighted in the presence of motorized boats (ANOVA: F= 5.968, p= 0.003, d.f.= 2) (Figure 2). However, a post-hoc Tukey test uncovered there to be no significant difference between the number of individuals in the presence of unmotorized vessels and any other group (Table 6).

A weak but significant negative relationship was detected between the number of vessels present within 5 km and the number of porpoise individuals sighted within the area (F (1,138) = 5.467, p= 0.021) (Figure 3). The regression value, R^2=0.031, indicates that changes in the number of active vessels accounted for only 3.1% of the variability in the number of individuals sighted. The number of porpoises which can be seen from land-based watches can be predicted using the following equation: (Number of Porpoise = 3.314 – 0.192 (Number of Vessels)).

3.2 | Surfacing Rate

The surfacing rate of *P. phocoena* differed significantly between each of the behavioural states witnessed during land-based watches (ANOVA: F= 22.562, p= 0.000, d.f.= 3). The mean surfacing rate during feeding was 6.41 min^{-1} (+/- 0.174), while the mean surfacing rate for travelling individuals was 7.56 min^{-1} (+/- 0.365) and individuals displaying avoidance behaviour had a mean surfacing rate of 2.57 min^{-1} (+/- 0.571). Finally, individuals which had an unknown behavioural state, surfaced 2.11 min^{-1} (+/- 0.309) (Figure 4). A post-hoc Tukey test identified a significant difference in surfacing rates between Feeding, Travelling and Avoidance. However no significant difference was found between individuals displaying avoidance behaviour and those whose behaviour was unknown (Table 3).

When simply comparing the surfacing rate of *P. phocoena* in the presence vs absence of marine vessels, there was no significant change detected (ANOVA: F= 0.026, p= 0.873, d.f.= 1). The mean surfacing rate in the presence on marine crafts was determined to be 6.40 min^{-1} (+/- 0.377), while in the absence of vessels was calculated to be 6.47 min^{-1} (+/- 0.203). However, when differentiating by type of craft (speed craft vs. non-speed craft), a one-way ANOVA uncovered a significant change in the surfacing rate of *P. phocoena* in the presence of speed crafts compared to surfacing rates in the absence of vessels and non-speed crafts (ANOVA: F= 3.735, p= 0.025, d.f.= 2). A post-hoc Tukey test identified there was no significant difference in the surfacing rate of *P. phocoena* in the absence of vessels and the presence of non-speed crafts, but the surfacing rate in the presence of speed crafts was significantly reduced compared to all other groups (Table 4). The mean surfacing rate of harbour porpoise in the absence of vessels was 6.47 min^{-1} (+/- 0.203, n = 159), for non-speed crafts the mean surfacing rate was calculated as 6.7 min^{-1} +/- 0.378 (n = 50). In the presence of speed crafts, the mean surfacing rate was 3.4 min^{-1} (+/- 1.029, n = 7) (Figure 5).

Regression analysis showed that the number of crafts within 5 km of the individual(s) had no significant effect on the surfacing rate of individuals (F (1,212) = 3.057, p= 0.082) (Figure 6). The regression value between the two variables was R^2 = 0.010, indicating that the number of vessels within 5 km of the individual only accounted for 1% of the variability in the surfacing rate of the individual.

3.3 | Behavioural State

A Chi-squared test highlighted that in the presence of marine crafts, there was a statistically significant change in the likelihood of individuals Feeding, Travelling, and displaying avoidance behaviour (X^2 (2) = 10.067, p= 0.007). The frequency of a porpoise detected feeding declined from 81.8% in the absence of vessel activity, to 57.6% in the presence of vessels. The frequency of travelling was found to increase from 16.4% in the absence of crafts, to 29.4% in their presence. The frequency of avoidance behaviour being observed increased in the presence of vessels, from 1.8% to 12.9% when marine crafts were within 5 km (Figure 7).

3.4 | Theodolite Tracking

Regression analysis found that the distance between a marine craft and a porpoise does not significantly influence the distance travelled underwater by a porpoise when using Point Lynas ($F(1,19) = 0.135$, $p= 0.717$) (Figure 8). There was an increase in the average distance travelled by a porpoise underwater in the presence of marine crafts, increasing from 20.7 meters to 23.2 meters in the presence of boats. However, a one-way ANOVA found there to be no significant difference in the distance travelled underwater between the two groups (ANOVA: $F= 0.298$, $p= 0.586$, d.f.= 1).

4. DISCUSSION

4.1 | Suspected Behaviour

The reduction in foraging behaviour, and concurrent increase in avoidance behaviour displayed by harbour porpoise (*Phocoena phocoena*) in the presence of marine crafts suggests that individuals may be perceiving any vessels passing through the site as a potential collision risk, causing individuals to switch from feeding to travelling away from the area or to display other avoidance behaviour. Earlier research undertaken by Pirotta et al. (2015) on Atlantic bottlenose dolphins also reported that individuals temporarily halted foraging behaviour in the presence of marine vessels, switching to avoidance behaviours to avoid contact with the approaching stimuli. The observed increase in avoidance behaviour may be occurring due to vessel noise causing increased stress levels in the organism or may be perceived as an approaching predator (Wright et al. 2007).

Studies undertaken by Wisniewska et al. (2018) on *P. phocoena* using passive acoustic monitoring also found that during exposure to 16 kHz 100 dB re 1 mPa noise, individuals ceased echolocating behaviour associated with feeding, implying a significant decline in prey capture attempts (Wisniewska et al. 2018). These findings support the results from the current investigation and are reinforced by Akkaya Bas et al. (2017) who also reported that porpoise in the presence of vessels were less likely to remain within a given behavioural state and would instead keep switching as they are disturbed. From video recordings taken during land-based watches, numerous individuals were witnessed to be displaying behaviours associated with feeding as vessels were approaching at distance, however as the vessel passed through the survey site individuals were witnessed to cease surfacing. Other individuals were observed to switch from diving in different directions, to diving in one direction, most commonly seen swimming South-East away from the feeding ground. This alteration to the diving behaviour may represent a behavioural change in the organism, switching from feeding, to travelling away from the site, therefore less time may be spent feeding, due to individuals becoming disturbed.

4.2 | Number of Individuals

The significant decline in the number of individuals sighted during observations in the presence of vessels may reflect that individuals are leaving the area during periods of high vessel traffic due to the anthropogenic vessel noise interfering with acoustic signals, while hindering their use of certain frequencies (Clark et al. 2009). As harbour porpoise use sound to navigate and find prey, the increased anthropogenic noise may make Point Lynas a less desirable feeding ground. Anthropogenic underwater noise from vessel traffic is also known to cause increased stress levels in *P. phocoena* (Wright et al. 2007). Therefore, due to the noise generated by small recreational crafts peaking at higher frequencies (leading to rapid transmission loss), individuals may not be able to detect crafts until they are within close range of the animal, which will add further to increased stress levels.

The insignificant change to the number of *P. phocoena* individuals sighted in the presence of unmotorized vessels furthers this theory, as unmotorized crafts will remain relatively undetected while using the area due to the lack of engine noise. Therefore, porpoise echolocating behaviour will not be hindered and there will be no perceived collision risk caused by the approaching vessel noise, thus reducing the likelihood of causing changes to the individuals' natural behaviours. It is acknowledged that although the average number of individuals sighted in the presence of unmotorized vessels was 4.3, the lack of significance may be attributed to the low sample size for this group (n=4). Many observations in the presence of unmotorized crafts were usually accompanied by the presence of at least one motorized vessel using the areas concurrently. Repeated exposure to anthropogenic vessel noise may lead to individuals decreasing their residency in an area, or avoiding areas completely (Lusseau, 2005; Bejder et al. 2006; Rako et al. 2013; Pirotta et al.

2015; Pérez-Jorge et al. 2016). Consequently, porpoises may select to use alternative areas where feeding conditions are less desirable but pose less stress on the animal.

4.3 | Surfacing Rate

The significant change in the surfacing rate of *P. phocoena* in different behavioural states indicates that porpoises alter their dive patterns when undertaking different activities. The significantly decreased surfacing rate observed when individuals are displaying avoidance behaviour may be because individuals are perceiving approaching vessel noise as a collision risk or predation risk, as prey are known to invoke anti-predatory techniques when a stimulus exceeds a given threshold (Frid & Dill, 2002). The reduced surfacing rate may occur due to porpoise individuals diving deeper to avoid potential contact with the approaching stimuli. This result is supported by research undertaken by Wisniewska et al. (2018) who identified that when exposed to vessel noise, harbour porpoises began swimming rapidly at a steeper angle away from the noise source, diving deeper while fluking vigorously.

The lack of a significant difference in the surfacing rate of *p. phocoena* in the presence vs absence of vessels was surprising, considering there was a significant change in porpoise behavioural state in the presence of vessels, along with a significant change in the surfacing rate of porpoises displaying different behavioural states. However, the non-significant difference in the surfacing rate of *P. phocoena* in the presence of marine crafts may reflect the highly desirable conditions provided at Point Lynas for individuals to find an abundant, reliable source of vulnerable prey compared to surrounding areas. Therefore, individuals may choose to forage even during periods of increased vessel activity and simply tolerate the heightened anthropogenic noise. Earlier findings by Wang et al. (2015) on the Yangtze finless porpoise (*Neophocaena asiaeorientalis*), also reported that individuals continued foraging in the presence of high vessel traffic. It is suggested that factors such as the quality of a foraging patch, social characteristics, health of an individual, and nature/extent of previous encounters may affect the intensity of a behavioural response (Blumstein, 2006). The lack of a significant change in the surfacing rate of *P. phocoena* in the presence of vessels may be attributed to the low sample size of surfacing rates taken in the presence of vessels compared to those in the absence of vessels (n=55). Alternatively, the lack of significance may be due to the high degree of variance recorded in the surfacing rates of individuals in the presence ($s^2 = 7.80$) and absence ($s^2 = 6.53$) of vessels. In the absence of vessels, porpoise' displayed surfacing rates, ranging between 1-14 min^{-1}.

Video analysis highlighted that for some surfacing individuals, although there was not a reduction in the surfacing rate in the presence of vessels, there was a clear change in the diving direction. Some were witnessed to continue surfacing rapidly, however instead of changing direction, would porpoise rapidly in one direction away from the feeding ground (Dyndo et al. 2015). During one interaction a speedboat was approaching at high speed, as numerous porpoise' were witnessed feeding in a concentrated patch. Individuals continued surfacing in changing directions until the craft was within <10 meters of the group, when individuals diving became very erratic, rapid, and unpredictable. Following the erratic burst some individuals were seen leaving the area South-Easterly while others were not seen again, indicating that many may have avoided surfacing completely during departure. This incident highlights the highly variable response elicited by differing porpoise individuals within the same situation and may be due to differences in individual's health or extent of previous encounters with recreational crafts (Blumstein, 2006).

The significant decline in the surfacing rate of *P. phocoena* around speed crafts such as speedboats and jet ski's highlight that these types of maritime crafts may be having a more detrimental impact on an individual's natural behaviours due to their erratic, fast movements, and undetectable nature. More negative responses may be occurring due to the high frequency noise generated by these vessels propagating less through the water column, therefore may not be detected by the porpoise until within a closer range of the individual. This lack of awareness may startle the individual and will be more likely to induce a rapid negative response (Evans, 1992; Gregory & Rowden, 2001), while larger vessels producing deeper noise will be perceived as less of a risk as the organism will detect the noise earlier and perceive it approaching as a slower speed.

4.4 | Theodolite Tracking

Theodolite tracking revealed which areas were heavily used by *P. phocoena* for feeding, and the high degree of movement across the entire area. Tracks reinforced the importance of Point Lynas as a foraging/feeding site although several porpoise individuals were tracked transiting through the area. The non-significant effect of the distance between the porpoise and craft compared with the distance travelled underwater by the porpoise may be attributed to the relatively small sample size (n= 21) for this analysis, since during interactions with vessels, on numerous occasions individuals were witnessed to simultaneously cease surfacing behaviour during a vessel pass.

Figure 9 showed that the presence of a speedboat moving through the study site at moderate speed caused the porpoise individual to clearly change its swimming behaviour. During the approach of the vessel the porpoise was witnessed diving in different directions (indicative of feeding behaviour). However, as the vessel neared, the individual switched to swimming unidirectionally north or north east away from the feeding site. This indicates that the foraging behaviour of the individual was clearly disturbed as the vessel passed and resulted in the animal leaving the area completely. By contrast, Figure 10 highlights the relatively unchanged movement pattern of the *P. phocoena* individual as the sailing boat moved through the area. From the dive track it appears that the individual continues foraging in the area during the vessel pass with no change to its behaviour. The difference in response between the two different vessel types indicates that motorized speed craft may cause more detrimental changes to an individual's behaviour than non-motorized vessels, probably due to the high frequency engine noise creating a perceived anthropogenic threat.

4.5 | Limitations

There are a number of limitations associated with this research in terms of the wider applicability of the results and limitations associated with the land-based watches. First, the findings from this research highlight the highly contextual nature of responses exhibited by *P. phocoena* in the presence of marine craft and should be interpreted with care when applied to other geographical areas. The findings from this study are specific to Point Lynas and needs to be replicated at other feeding sites to provide local context. The fact that surveys were only undertaken during the summer means that the results may not extend into the winter months as the behaviour and distribution of both predator and prey may change seasonally. Thus, the investigation should be undertaken throughout the year to provide a more comprehensive conclusion. There are also various limitations associated with land-based watches, such as the detectability of porpoises and inability to determine their true behaviour while under the water. For example, when measuring the surfacing rate of individuals, counts of 1-2 surfaces min^{-1} may be a true reflection of the animal's behaviour, or it may be that the observer missed a resurfacing due to the cryptic nature of porpoises when viewed at a distance from land (on the other hand, video recordings helped mitigate this). It can also be difficult to determine the true behaviour of *P. phocoena* at a distance and this can only be inferred from the diving behaviour of the animal. This problem is complicated by the additional use of various different observers through the study, resulting in the possibility that different observers may perceive the same behaviour in different ways. The fact that observations were taken from a static observation point meant that it was impossible to determine the true density and abundance of porpoises within the area. Finally, it is possible that during land-based watches the same individual may have been recorded more than once, or there may have been confusion over who was the target individual as no photo-ID was possible in the present study.

5. CONCLUSIONS

The results of this study indicate some levels of disturbance resulting in behavioural changes in harbour porpoise (*Phocoena* phocoena) individuals around Point Lynas, an important foraging site for the species. In the presence of vessels, the significant reduction in feeding behaviour and concurrent increase in avoidance behaviours is of particular concern, as the increased vessel usage in the area may cause not only missed foraging opportunities, but also increased energy expenditure. Any activities which interfere with the energy budgets of the animals may pose long-term negative impacts at an individual level with population consequences on biologically important processes such as reproduction (Wisniewska et al. 2018). It is clear that motorized vessels are having a more significant impact on the abundance of porpoise which are using the area than un-motorized vessels. The increased anthropogenic underwater noise caused by engine noise reduces the quality of Point Lynas as a feeding ground due to vessel noise masking important acoustic cues and increasing stress levels in the animal. As a result, the increased noise may cause long-term shifts in habitat usage by harbour porpoise, as individuals may select to use other areas which are easier to exploit but may be suboptimal in terms of food availability. Changes to the distribution of animals within the region may have large scale negative impacts on ecosystem functioning as a whole due to the predatory role that harbour porpoise play within their food web. The significant decline in surfacing rates of *P. phocoena* in the presence of motorized speed craft is further support of the negative impacts which they are causing and confirms that individuals are perceiving these types of craft as a significant threat, thus stimulating antipredator responses. This difference between motorized speed crafts and unmotorized vessels is demonstrated also by the contrasting responses of porpoises in the presence of the two different vessel types (Figures 9 & 10).

5.1 | Conservation Initiatives and Future Research Recommendations

From the results of this research, it is clear that both the number of vessels and the type of vessel within the area influences the number and behaviour of porpoises at Point Lynas. To mitigate human-wildlife conflicts and interactions, one potential conservation initiative could be the implementation of a vessel exclusion zone around Point Lynas to stop vessels from passing through the feeding ground. Since speed craft are more likely to cause detrimental impacts to natural behaviours than slower moving fishing, research and sailing vessels, it is proposed that all speedboats and jet skis should be excluded from the site to prevent startling individuals and causing increased stress levels. As the number of vessels within 5km of the site is found to influence the number of animals using the area, restrictions may be put in place to prevent numerous vessels using the area concurrently. Alternatively, around Point Lynas there could be a speed restriction zone, preventing crafts speeding through the area and reducing the chance of collision with any *P. phocoena* individuals. Such speed restrictions have been imposed elsewhere, with vessels prohibited from travelling at speeds exceeding 5 or 10 knots.

Although it is now acknowledged that differing marine craft influence porpoise behaviour to varying degrees, to further this research, it is recommended that the vessel's behaviour, speed and distance to the animal be investigated in more depth to determine whether changes in these vessel characteristics may influence the intensity and likelihood of a negative behavioural response. It is also proposed that hydrophones or satellite tags could be used to aid in providing a more holistic understanding of what *P. phocoena* are doing under the surface and potentially to detect changes in the echolocating behaviour of porpoise in the presence of marine craft. To further our understanding of how these changes in behaviour may impact the animals in the long-term, studies should aim to assess whether there are changes to the energy budgets of individuals affected and determine whether there are any negative effects on important life-history events such as reproduction and infant care.

ACKNOWLEDGEMENTS

I would first like to sincerely thank Dr Peter Evans for his continued support throughout this project, his guidance and advice have been invaluable in helping me complete this research. Secondly, I would like to thank Bangor's School of Ocean Sciences for allowing me access to all the equipment and transportation required to collect all the data required for this research. I also must give a special thank you to all the research assistants (Helen Millar, Roman Arroyo, Braden Furness, Ellie Sammer, Brandon Craven and Leonie Lepple) who assisted with land-based watches throughout, without these observers this project would have been logistically impossible. Finally, I would like to thank the Sea Watch Foundation for their ongoing contribution to the conservation of UK marine mammals and allowing this research to take place.

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FIGURES

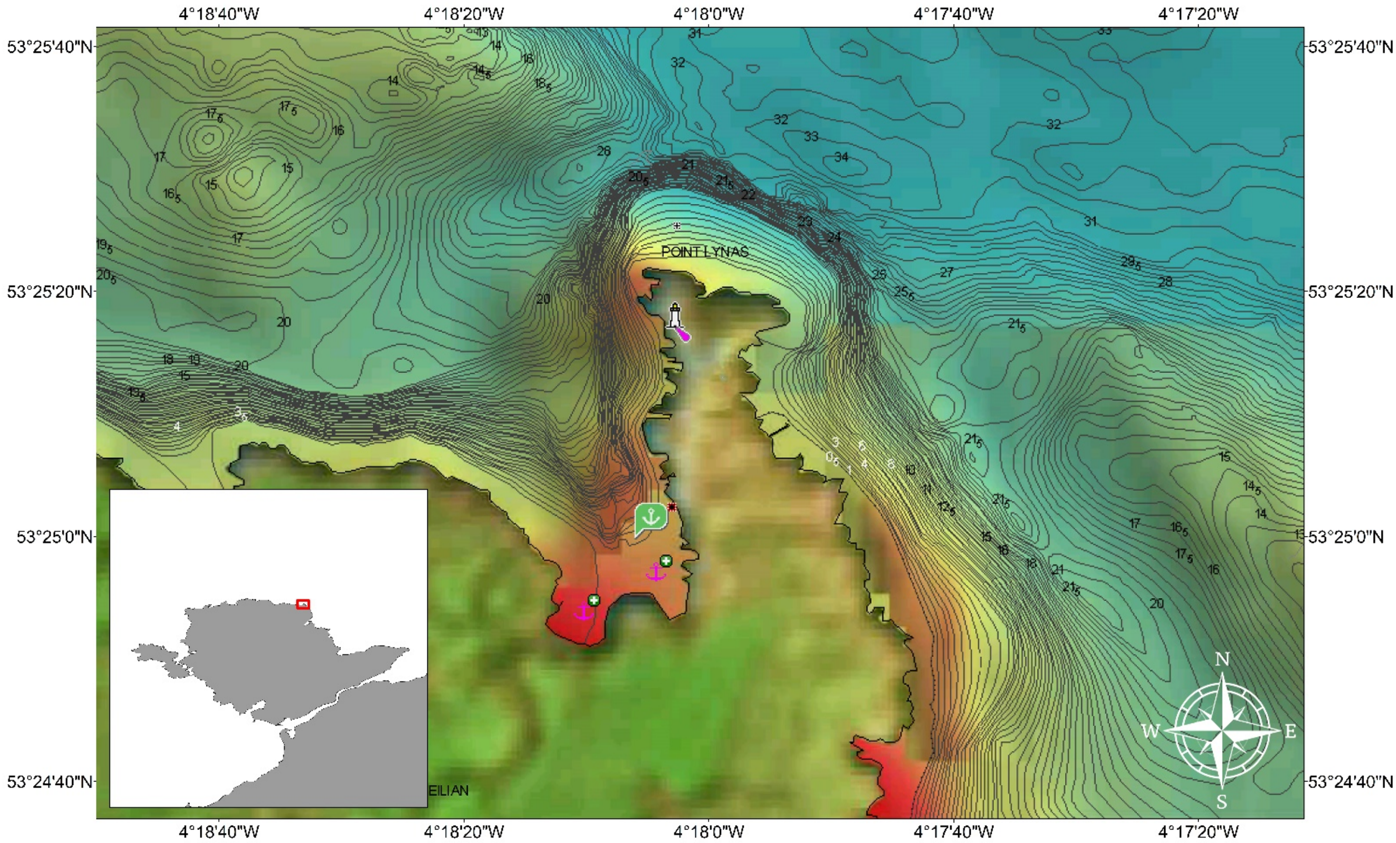


Figure 1: Displays a map of the study area, indicating the depth across the study area. Map also displays the location of lighthouse and anchor points within the Bay

Depth (Meters)
0
35

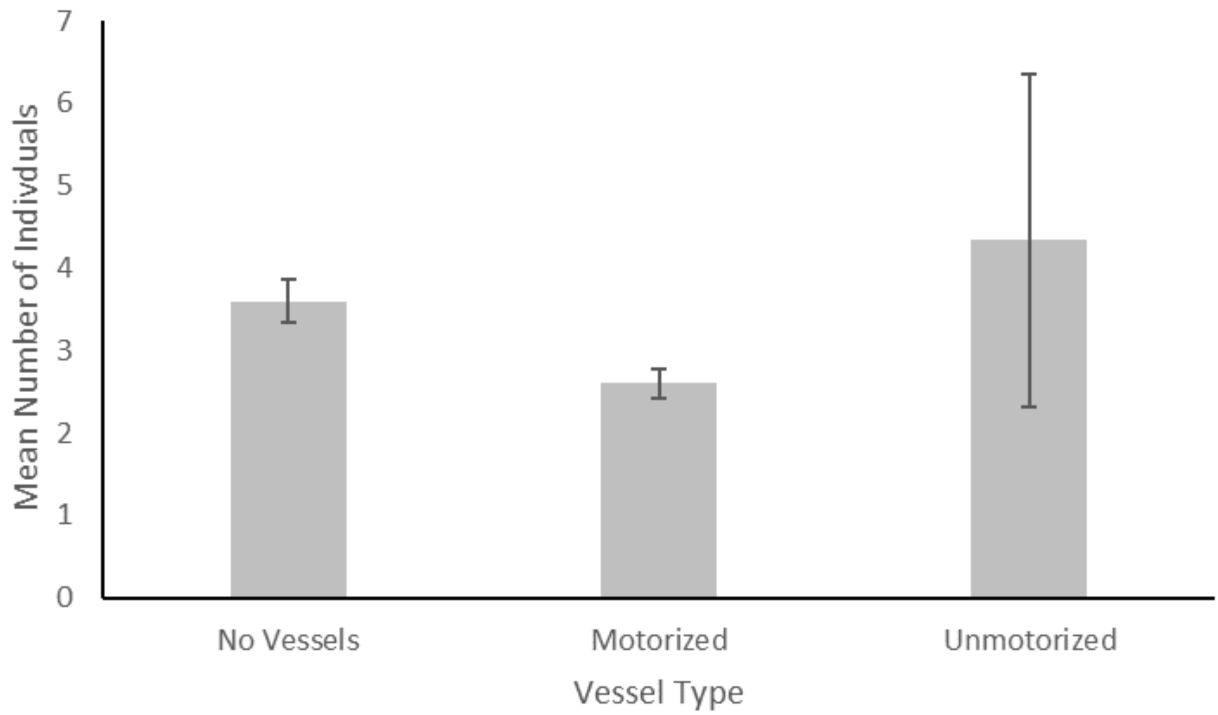


Figure 2: Highlights the mean number of Harbour Porpoise sighted from land-based watches in the absence and presence of motorized and unmotorized marine crafts. Error bars display +/- 1 Standard Error.

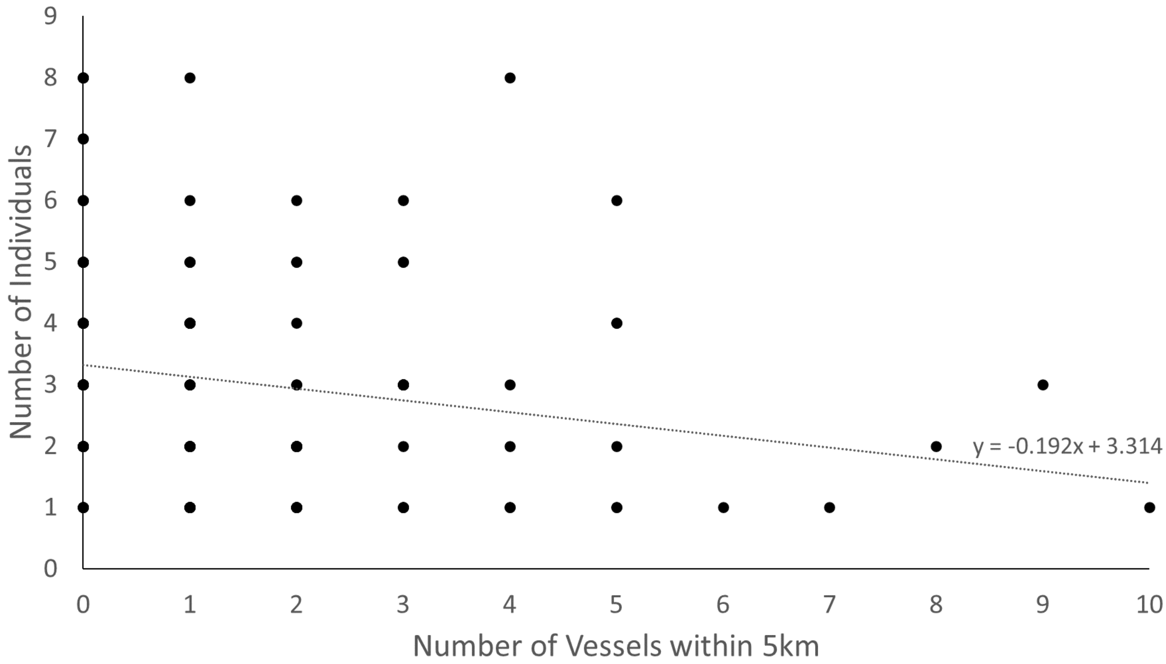


Figure 3: Displays the relationship between the number of vessels within 5km and the number of Harbour Porpoise sighted from land-based watches undertaken at Point Lynas.

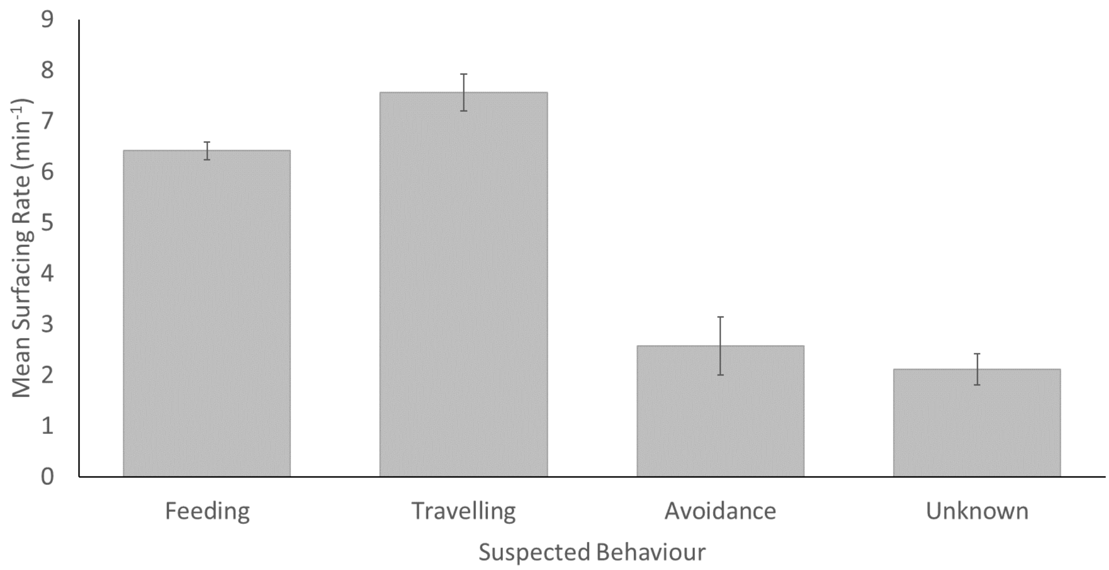


Figure 4: Displays the average surfacing rate of Harbour Porpoise displaying different behavioural states. Displaying +/- 1 Standard Error.

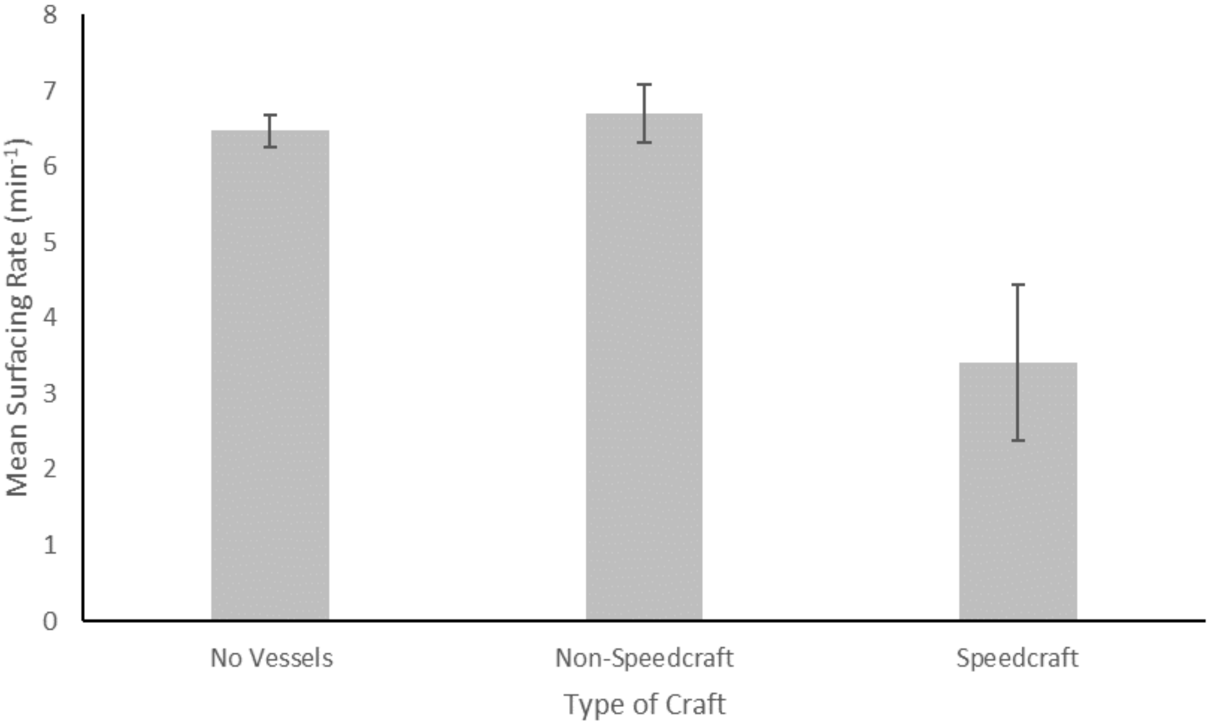


Figure 5: Displays the mean surfacing rate of Harbour Porpoise in the presence of Speed crafts, non-Speed crafts, and no vessels within 5km. Displaying +/- 1 Standard Error.

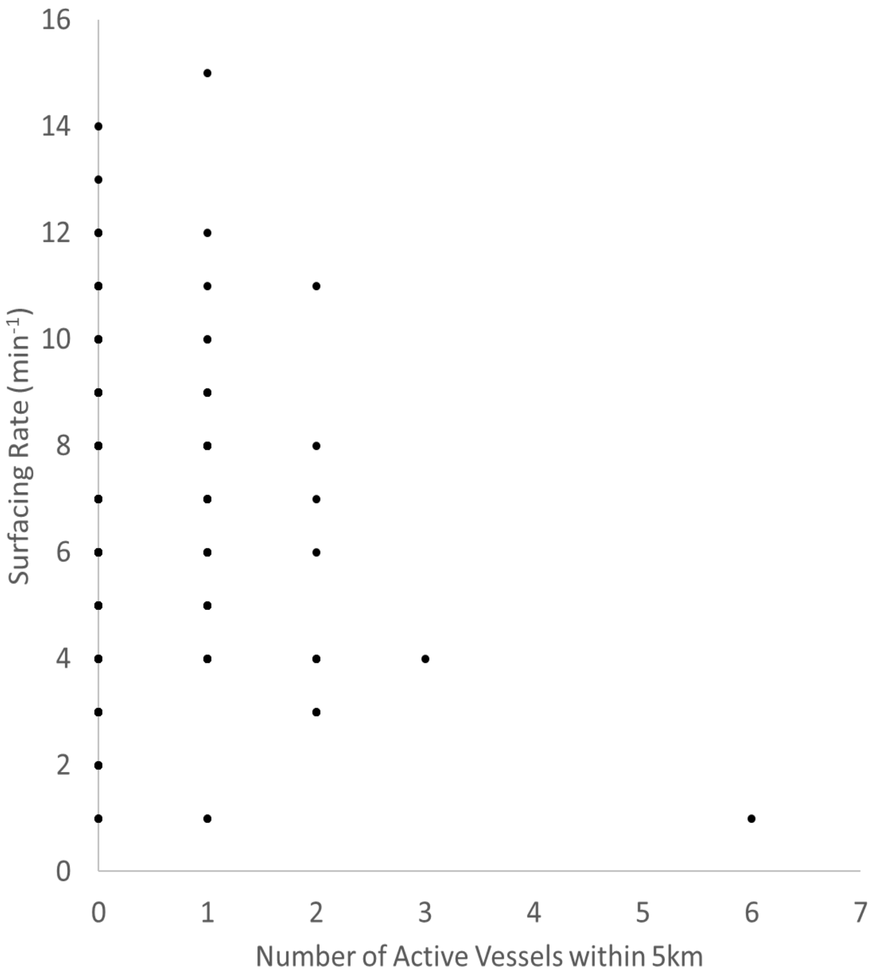


Figure 6: Displays the relationship between the number of active vessels within 5km of the feeding ground and the surfacing rate of Harbour Porpoise at Point Lynas.

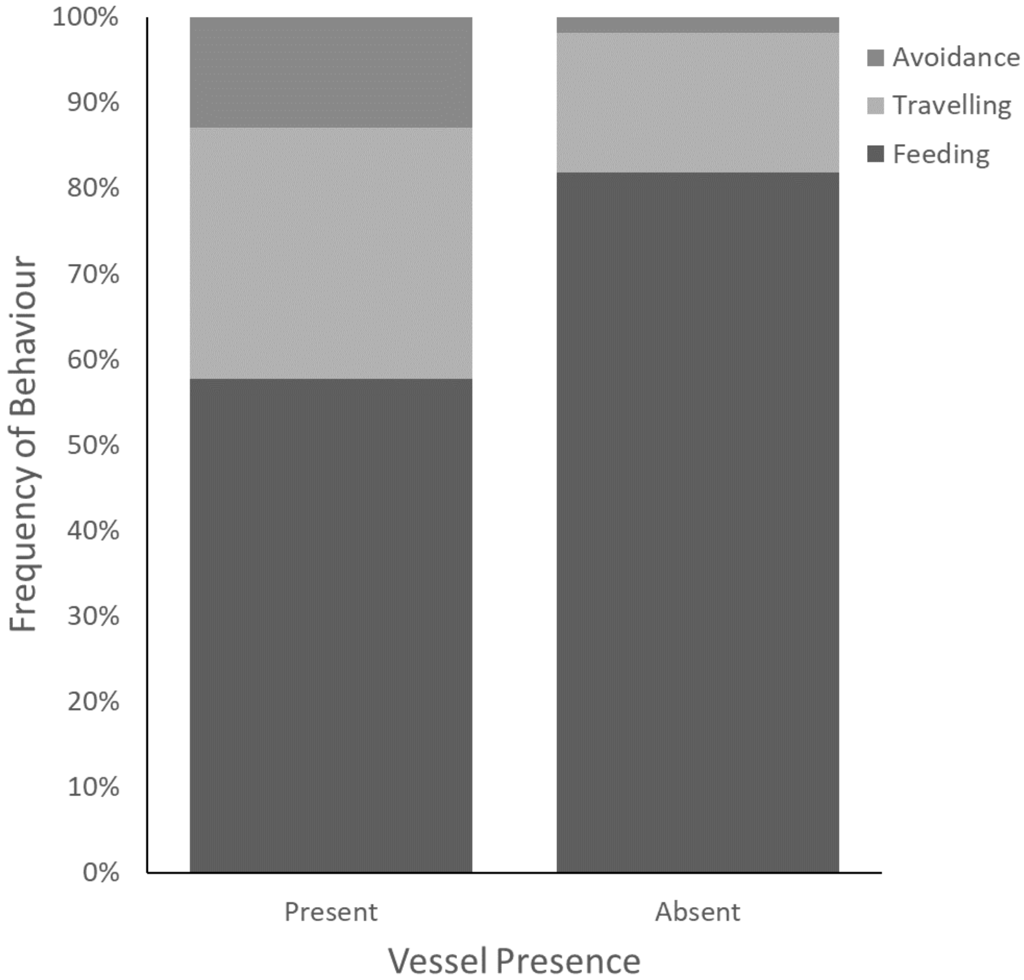


Figure 7: Highlights the frequency of each behaviour observed during land-based watches in the presence or absence of marine crafts at Point Lynas.

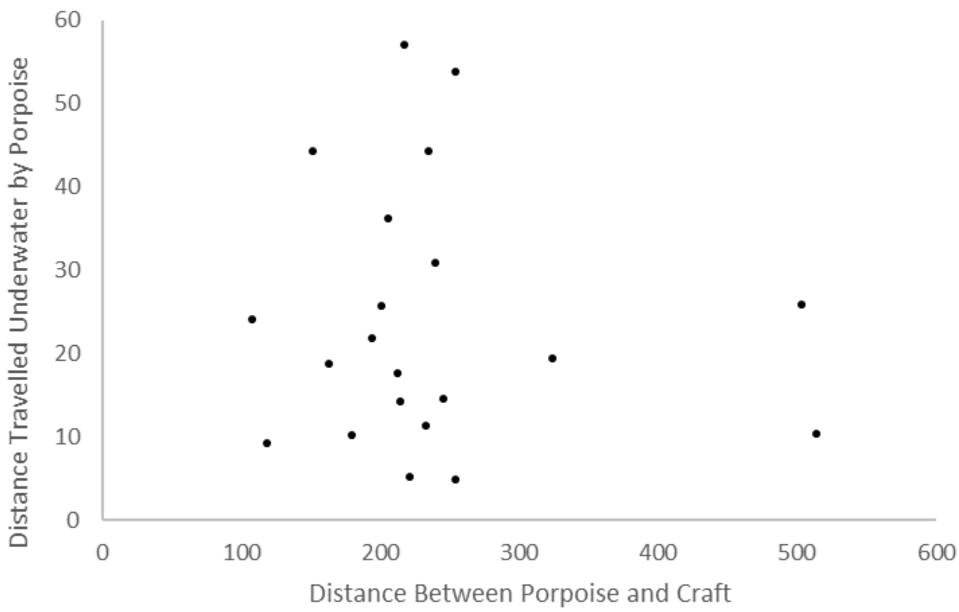


Figure 8: Displays the relationship between, the distance between the harbour porpoise individual and the craft and the distance travelled underwater by the harbour porpoise.

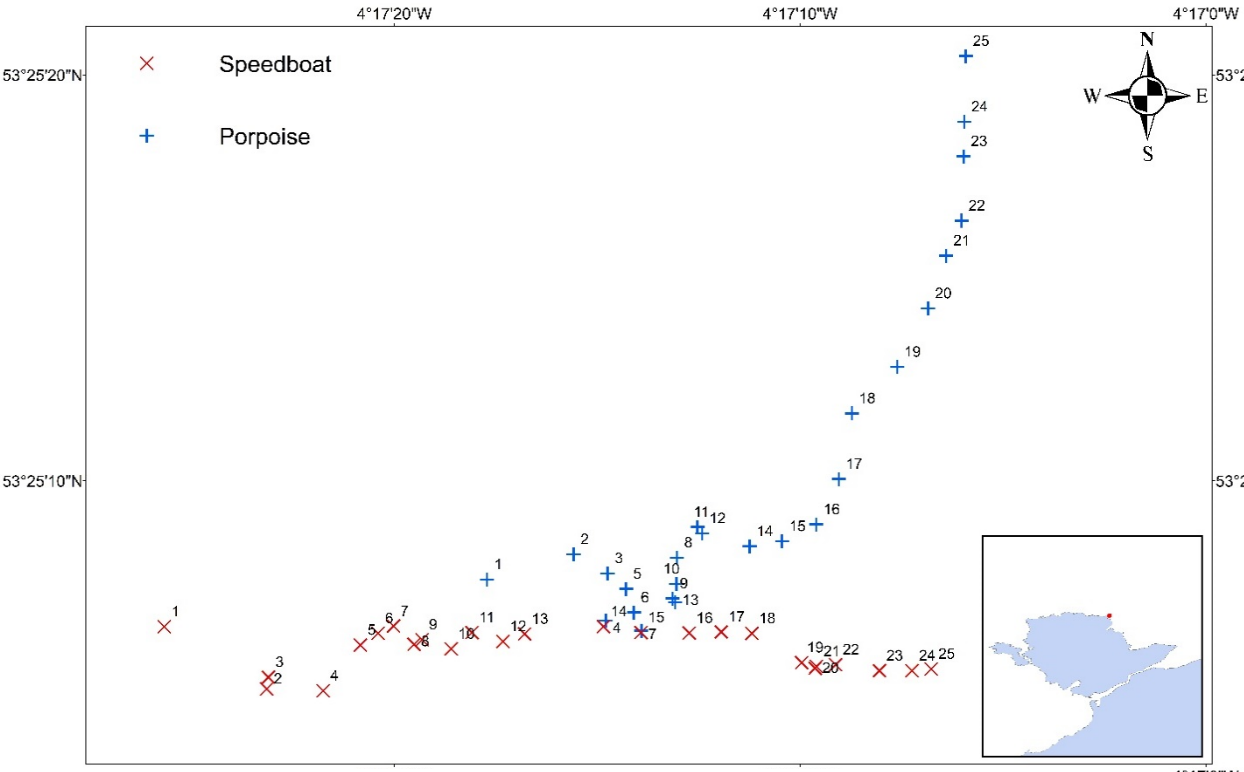


Figure 9: Displays the movement of Harbour Porpoise in the presence of speedboat passing through the study area. Numbers represent the sighting number for both the organism and vessel.

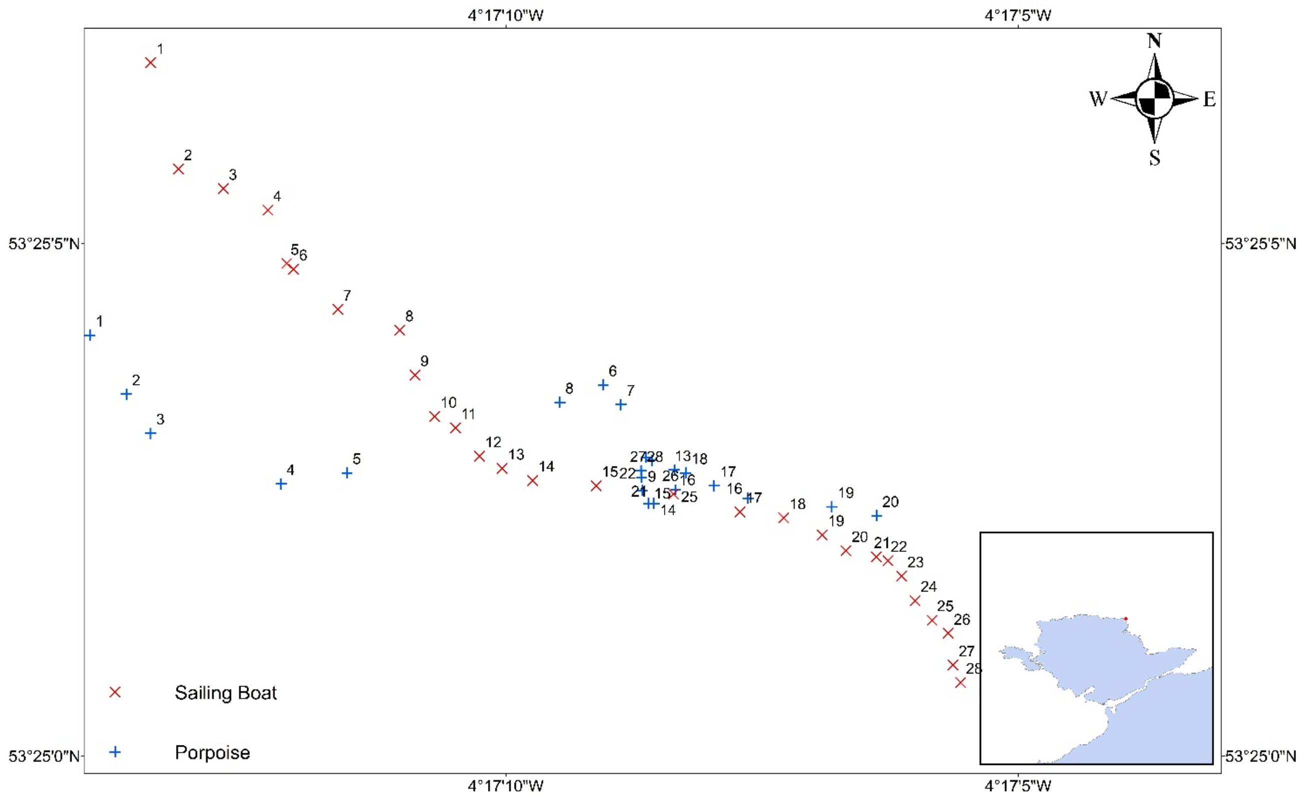


Figure 10: Displays the movement of Harbour Porpoise in the presence of Sailing Boat passing through the study area. Numbers represent the sighting number for both the organism and vessel.

FORMULAE

Formula 1: Trigonometric equations used to convert Horizontal and Vertical angles obtained from electronic theodolite every time the individual resurfaced. VA = Vertical Angle, HA = Horizontal Angle, Θ_p = Angle to Porpoise, DFT = Distance from Theodolite

$$Theodolite\ Height = Total\ Height\ of\ Theodolite\ Above\ Sea\ Level - Tidal\ Height$$

$$\theta_p = \pi - VA$$

$$Distance\ From\ Theodolite\ (DFT) = \tan(\theta_p) * Theodolite\ Height$$

$$X = \sin(HA) * DFT$$

$$Y = IF(HA > \frac{\pi}{2}, \cos(2\pi - HA) * DFT,\ \cos(HA) * DFT$$

$$Easting = Theodolite\ Easting + X$$

$$Northing = Theodolite\ Northing + Y$$

Table 4: Displays the categories used when determining the Beaufort Sea State during land-based watches at Point Lynas.

Categories	*Descriptor*
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 Blows in Streaks.

Table 3: Displays the categories used to determine the Glare and Lighting conditions during land-based watches at Point Lynas.

Categories	*Descriptor*
0	No Glare, Excellent Lighting.
1	Mild Glare, Good Lighting.
2	Moderate Glare, Moderate Lighting.
3	Strong Glare, Poor Lighting.

Table 2: Displays the pairwise comparisons of the mean surfacing rate of Harbour Porpoise obtained from the post-hoc Tukey test.

Comparison	***Mean Difference***	***Standard Error***	***P-value***
Feeding vs. Travelling	1.15205	0.34756	0.006
Feeding vs. Avoidance	3.83902	0.88686	0.000
Feeding vs. Unknown	4.29934	0.78766	0.000
Travelling vs. Unknown	5.45139	0.81432	0.000
Travelling vs. Avoidance	4.99107	0.91062	0.000
Avoidance vs. Unknown	0.46032	1.15275	0.978

Table 1: Displays the pairwise comparisons of the mean surfacing rate of Harbour Porpoise in the presence of different types of craft obtained from the post-hoc Tukey test.

Comparison	***Mean Difference***	***Standard Error***	***P-value***
No Vessels vs Non-Speed Crafts	0.23459	0.41814	0.841
No Vessels vs Speed Crafts	3.06541	1.17129	0.026
Speed Crafts vs Non-Speed Crafts	3.30000	1.20959	0.019

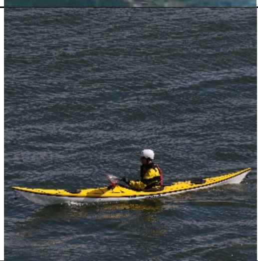
Vessel Type	Vessel Example	Reference
Small Fishing Boat		(E. Grundy, 2021)
Large Fishing Vessel		(E. Grundy, 2021)
Research Vessel		(E. Grundy, 2021)
Speed Boat		(E. Grundy, 2021)
Jet Ski		(E. Grundy, 2021)
Kayak		(P.G.H. Evans)
Sailing Boat		(P.G.H. Evans)

Table 5: Displays the different marine crafts seen throughout land-based watches

Table 6: Displays the pairwise comparisons of the mean number of Harbour Porpoise in the absence and presence of motorized / un-motorized crafts at Point Lynas.

Comparison	***Mean Difference***	***Standard Error***	***P-value***
No Vessels vs Un-Motorized	0.7333	1.06202	0.769
No Vessels vs Motorized	1.00244	0.31220	0.005
Motorized vs Un-Motorized	1.73577	1.05294	0.229

LAND-BASED EFFORT & SIGHTINGS RECORDING FORM

sea watch FOUNDATION

Day/Month/Year .... **Site Name** .... **Latitude** .... ° .... ' N **Longitude** .... ° .... ' W ☐ E ☐

Obs. Name/Address .... **E-mail:** .... **Tel:** ....

Effort and Environmental Data: make a new record every 15 minutes or when there is a break in effort.

Effort Time (GMT or BST?) Start	End	**Sea state**	**Swell height**	**Visibility**	**Glare / Lighting**	**Active Vessels within 5 km**	**Additional notes**

Sightings: make a new record for each sighting – start a new form if necessary.

Sighting Time		**Species**	**Confidence**	**Group Size**	**Number of Calves**	**Number of Juveniles**	**Bearing to Animal**	**Distance from Coast**	**Animal Heading (e.g. N or SW)**	**Behaviour**	**Associated Seabirds**
First seen	**Last seen**										

DATA DEFINITIONS: *use categories provided where possible* *Continue on separate sheet if necessary*

Sea State: 0 = mirror calm; 1 = slight ripples, no foam crests; 2 = small wavelets, glassy crests, but 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 blows in streaks

Swell Height: Light = <1m; Moderate = 1-2 m; Heavy = >2 m **Visibility:** < 1km; 1-5 km; 6-10km; >10km

Glare / Lighting: 0 = no glare, excellent lighting; 1 = mild glare, good lighting; 2 = moderate glare, moderate lighting; 3 = strong glare, poor lighting

Boat Activity: Record No of each and type: NB = No boats, VE = unspecified vessel, YA = yacht, RB = row boat or kayak, JS = jet ski, SPB = speed boat, VPB = visitor passenger boat, MB = motorboat (unspecified), FI = fishing boat, FE = ferry, LS = large ship, SV = seismic vessel, WA = warship

Species Confidence: Definite (DEF); Probable (PROB); Possible (POSS) **Group Size/Calves/Juveniles**: Give total number, identifying any obvious calves or juveniles (based on relative size)

Bearing to Animal: Compass bearing in degrees **Distance from shore:** Estimate distance from nearest piece of coast (express whether metres or kilometres)

Behaviour: Surfacing (SURF), Slow (SS), Normal (NS) or Fast Swim (FS); Feeding (FEED); Leap/Breach (LEAP); Bow-Ride (BOWR); Body Slap (BODSL), Tail Slap (TAILSL), Flipper Slap (FLIPSL); Spy-hop (SH); Bottling in Seals (BOT); Logging (LOG), Milling (MILL); Aggressive (AGG), Socialising (SOCIAL), Sexual/Mating (SEX)

Please return forms either digitally at formsswf@gmail.com (as jpg or pdf) or by post to Sea Watch Foundation, Ewyn y Don, Bull Bay, Amlwch, Anglesey LL68 9SD, UK

Figure 11: Sea Watch Foundation land-based watch sightings and effort forms

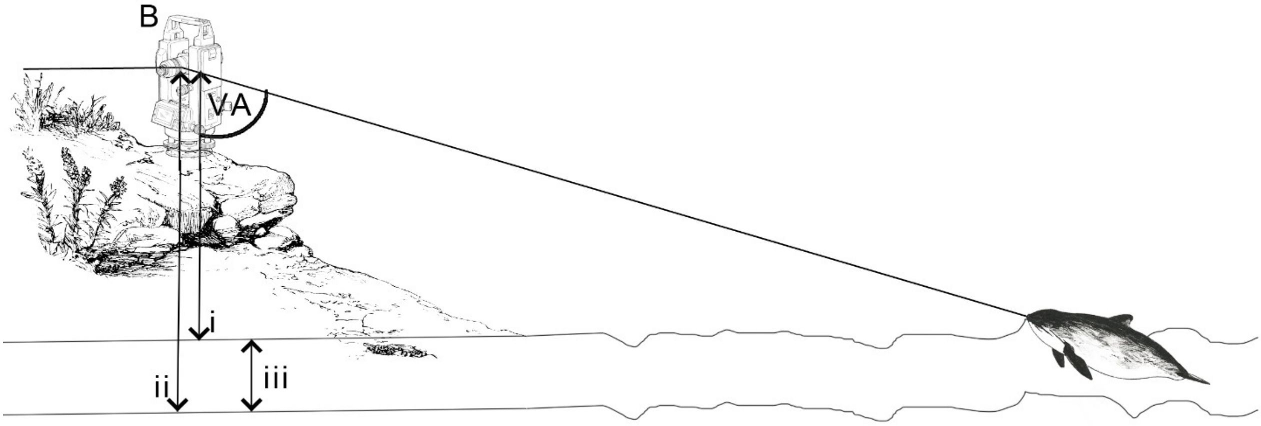


Figure 12: Displays the angles and distances used to convert theodolite vertical and horizontal angles into GPS coordinates of harbour porpoise, using the known location of the theodolite. (i) Theodolite Height from sea level, (ii) Theodolite Height from ground, (iii) Tidal Height, (VA) Vertical Angle.