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Occupancy patterns of sea birds in relation to oceanographic conditions at sites on the Llŷn Peninsula

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Abstract

With the current increase in the emergence of offshore renewable energy installations it is becoming increasingly important to monitor and study seabird populations. In order to understand the potential impacts of these installations we must first understand the spatial and temporal factors affecting seabirds site usage which may then inform future monitoring and management.

In this study a series of shore based surveys were carried out to assess the occupancy patterns of seabirds in relation to oceanographic conditions at three sites along the Llŷn peninsula. One site, named Bardsey Sound is a proposed site for tidal energy extraction due to fast current speeds moving through the area, compared with the two other sites with slower average current speeds recorded. Statistical analysis was carried out on the collated data to identify differences in sightings between the three locations, as well as differences in the number of sightings associated with tidal phase.

The results of the study show significant differences between the number of seabird sightings at the three locations, specifically that total seabird sightings, kittiwake and razorbill sightings were significantly different at Porth Dinllaen, to Porth Colmon and Bardsey Sound. A relationship with the tidal phase could not be deduced from this study and future work should focus on looking at these relationships to inform the safe operation of the potential tidal turbine. This would ensure minimum effect on surrounding seabird populations. However, this study is successful in showing an initial insight into how seabirds are using the sites in this area, the possible reasons for these preferences and provides a foundation for future research.

Background

It is broadly understood that to alleviate the detrimental impacts of anthropogenic climate change and to meet global carbon reduction and sustainability targets it is imperative to shift global energy from fossil fuels to energy from renewable sources (King, 2004). The UK government plans to increase the percentage of energy derived from renewable resources from 5% in 2011 to 30% by 2020 (DECC, 2009). The marine environment has great potential to harness energy, which has led to the increase in demand for offshore renewable energy developments. The alternative onshore renewable energy devices being in some cases particularly unfavourable due to competition with other land uses, because the infrastructure may be unsightly leading to societal conflict as well as many environmental impacts associated with installation and operation (Devine-Wright, 2005). The use of tidal energy, which encompasses tidal stream energy and tidal range energy is a favourable form of electricity generation. It is a reliable and predictable source, unlike alternatives such as, offshore wind energy. Moreover, tidal energy is an abundant resource which has the potential to produce a dependable electricity supply.

The increase in offshore renewable energy development makes increased studies investigating potential impacts on the surrounding marine environment necessary (Willsteed *et al.*, 2017). Grecian *et al.* (2010) suggested there are numerous negative effects for marine birds associated with the installation and operation of marine renewable energy devices, including disturbance, habitat degradation and collision risk. Marine birds may also be affected by wave and tidal power devices due to changes in oceanographic parameters which may in turn affect food availability and foraging success. Grecian *et al.* (2010) also highlighted some potential positive effects on marine birds; de facto protected areas may be created due to restricted fishing and other anthropogenic activities as well as creation of new habitats, the ‘artificial reef effect’ (Langhamer, 2012). The artificial structures are colonised hosting and aggregating fish and decapods in greater densities, which may lead to increased prey availability. Despite Marine Renewable Energy Instalments (MREI) having both potential beneficial and detrimental effects on the surrounding environment there is little evidence for this and Grecian *et al.* (2010) suggest further study into this topic and recommend policy makers decide carefully on potential sites and whether efforts are made to minimise negative environmental impacts or designed with the purpose of restoring the ecosystem.

As the marine renewable energy sector develops effort also needs to be focused upon creating efficient ways to monitor target species. Under the European Directive: 85/337/EEC there is a legal obligation to access and mitigate the negative impacts of tidal stream effects on deep sea diving birds. The global increase in tidal stream turbine installations, has led to an increased need to identify and mitigate potential impacts on sea birds. Waggitt *et al.* (2017) carried out shore surveys to assess the usage of different microhabitats with contrasting current speeds and across different tidal states. The collection of such data may be used to protect vulnerable sea bird populations in the future and can be used to inform and direct marine renewable energy developments to manage the potential detrimental effects upon surrounding marine life.

Tidal streams are highly variable environments, specifically with fluctuating current strengths that may lead to changes in prey availability. This creates times of preference throughout tidal phases at which marine animals may use the environment. Many species are attracted to tidal stream environments for several different reasons; channels of fast flowing water may be used by birds for navigation from breeding to foraging areas and for annual migrations. There is also evidence that suggests animals favour tidal stream environments due to increased foraging opportunities (Zamon 2001, 2003).

Conservation Considerations

It is important to monitor sea birds to conserve and manage vulnerable species. Sea birds may be used as ecological indicators, offering information about the health and status of an ecosystem, breeding success may be a useful indicator of the conditions of the surrounding marine environment. They are also sensitive to variations in food supply and therefore may be used to monitor lower trophic level status. As top level consumers within the marine food web they can offer the opportunity to detect changes in physical parameters that may in turn have ecological effects on the entire ecosystem. In this way, sea birds can be used for ecosystem management to develop goals for policy and conservation (Kruse *et al.*, 2006).

There are several conservation initiatives that protect sea bird species within the UK. Under European law, the Birds Directive is the instrument used for conservation of wild birds in Europe. It is under this directive that member states are required to designate special areas of protection (SPAs). SPAs are strictly protected sites classified within Article 4 of the EC Birds Directive (JNCC). These SPAs are crucial for the protection of rare and vulnerable species across the UK and play a major role in conserving sea bird populations in the light of current and future anthropogenic threats.

Literature Review

Monitoring methods

<u>Vantage Point Survey</u>

Vantage point (VP) surveys have emerged as a useful method for assessing the distribution of marine animals in a proposed site for tidal stream energy. VP surveys may be undertaken on land, from elevated positions. Binoculars or a telescope are used to scan an area of ocean, and any animals seen at the surface are recorded with location, behaviour and species. A vantage point survey is an approach to recording observational animal data at the surface, it can be as simple as a count of animals seen at the surface in a snapshot of time or it may be more complicated where positional data is noted using a compass bearing with distance or angle of declination (Scottish Natural Heritage, 2016).

Some constraints of shore based surveys include the increasing difficulty in the ability to detect seabird species and behaviour with increasing distance or if there is a rough water surface, leading to undercounting (Waggitt and Scott, 2014). The vantage point must also be chosen carefully with a suitably elevated position and a good view point for effective data collection. Another drawback to this method is that the quality of the data is dependent upon the weather conditions, this method of survey is ineffective above sea state 4 (Scottish Natural Heritage, 2016). Shore based surveys may also be unsuitable for monitoring large scale installations

(Waggitt *et al.*, 2014) where issues of spatial variation in the detectability of birds and monitoring in large channels over vast areas may become increasingly difficult. Waggitt *et al.* (2014) suggests this type of survey may be most appropriate for small tidal passes where several observers in different locations may be used to ensure that birds are not undercounted.

There are a number of studies in tidal passes investigating the fine scale foraging distributions of different species (Holm and Burger 2002 ; Zamon, 2003) In some cases it may be effective to combine shore based and vessel based surveys as suggested by Giacoma, Papale, & Azzolin (2013) in a project monitoring bottlenose dolphin community in the Pelagic Archipelago. This study was undertaken to see if shore based surveys could be used as an alternative to vessel based surveys when monitoring cetacean species. In the study, both were found to be effective if used together and this may be the case in numerous other projects where the combination of these surveys may generate broader more accurate results.

<u>Vessel- based survey</u>

Boat based surveys have been used as a favourable way to monitor sea birds for some time, methods are standardised through the European at Sea (ESAS) to produce reliable data throughout Europe. Methods may include recording of birds seen within transect lines parallel from a boat. According to Scottish Natural Heritage (2016) the main constraint associated with vessel based surveys is survey conditions where weather and sea state may often be a limiting factor, with restricted opportunity to collect data due to short days in winter and unpredictable weather conditions. This may result in limited spatial and temporal data (Waggitt *et al.*, 2014). Another problem with these surveys is the availability of survey vessels appropriate for the work as well as qualified and experienced surveyors. Although on a large-scale vessel based surveys may be effective for monitoring sea birds, for fine scale observations some microhabitats may be under sampled due to limited ship manoeuvrability (Waggitt *et al.*, 2014).

Vessel based surveys may be useful when combining biological (distribution and abundance) data with oceanographic data. Vessels with mounted echosounders may be used to obtain bathymetric data such as seabed roughness and hardness, using zig zag and vessel based transects (Waggitt *et al.*, 2016). Observational data may also be collected by using similar techniques to shore based surveys, observers can provide accurate positioning's of seabirds at the surface and can identify bird's behaviour more easily due to a closer proximity than studies undertaken from the shore.

<u>Telemetry</u>

Telemetry involves attaching a radio transmitter to an animal and then tracking the signal to determine the animal's movements. Signals from tracked devices can obtain data such as: location, depth, temperature, light, salinity, acceleration, speed, acoustics and physiological parameters (Block *et al.*, 2016).

Telemetry can provide oceanographic data in real time and in remote areas that may be otherwise inaccessible or highly expensive to monitor by other methods. Other tracking methods such as mark-recapture/ resight studies do not allow such detailed information to be gathered, as birds may not be seen for long periods of time after being tagged. However, telemetry is labour intensive and generally only a small number of animals can be tagged at one time. This can make it hard to detect overall patterns in foraging behaviour (Zamon, 2001). It is suggested by Hart and Hyrenbach, (2010) that studies would benefit from individuals being tagged across multiple sites to account for different geographical locations and tagging should take place over a number of years to account for interannual variability.

Telemetry may be used to monitor bird's movements over differing spatial scales, for example local movements within breeding colonies to routes used for migration (Fuller *et al.*, 2005). Observations gained from telemetry enable scientists to sustain populations and biodiversity and implement ecosystem-based management due to increased knowledge of behaviours, processes and ecosystem functioning (Block *et al.*, 2016).

Tagged animals can also be used to identify patterns in habitat utilization, which may allow the mitigation of the impacts from marine industrial developments such as offshore renewable energy. Tags may be used to gather baseline behaviour and movement data to aid agencies with Environmental Impact Assessments an essential pre-requisite to any development. Animals behaviour's and responses may also be monitored around an operating renewable energy device for example a tidal turbine. Tagged animals may be used to understand how animals respond to the device and how their movements may change as a result of the installation (Sparling *et al.*, 2017).

Previous Study

<u>Currents</u>

The main reason for sea birds being attracted to tidal stream environments is believed to be the increased foraging opportunity. Different species of seabird have different prey preferences as well as foraging techniques. Some forage plankton near the surface, including gulls, albatrosses and storm petrels. Others dive in pursuit of prey, 'pursuit diving birds' dive to great depths in the water column (Waggitt *et al.*, 2016). Another reason for marine birds being attracted to tidal-stream environments is because of enhanced prey vulnerability (Embling *et al.*, 2012). Focusing foraging effort at times of increased prey vulnerability has been shown to increase foraging success.

Studies have been undertaken considering how diving sea birds use oceanographic conditions when foraging in areas that are suitable for tidal energy extraction. Studies generally found that interactions of species with tidal currents and topographic features play a role in marine predator-prey dynamics (Zamon, 2001). The findings may be used to identify times when interactions are most likely to take place and this may help to inform developments and mitigate potential impacts. However, there have been contrasting findings when it comes to sea bird's interaction with tidal currents. Waggitt *et al.* (2016) observed the relationship between two benthic foraging sea birds black guillemots *Cepphus grille,* European shags *Phalacrocorax aristotelis* and several predictable oceanographic conditions (current speeds, water elevation, turbulence). As a result of these birds foraging benthic and epibenthic organisms they are particularly susceptible to the risk of collision. At the study site, it was found that the collision risk may be decreased if the tidal turbine was operated during both lowest water elevation and lowest horizontal current speeds, due to findings that the density of species decreased with increasing horizontal current speed. Waggit *et al.* (2016) suggested this may have been because higher flowing water caused an increased energetic cost when diving.

In another study, Holm and Burger (2002) investigated the distribution and behaviour of 21 species of diving bird off Vancouver Island, Canada. This study highlights the importance of studying different species behaviour around these oceanographic features. Ancient Murrelets *Synthliboramphus antiquus, a* plankton feeder foraged more often in deeper water with a fast-tidal flow and increased turbulence. Whereas, pelagic cormorants, Phalacrocorax pelagicus, a piscivorous feeder made use of areas with slower currents. Birds foraging on benthic organisms were found to be foraging mainly in relatively shallow, slack water with minimal turbulence. The uncertainty surrounding the data obtained from these studies suggests that this is an area needing more research and that it is particularly important to focus research on different species as well as in different locations.

<u>Tidal Phase</u>

In coastal waters the abundance and accessibility of prey is often influenced by tidal temporal variability (Nol and Gaskin, 1987; Holm and Burger, 2002). Several authors have suggested that in coastal areas where rips and jets may occur the energy flow to piscivorous predators is strongly associated with the tidal phase (Hunt *et al.*, 1999; Zamon, 2001) this is referred to as the tidal coupling hypothesis (Zamon, 2003).

Several studies have investigated the relationship of seabird presence with tidal phase, prey species may also often be considered to understand predator prey interactions and seabird habitat preferences. For example, Embling *et al.* (2012) investigated the relationship between sandeel, *Ammodytes* spp. schooling and kittiwake *Rissa tridactyla* foraging with tidal currents. Throughout all surveys sandeels were found to be aggregated close to the surface at times of maximum ebb tide, similarly high numbers of kittiwakes were also seen at maximum ebb suggesting they were exploiting the spatially and temporally predictable surface aggregations found at phase of tide. Similarly, Irons (1998) also found kittiwakes to focus their foraging trips on maximum ebb and flood tide. Alternatively, Cox *et al.* (2013) findings were not consistent with past studies, kittiwake foraging trips were found to be lowest on maximum flood and ebb tides, thought to be because surveys were not carried out in the right location at the right time to sample foraging events effectively. However, guillemots were also included in the study and were found to have a strong positive association with increasing and maximum ebb tides, which coincided with increasing prey density found at ebb tide. Another study considered the relationship of seabird foraging with the spring-neap tidal cycle; Scott *et al.* (2013) sampled the foraging locations of gannets and storm petrels over contrasting habitats: a bank and flat area, over daily tidal cycles during spring and neap tides. Higher densities of foraging gannets were significantly more likely to be found on ebb tides in both bank and flat regions, and gannets were seen in much higher densities at neap tides than spring tides, due to lower tidal speeds during neap tides, resulting in less turbulent mixing and a more stable water column, creating opportunity for increased primary production (Sharples, 2008) and increased aggregations of zooplankton.

Aim of the study
The aim of this study is to observe contrasting occupancy patterns of sea birds at three sites along the north coast of the Llŷn peninsula in relation to oceanographic conditions and suggest how this may influence future development for tidal energy extraction in this region.

Objectives
1. Collate data on bird sightings at three contrasting sites along the Llyn Peninsula.
2. Test to investigate whether there are statistical differences between the number of birds using each site.
3. Test to investigate the relationship between bird sightings and the tidal cycle.
4. Correlate sea bird sightings with physical properties of each site: current speed and depth.
5. Comment on the implications of tidal energy extraction at Bardsey Sound in regards to the findings of this study, use the findings of this study to inform the safe operation of the turbine at times of low site usage.

Structure of the thesis
This paper first describes the locations in which the data was collected; their relevance to the original question, so providing justification for the sites chosen for the study. The primary data collection techniques are outlined and the subsequent statistical analysis carried out is also explained. Then the results are displayed in a series of bar charts providing a clear visual representation of the differences observed between sites, and the main findings of the study are presented. These findings are then discussed, with suggestions made to explain how these findings relate to the physical oceanography of the area. Finally, the implications of the sea bird sightings are then considered in terms of the plan to develop tidal energy project at Bardsey Sound.

Methods

Study Area
Surveys were carried out at sites along the Llŷn Peninsula; a projection of land extending 30 miles into the Irish sea from north Wales, South west of the Isle of Anglesey, its location within the UK is shown in Figure 1. The rocky shoreline and offshore islands of the Llŷn Peninsula provide refuge for an abundance of nesting sea birds in the summer breeding season; such as Manx shearwaters, puffins, razorbills, guillemots, black guillemots, shags, cormorants and kittiwakes, and is therefore a prime spot for bird watching. The area also acts as an important route for migratory birds with a ringing station in place on Bardsey Island to record birds in transit.

Lying just off the tip of the peninsula, Bardsey Island is a great bird watching location. The area is a designated Special Protected area due to its large breeding colony of Manx shearwater present in the summer months. There is also another large seabird colony on the east side of the island supporting 11 species of seabird including the kittiwake, storm petrel, razorbill and guillemot.

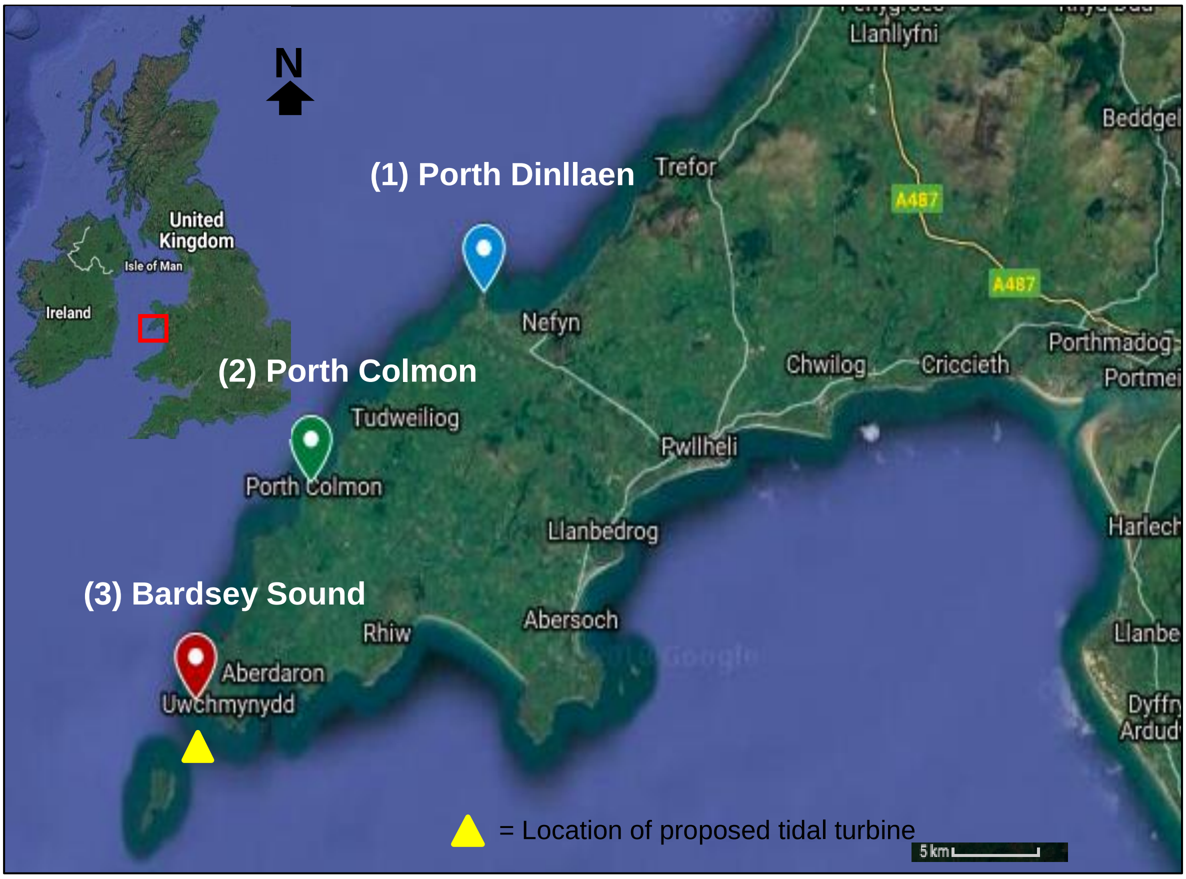

Figure 1: Map of study area, Llŷn Peninsula location within the UK, as well as location of sites along North coast of the peninsula, Porth Dinllaen, Porth Colmon and Bardsey Sound. (Map data: Google; Landsat / Copernicus ©2019 DigitalGlobe, Data SIO, NOAA, U.S. Navy, NGA, GEBCO; © 2018 Google; © 2009 GeoBasis-DE/BKG)

Despite this, in 2017 the tidal energy company Nova Innovation was given an Agreement for Lease to conduct study into the area of water in Bardsey Sound, positioned between Bardsey Island and the tip of the Llŷn Peninsula. The site finds itself suitable for tidal energy extraction due to the strong tidal current in the area with flows recorded of up to 9 knots. A 12-month Environmental Impact Assessment (EIA) is to be conducted to evaluate the possible environmental impacts of the proposed development.

Due to an extensive seabird population on Bardsey Island and the prospect of a tidal turbine within the sound, this area was chosen as a site for surveying. A comparison of bird sightings could be made between a site suitable for tidal energy extraction and sites not suitable for tidal energy extraction, such as the other two chosen sites: Porth Dinllaen and Porth Colmon. The three sites had differing physical properties allowing for a comparison of sea bird sightings between the sites, and investigation into the reasons for these differences and the implications of these findings. Porth Dinllaen and Porth Colmon are also popular locations for bird watching on the Llŷn peninsula and are also areas known to be used by sea birds, ensuring enough sightings to carry out statistical analysis.

Species of interest

Despite observing an abundance of different seabird species during the surveys, the study focuses on three particular species, to ensure the project was manageable within the time frame. The species were the black legged kittiwake (*Rissa Trydactyla),* the northern gannet (Morus bassanus) and the razorbill *(Alca torda).* These species were chosen due to their different foraging techniques and habitat preferences which would make for interesting comparisons between sites.

Kittiwake

The black legged kittiwake is a medium sized gull with a small yellow bill, characterised by wings with black tips. Kittiwakes are surface feeders and feed mainly on sand eels (*Ammodytes* spp.). They are particularly vulnerable to changes in marine ecosystems with declines in breeding success linked to fisheries exploitation of sandeels (Daunt *et al.*, 2008).

Gannet

Northern gannets are large seabirds capable of travelling hundreds of kilometres from breeding grounds to foraging areas. They feed on a broad range of prey species and sizes (Hamer *et al.*, 2000); this together with their ability to travel long distances makes them less vulnerable to impacts from environmental variability (Montevecchi *et al.*, 2009).

Razorbill

Razorbills are stocky medium sized birds that are known as 'pursuit divers', using their wings to propel them through the water (Mitchell *et al.*, 2004; Davis *et al.*, 2005). Local declines in numbers and productivity have been noted by Mitchell *et al.* (2004) and Heath *et al.* (2009), and the razorbill therefore has an amber status on the list of UK birds of Conservation Concern (Eaton *et al.*, 2009).

Data collection

Shore based surveys were performed at three sites along the north coast of the Llŷn Peninsula: (1) Porth Dinllaen (52° 56'49.9'N, 4°34'01.6'W), (2) Porth Colmon (52°52'31.9'N, 4°41'12.3'W), (3) Bardsey Sound (52°47'40.4'N, 4°45'58.1'W), see Figure 3. The survey period spanned 9 days from 14th June to 22nd June 2017. All surveys were undertaken during the breeding season where breeding adults were nesting and rearing chicks. Sites were spread approximately 13 kilometres' distance from each other.

Observers were positioned at fixed, predetermined vantage points at each of the study sites. Vantage points were allocated ensuring sufficient elevation; allowing good visibility of the entire site, as well as considering the accessibility with equipment and safety of observers. Survey methods were adapted from those outlined by Waggitt *et al.* (2014). Surveys were generally 2 hours in length and scans were undertaken every 5 minutes using Optictron binoculars at x10 magnification, to allow for a short rest period between each scan to record data and avoid observer fatigue. Scans consisted of one steady sweep across the survey area fast enough so seabirds did not redistribute but not so fast that individuals were missed, effort was also made to ensure scans were equal in duration. Whilst performing the scan observers recorded bird sightings, including: species, number, behaviour and in the case of a mammal sighting direction was also noted. Environmental data was also noted every 15 minutes: visibility, glare, sea state, precipitation and tidal state were recorded.

An effort was made to undertake an equal number of surveys at each of the three sites as well as surveys being equally distributed across the ebb, flood tide and equal coverage of different times of day. It was ensured that there were enough replicas of each variable to carry out appropriate statistical analyses. Scans were also only performed in sea state Beaufort 4 to minimise the variation in detectability of seabirds which may be associated increased sea (Waggitt *et al.*, 2014).

Data analysis
Current speed and elevation were extracted using TELEMAC models from SEACAMS. The data obtained was for July 2017, June data was not accessible for the purpose of this study, therefore Microsoft Excel was used to calculate average current speed and depth values as well as standard deviations. These averages were then used to characterise each of the three sites and used to help justify the findings of the study, however no statistical analysis could be undertaken. Tidal data was also obtained across the study period, this enabled bird sightings to be correlated with tidal state; this data was obtained from British Oceanographic Data Centre (BODC) data was located from the nearest tidal gauge in Holyhead, Anglesey.

Bird sightings statistical analysis was carried out using Minitab, specifically a kruskal-wallis test was used to identify whether there was a statistically significant difference between the number of sea birds at each site, using the null hypothesis, H_0 there is no statistically significant difference between the number of birds at each site ($p<0.05$) and the alternate hypothesis, H_1 there is a statistically significant difference between the number of birds at the three sites ($p >0.05$). The Kruskal Wallis test was used to compare the medians of two or more samples and to output an H statistic and P value. Additionally, a Tukey's pair wise correlation was also performed to identify where the differences were within the data.

A Mann Whitney U test was performed to investigate the difference in number of sea bird sightings at tidal flood and ebb tide, again using Minitab. The hypotheses used were as follows: H_0there is no significant difference between the number of sea bird sightings on flood and ebb tide and H_1 there is a significant difference between the number of seabird sightings on flood and ebb tide. The medians of the samples were compared and a W statistic and P value were outputted.

Results

Site Overview
Analysis of current speed data was carried out to characterise the physical characteristics of the sites. The highest average current speed was observed at Bardsey Sound, where the current speed was over twice the speed than that of the other two sites. Bardsey sound also had the highest average depth of the three sites, again over twice the average depth of Porth Dinllaen and Porth Colmon (see Table 1).

Porth Dinllaen and Porth Colmon were much shallower sites with lower current speeds. Standard deviation of current speeds are very low showing little variation in daily current speeds with standard deviation for depth generally slightly higher as expected when accounting for tides.

Table 1: Table showing average current speed and depth for each of the three study sites as well as standard deviation.

Site	Average Current Speed (m/s)	Standard deviation	Average Depth (m)	Standard deviation
Porth Dinllaen	0.43	0.19	6.17	1.09
Porth Colmon	0.44	0.21	6.74	1.03
Bardsey Sound	1.12	0.52	13.53	0.97

Differences between sites

Total Birds

Analysis of bird sightings showed extensive variation in the average number of sightings per hour survey between the three sites Porth Dinllaen, Porth Colmon and Bardsey Sound, see Figure 2. Porth Dinllaen had an average of 204 birds seen per hour survey, this site also had the highest standard deviation value of 168.4 demonstrating a larger variation of birds seen within the surveys. Porth Colmon had a much lower average than Porth Dinllaen of 42 seen per hour and a standard deviation of 85.7. Whereas Bardsey sound had a considerably lower average than both sites with an average of 14 birds seen per hour survey and the smallest standard deviation of the three sites at 16.0, showing less variation of sighting numbers between surveys.

Kruskal-Wallis test was undertaken to see whether there was a statistically significant difference between the number of sea bird sightings at each of the three sites. The Kruskal-Wallis test results indicated that there is a significant difference between the median number of sightings at Porth Dinllaen (rank19.3), Porth Colmon (rank=9.9) and Bardsey Sound (rank = 8.3) at $p<0.05$ level; (H(DF 3) = 11.33, p = 0.003 (see Figure 3). The results have led to the rejection of the H_0 that there is no difference between the numbers of sightings at each site, and accept the H_1 that there is a statistical difference in the numbers of sightings at the three sights. Additionally, a Tukeys pairwise correlation was carried out to identify where the differences were in the data.

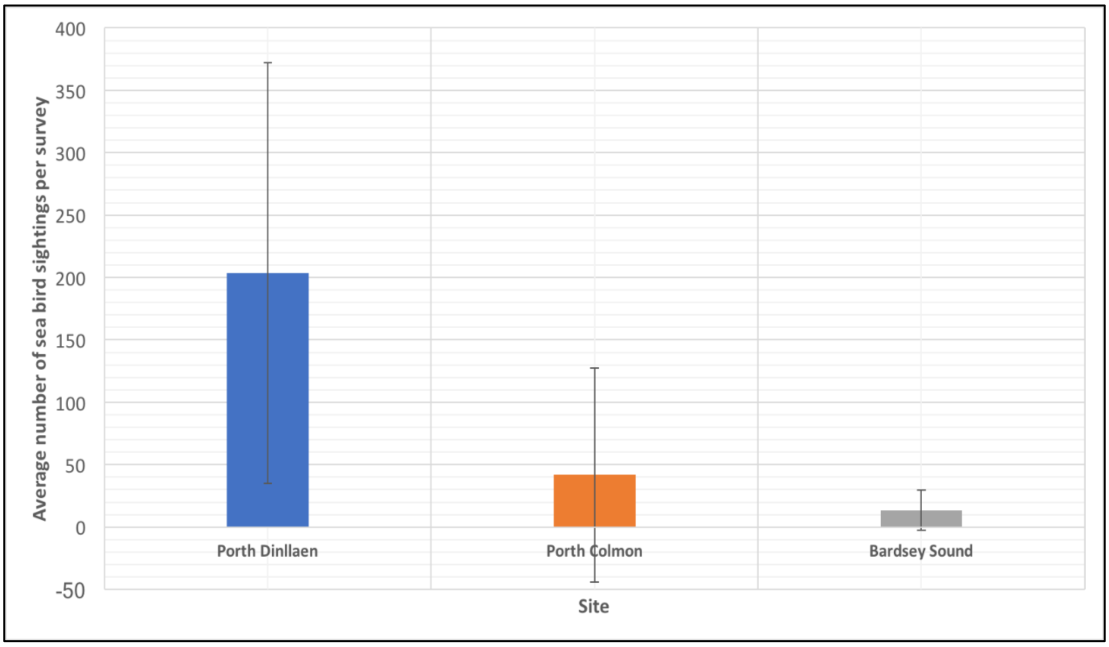

Figure 2: Average number of seabird sightings per hour survey with ± standard deviation of the mean at the three sites, Porth Dinllaen, Porth Colmon and Bardsey sound.

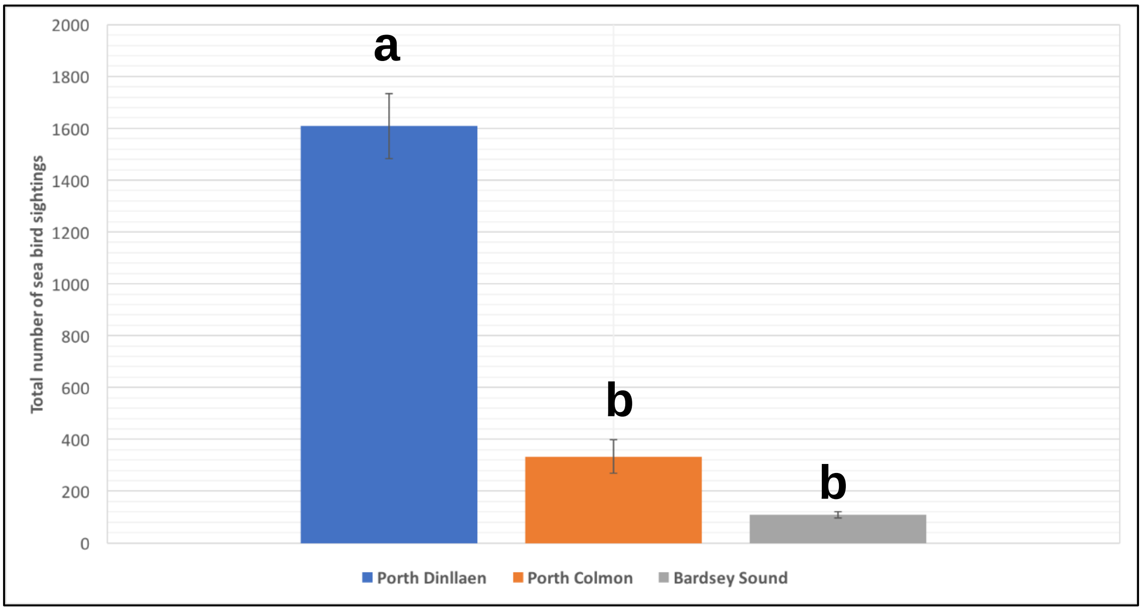

Figure 3: Bar chart displaying total number of sea bird sightings across all surveys at each study site, Porth Dinllaen, Porth Colmon and Bardsey Sound. Bars labelled with different letters are significantly different, bars sharing the same letters are not significantly different.

Species

The study also aimed to investigate the difference in the number species at each site, again a Kruskal - Wallis test was used to see if these differences were statistically significant. The three species tested were: *Morus basanus* (Northern gannet), *Rissa trydactyla* (kittiwake) and *Alca torda* (razorbill).

The difference in number of sightings of kittiwakes between the sites was found to be significant; Porth Dinllaen (rank 19.1), Porth Colmon (rank7.1) and Bardsey Sound (rank 11.3) at p<0.05 level; (H(DF 3) =11.98, p=0.003. Therefore, in order to identify where these differences were a Tukeys Pairwise correlation was undertaken. Results from the tukeys showed that sightings at Porth Dinllaen and Porth Colmon and Porth Dinllaen and Bardsey Sound were statistically different (Figure 4).

The difference in number of gannets, at each site was found to be non-significant; Porth Dinllaen (rank 10.4), Porth Colmon (rank 7.1) and Bardsey Sound (rank 13.9) at p<0.05 level;(H(DF 3) = 1.06, p = 0.589. This is shown in Figure 5.

This test was also carried out for razorbill sightings, where a significant difference was found between sites; Porth Dinllaen (rank 8.5), Porth Colmon (rank 8.5) and Bardsey Sound (rank 20.5) at p<0.05 level; (H(DF 3)=15.36, p=0.00, Figure 6. These differences were again identified using Tukeys pairwise correlation, where results showed Porth Dinllaen to be significantly different from Porth Colmon and Bardsey Sound, whereas Porth Colmon and Bardsey Sound were not significantly different.

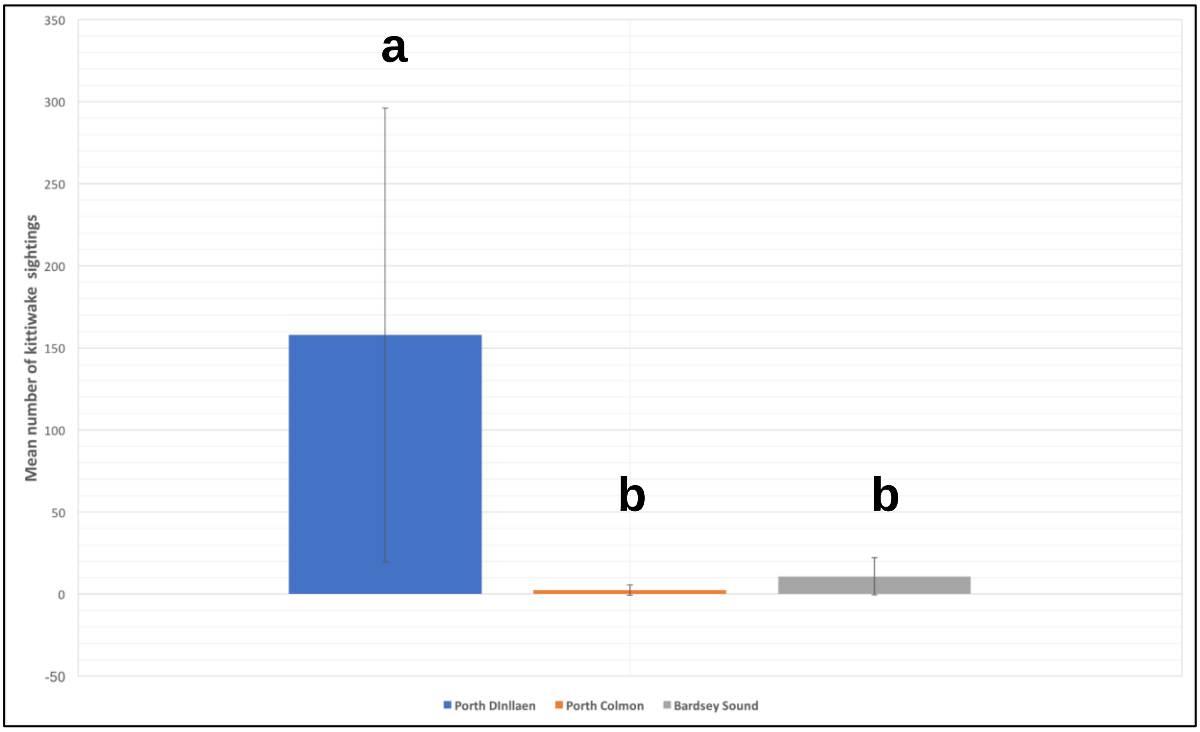

Figure 4: Bar chart displaying mean number of kittiwake sightings across all surveys and 95% confidence intervals.

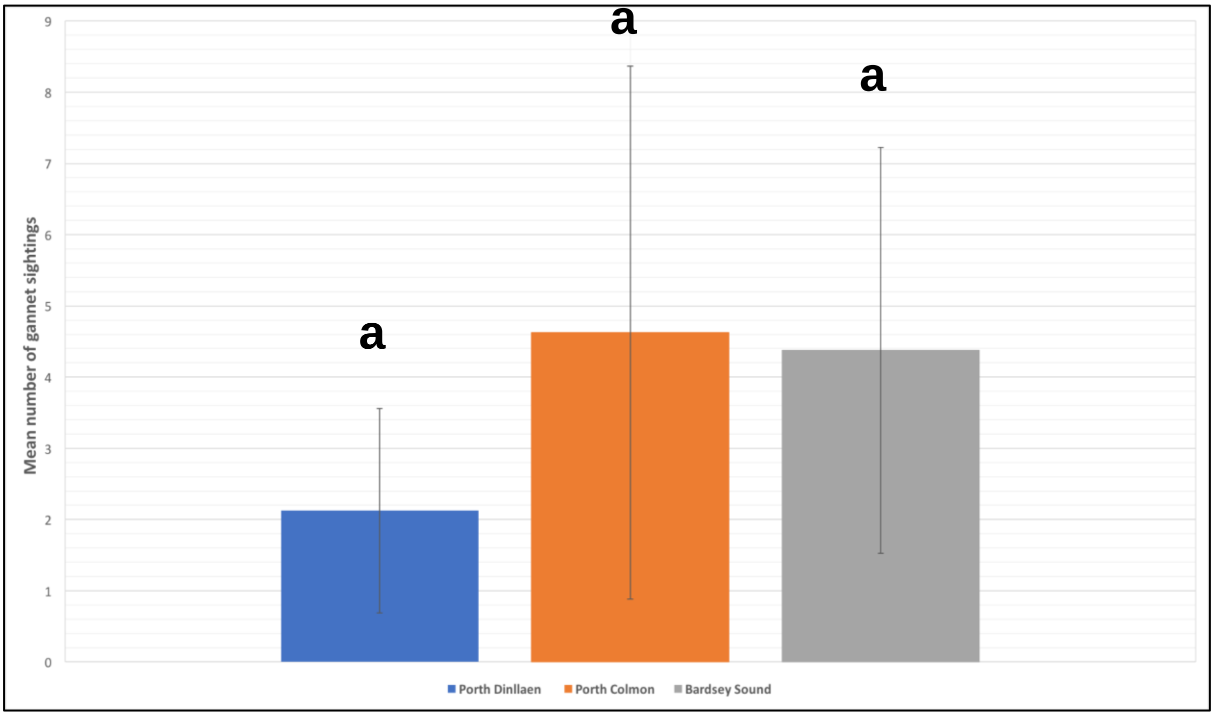

Figure 5: Bar chart displaying mean number of gannet sightings across all surveys and 95% confidence intervals.

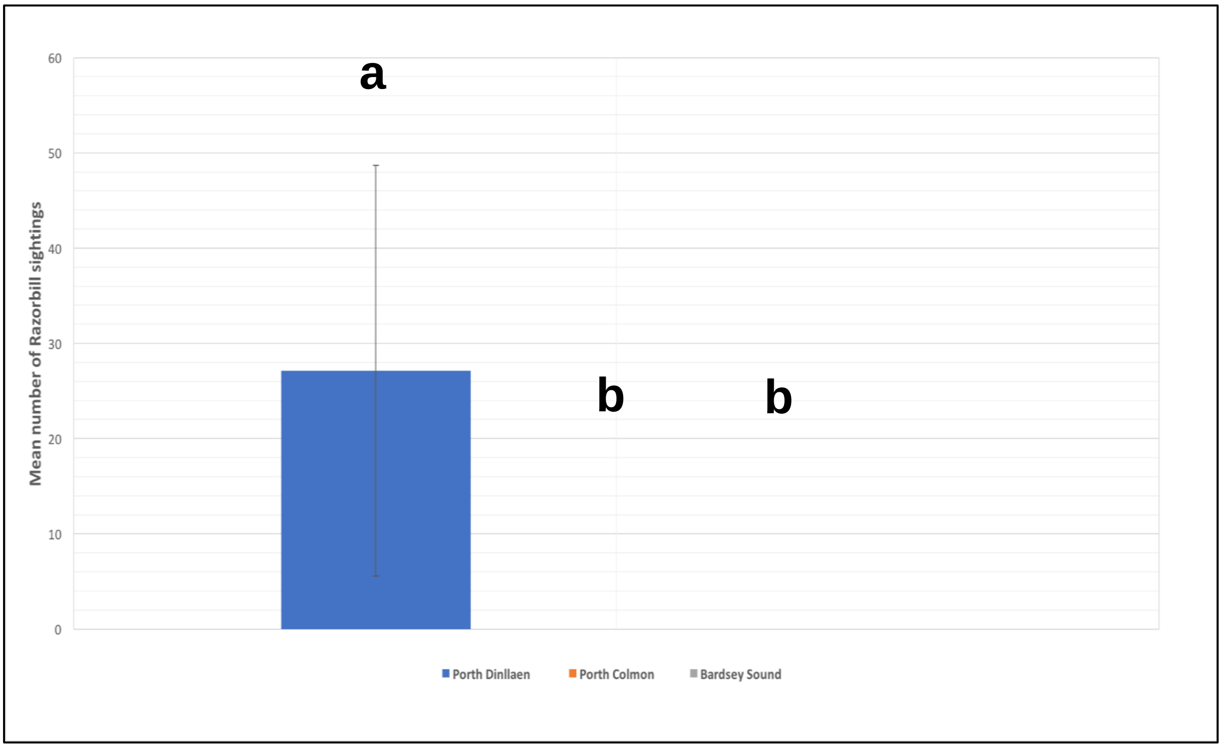

Figure 6: Bar chart showing mean number of razorbill sightings across all surveys and 95% confidence intervals. Note that no razorbills were observed at Porth Colmon or Bardsey sound.

Relationship with Flood and ebb cycle

Total Birds
In this study a Mann Whitney U test was used to investigate the difference in the number of birds at each site on flood and ebb tide, specifically to determine whether there was a preference for either state of tide. The Mann Whitney U was used to examine several variables. The test was used to see if there was a significant difference between the total number of seabird sightings across all the surveys on the flood (Mdn=283.6) and ebb (Mdn=49.5); W=13.0, p = 0.3827, see Figure 7. Therefore, the null hypothesis is accepted that there is no significant difference in the number of seabird sightings on flood and ebb tide.

In the same way a Mann Whitney U test was run for each site; Porth Dinllaen, Porth Colmon and Bardsey Sound independently. All three sites were found to have no significant difference between the number of sightings on the flood and ebb tide, see Table 2. Species

Mann Whitney U tests were also carried out to examine the relationship with three particular species and flood and ebb tide, kittiwake, gannet and razorbill. The test was carried out to examine the difference in total sightings for each of the three species on flood and ebb tide across the three sites, additionally a test was also run to look at each species total at each of the three sites independently. There were no significant differences found between flood and ebb tide, these findings are summarised in Table 2.

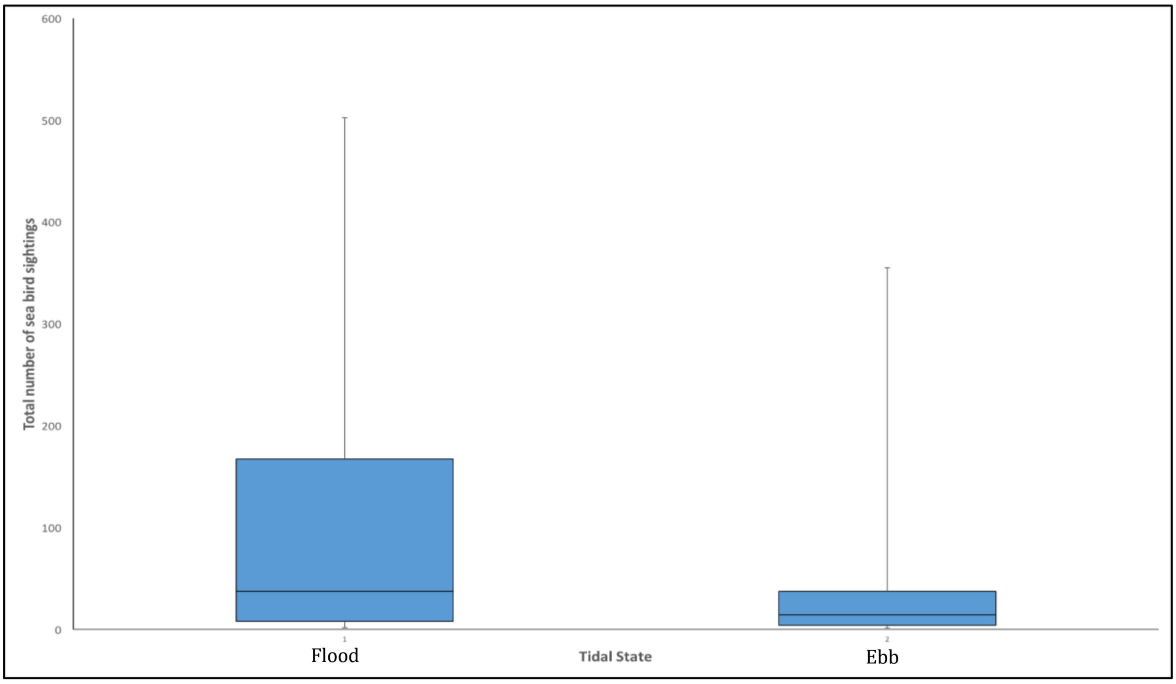

Figure 7. Boxplot displaying the total number of seabird sightings throughout the surveys on flood and ebb tide. Median and outlier values are displayed on graph.

Table 2: Table summarising non-significant findings between sightings on flood and ebb tide. Note: where blank there was insufficient data to perform analysis.

Variable	**Median**	**W value**	**P value**
Total sightings on flood and ebb tide.	Flood = 283.6 Ebb =49.5	13.0	0.3827
Total sightings at Porth Dinllaen	Flood = 235.8 Ebb = 97.3	22.0	0.3123
Total sightings at Porth Colmon	Flood =7.0 Ebb = 14.3	17.0	0.8852
Total sightings at Bardsey Sound.	Flood = 17.0 Ebb = 3.25	24.0	0.1124
Total Kittiwake sightings	Flood = 11.5 Ebb = 4.0	160	0.5834
Kittiwake sightings at Porth Dinllaen	Flood = 158.0 Ebb = 27.5	21.0	0.4705
Kittiwake sightings at Porth Colmon	-	-	-
Kittiwake sightings at Bardsey Sound	Flood = 11.5 Ebb = 0.5	24.0	0.1124
Total Gannet sightings	Flood = 2.0 Ebb = 4.5		0.1489
Gannet sightings at Porth Dinllaen	Flood = 2.0 Ebb = 1.50	18.5	1.00
Gannet sightings at Porth Colmon	Flood = 1.5 Ebb = 7.5	13.0	0.1939
Gannet sightings at Bardsey sound	Flood = 2.0 Ebb = 4.50	13.0	0.1939
Razorbill sightings at Porth Dinllaen	Flood = 2.0 Ebb = 4.50	15.0	0.4705
Razorbill sightings at Porth Colmon	-	-	-
Razorbill sightings at Bardsey Sound	-	-	-

Discussion

This study was undertaken to increase the understanding of seabird occupancy patterns across sites with varying characteristics on the Llŷn Peninsula, North Wales. The study set out to examine the differences in sea bird abundance between three sites with varying physical characteristics, as well as the differences in number of sightings in relation to the tidal phase. The study aimed to identify the reasons for these differences and discuss them in the context of potential tidal energy extraction in the area.

It should be noted that seabird observations only covered a limited period and therefore only represent a part of the seabird's annual pattern. It is also important to consider that the reasons for these differences can only be suggested, as there are

multiple variables that may affect the number of bird sightings. In this study, current speed, depth and tidal phase are discussed. Nevertheless, this study is the first of this nature along the Lln Peninsula and may be useful in identifying important habitats for coastal seabirds within the summer breeding season and
ay help to inform potential future impacts on seabirds due to tidal energy extraction in the area.

Differences between sites

The average number of birds seen per hour survey was calculated and demonstrated clear differences between sites (Figure 8). At Porth Dinllaen over 200 birds were seen per hour, this site also had the highest variation in sightings, indicated by the high standard deviation. Bardsey Sound however, had the lowest number of sightings per hour at only 14 and also the lowest variation in sightings, the bird count was low on all surveys. This was further consolidated by a Kruskal- Wallis test indicating a significant difference between the number of seabird sightings at each site; sightings at Porth Dinllaen were shown to be significantly different to sightings at Porth Colmon and Bardsey Sound.

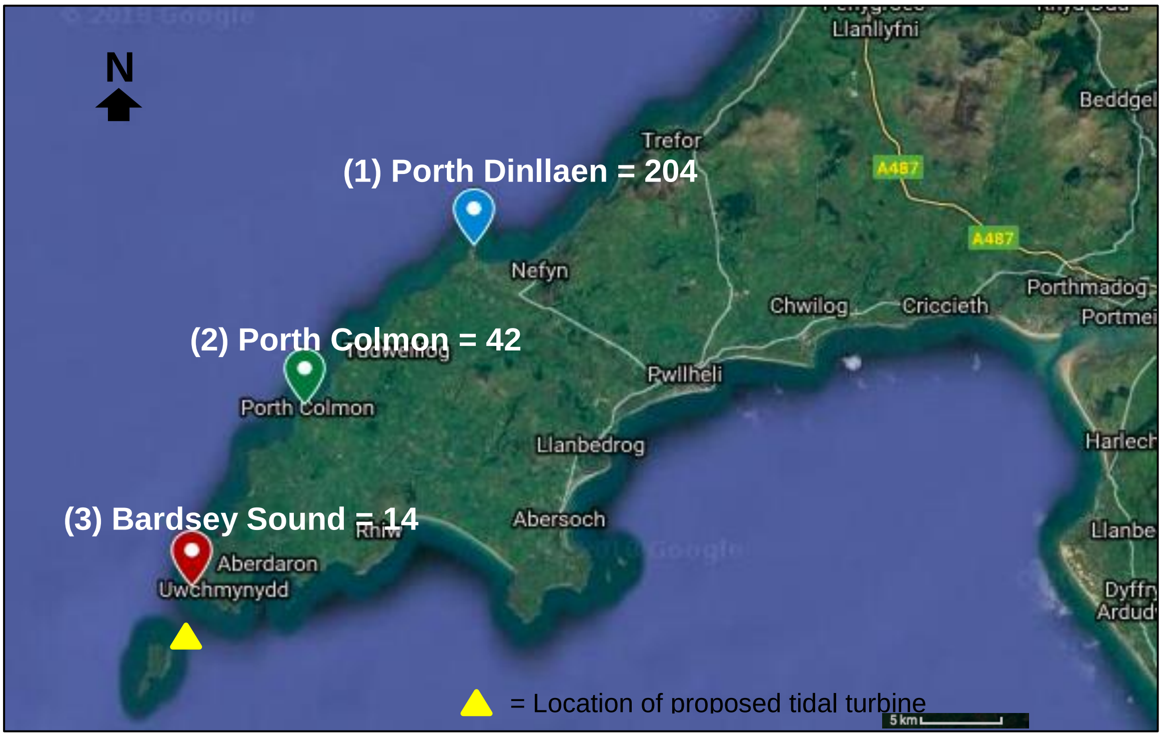

Figure 8: Map of Llyn Peninsula showing location of vantage point survey sites and results of average number of seabird sightings per hour, clearly showing a decrease in site usage as proximity to proposed turbine area increases. (Map data: Image © 2019 DigitalGlobe, Data SIO, NOAA, U.S. Navy, NGA, GEBCO; © 2018 Google)

From these results seabirds show a clear habitat preference to Porth Dinllaen over the other two sites. Although similar to Porth Colmon, Porth Dinllaen exhibited a much lower average current speed and average depth in comparison to Bardsey Sound where much lower bird counts were obtained. This suggests that there are oceanographic processes occurring because of these differing characteristics that make this a profitable foraging location. This may be due to high prey densities in this location, where energy costs may therefore be reduced, or particular oceanographic processes may increase predator- prey interactions, leading to more successful foraging (Zamon, 2003). The current speeds and directions at this site may bring about changes in densities and distributions of fish and zooplankton that seabirds may exploit (Ross and Sharples, 2007). Birds favouring sites with lower current speeds corresponds with Waggit *et al.* (2016) findings where the density of bird species decreased with increasing horizontal current speed, is thought to be due to the increased energetic cost of diving. However, it is certain from other studies such as Holm and Burger (2002) that different seabird species utilise currents in different ways and it is therefore necessary for further study to fully understand the relationship with current speeds.

Tidal Phase

In order to ensure an ecosystem approach to the conservation of seabirds, we must understand the temporal variation in their presence in specific locations. Sea birds may use a variety of temporally predictable oceanographic processes, including the tidal cycle, to maximise foraging (Zamon, 2001; Embling *et al.,* 2012; Cox *et al.,* 2013; Scott *et al.,* 2013), which in turn influences times of aggregations. By having an understanding of these temporal preferences, it may help us in terms of their management. This knowledge can be used to inform marine planning relating marine renewable energy developments as well as the designation of Marine Protected areas.

In this study a significant difference between the number of birds seen on flood and ebb tide was not obtained. This was probably because there was not enough surveys to see a difference across the tidal state. Cox *et al.* (2013) witnessed a similar problem when only a small sample of kittiwake observations were obtained due to surveys not being in the right location at the right time. Embling *et al.* (2012) sampled the same foraging locations repeatedly on different phases of the tide to ensure enough data was available, and to allow for tidal temporal interactions to be identified.

It was expected that findings of this study in terms of seabirds and their relationship with the tidal cycle would follow trends with previous studies, for example, where seabirds were present in higher numbers on ebb tide rather than flood (Embling *et al.,* 2012; Irons, 1998; Scott *et al.,* 2013).

Although the exact reason for all tests showing non-significant differences between seabird sightings on flood and ebb tide is not known, it is likely that there was not sufficient data collected to show significant differences. Further shortfalls of this study are discussed in the limitations section.

Species sightings

The three sites were shown to be favoured by particular species; kittiwakes were found in very high numbers at Porth Dinllaen with an average of 150 seen per survey. Whereas although they were observed at Porth Colmon and Bardsey Sound, they were in much lower numbers. This follows the general trend of Porth Dinllaen being the most favoured site. Kittiwakes are surface feeders and must feed in locations where prey is accessible in the surface layers (Furness and Tasker, 2000). Studies suggest that kittiwakes may have a more restricted habitat than diving seabirds, this is supported by the very low numbers of kittiwakes observed at both Porth Colmon and Bardsey Sound. This suggests that there are oceanographic processes making prey accessible to surface feeding kittiwakes that other species are also taking advantage of.

Razorbills were observed in relatively high numbers at Porth Dinllaen, although not in such high numbers as kittiwakes, it is also interesting that there were no razorbills observed at Porth Colmon or Bardsey Sound. This is of particular importance due to the breeding colony nearby on Bardsey Island. This may be due to razorbills of the Bardsey island colony using foraging grounds closer to the island itself, so that they could not be seen from the chosen vantage point. It is also important to note that razorbill density has been seen to peak in water depth 50-100 m (Stone *et al.*, 1995). In another study razorbills were found to stay very close to the colony during the breeding season, due to the need to return often to care for their chicks (Kuepfer, 2012). Previous studies have found diving birds such as guillemots and razorbills exploit different habitats spatially and temporally (Cox *et al.* 2013; Begg and Reid 1997; Pinaud and Weimerskirch, 2007). These findings may stem from differences in flight and diving behaviour, their method of prey capture as well as competition. Razorbills are adapted to dive in pursuit of their prey (Montevecchi *et al.*, 2006, Langton *et al.*, 2011), rather than to rely on oceanographic processes to bring prey to the surface layers, suggesting they may be less limited to foraging sites than kittiwakes. The findings of this study suggest that this is not the case and future work should focus on understanding why Porth Dinllaen has such an abundance of seabirds in comparison to other locations.

Northern gannets were observed at all three sites, but in relatively low numbers, an average of 2, 5 and 5 birds seen at Porth Dinllaen, Porth Colmon and Bardsey Sound, respectively. Gannets can forage for prey in a variety of habitats, as a result of their wide range of foraging techniques including surface foraging to very deep plunging dives, as well as being able to swim in pursuit of their prey underwater (Garthe *et al.*, 2007; Mullers *et al*., 2009; Camphuysen, 2011). This may be the reason that gannets were present in similar numbers at all three sites; with these foraging techniques allowing them to adapt their prey capture technique to suit the location. They may also be a species rely less upon predictable oceanographic processes to aid foraging (Scott *et al.* 2013).

Implications for future tidal energy extraction

In terms of the site being a potential location for tidal energy extraction this study suggests that due to the low number of sea birds observed during the surveys, the tidal turbine is unlikely to have extensive effects on the populations. Few seabirds were seen using the site and almost none shown to be foraging. This is particularly relevant to this form of renewable energy where threats mainly arise from risk of collision with underwater turbine rotors (Scottish Heritage, 2016). Collision risk is highest for pursuit diving sea birds, whereas birds that are primarily surface feeders are perceived to be less at risk (Robbins *et al.*, 2014). The study also shows a particular absence of diving seabirds at this particular site, in particular no razor bills were observed at Bardsey Sound, a species shown to have high vulnerability when ranked on the vulnerability index (Robbins *et al.*, 2014).

Due to the non-significant findings of the relationship of bird sightings and tidal phase, times of tide where high bird numbers could not be properly identified. Therefore, the safest times of operation could not be suggested. An objective of this study was for observations and findings to inform the operation of the tidal turbine in Bardsey Sound, for example, it being turned off at times of particularly high site usage by seabirds. However, more work would need to be undertaken for this to be effective, because there may be many other underlying processes influencing the temporal site usage of Bardsey Sound that have not been examined within this study.

Limitations

It is, however important to note that this study only covered 9 days of data collection, which is not a large enough data set to be certain that a tidal energy installation would not pose a threat to surrounding sea birds. It is also important to consider that these surveys were carried out during the breeding season, which may have led to very different results than a survey conducted in a non-breeding season, specifically we can predict that bird sightings would be lower during the non-breeding season.

Other limitations of the study involve the data collection method of performing shore-based surveys. There is a capacity for human error within this study, due to most birds being a considerable distance away from the observer, mistakes may have been made with accurately determining the behaviour and species of sightings, which could potentially have a considerable impact upon the accuracy of the results. Another issue encountered, was the declining detectability of birds with distance (Waggitt *et al.*, 2014), where birds further away from the vantage point may be harder to identify. There were also no physical boundaries for the survey area, resulting in some surveys scanning a larger area than others, which may had led to affected the number of sightings.

Although this study can confirm differences between the sightings occurring at the three different sites and to some extent can link these to the differing oceanographic conditions, there is not a large enough data set to inform future tidal energy instalments on the Llŷn Peninsula.

Future recommendations

As a result of this project, it would seem that future studies would be beneficial, in order to progress this field of work. One important aspect to look at, would be the spring and neap tidal cycle, surveys could be carried out across both phases of the tidal cycle to observe trends and relationships between sightings and the spring and neap cycle. It may also be useful to use multiple vantage points to monitor one site to ensure seabirds using the site are not missed.

Similar surveys could also be carried out in the non-breeding season, i.e. during the winter, to look at seasonal differences in sightings. It may also be advantageous to repeat the methods undertaken in this survey during future breeding seasons to add to the data set, as well as to make annual comparisons

This study focuses on seabird species, however studies observing marine mammals including grey seal *(Halichoerus grypus)*, harbour porpoise (*Phocoena phocoena)* and possibly bottlenose dolphins (*Tursiops truncates)* may also be beneficial, especially in light of the ever-increasing need for an ecosystem based approach to management.

Conclusion

This is the first study of its nature to look at the differing occupancy patterns of seabirds along sites of the Llŷn Peninsula. Studies such as this are vital for understanding how seabirds use the marine environment and to help protect them against detrimental impacts stemming from new developments.

Although this study was constrained by time and survey effort, and therefore limited data was collected it has fulfilled its aim of observing contrasting occupancy patterns between the three sites, including total birds and the three species of interest the kittiwake, the northern gannet and the razorbill. The study identified Porth Dinllaen as having the highest number of seabirds present across the surveys, this was suggested because of the lower current speeds at this site in comparison to Bardsey Sound, enhancing prey availability and reducing energetic cost of diving. The species investigated within the study generally showed a preference towards Porth Dinllaen with highest numbers except for gannets observed at this site. Importantly no razorbills were observed at Bardsey Sound, an interesting and positive finding in terms of plans to develop tidal energy extraction in the area, as diving sea birds such as razorbills are perceived to be most vulnerable to collision risk.

The study failed to identify a relationship with seabird sightings and the flood and ebb cycle, but it has made a start in understanding how seabirds in the area use temporal tidal variations and it is hoped that future findings can be used to inform the safe operation of the turbine in this area as well as other locations. This study found Bardsey Sound to have to lowest number of sightings during the study period, which suggests a tidal turbine in the area may have significantly less effect on seabird populations than previously thought. Again, however, further study should be undertaken during non-breeding season, along with the constant monitoring of local bird populations into the future. It is still important to consider the large colonies of breeding seabirds on Bardsey Island, very close to the potential turbine site as even though this study did not find them to be using the area there may still be impacts upon these colonies, and effort should be made to ensure their protection into the future.

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References

Begg, G.S. & Reid, J.B. (1997). Spatial variation in seabird density at a shallow sea tidal mixing front in the Irish Sea. ICES Journal of Marine Science, 54, 552-565.

Block, B. A., Holbrook, C. M., Simmons, S. E., Holland, K. N., Ault, J. S., Costa, D. P., & Kochevar, R. E. (2016). Toward a national animal telemetry network for aquatic observations in the United States. *Animal Biotelemetry*, *4*(1), 6.

Camphuysen, C., Scott, B. & Wanless, S. (2011). Distribution and foraging interactions of seabirds and marine mammals in the North Sea: a metapopulation analysis. pp. 82- 97. In: Boyd, I.L., Wanless, S. & Camphuysen C.J. Top Predators in Marine Ecosystems: Their Role in Monitoring and Management. Conservation Biology (No. 12).

Daunt, F., Peters, G., Scott, B., Gremillet, D. & Wanless, S. (2003). Rapid-response recorders reveal interplay between marine physics and seabird behaviour. Marine Ecology Progress Series, 255, 283-288.

Davis, S.E., Nager, R.G. & Furness, R.W. (2005). Food availability affects adult survival as well as breeding success of parasitic jaegers. Ecology, 86, 1047-1056.
Department of Energy and Climate Change. (2016). UK Energy Statistics, 2015 and Q4 2015. *Statistical Press Release*, pp. 1–16.

Devine-Wright, P. (2011). Enhancing local distinctiveness fosters public acceptance of tidal energy: A UK case study. *Energy Policy*, *39*(1), 83–93.

Eaton, M.A., Brown, A.F., Noble, D.G., Musgrove, A.J., Hearn, R.D., Aebischer, N.J., Gibbons, D.W., Evans, A. & Gregory, R.D. *et al.*. (2009). Birds of conservation concern 3. British Birds, 102, 296-341.

Embling, C. B., Illian, J., Armstrong, E., van der Kooij, J., Sharples, J., Camphuysen, K. C. J., & Scott, B. E. (2012). Investigating fine-scale spatio-temporal predator-prey patterns in dynamic marine ecosystems: A functional data analysis approach. *Journal of Applied Ecology*, *49*(2), 481–492.

Fuller, M.R., Millspaugh, J.J., Church, K.E. & Kenward, R.E. (2005). Wildlife radiotelemetry. *In* Braun, C.E., ed. *Techniques for wildlife investigations and management*, pp. 377-417. The Wildlife Society, Bethesda, USA.

Furness, R. W. & Tasker, M. L. (2000). Seabird-fishery interactions: quantifying the sensitivity of seabirds to reductions in sandeel abundance, and identification of

References 157 key areas for sensitive seabirds in the North Sea. Marine Ecology Progress Series, 202, 253-264.

Garthe, S., Montevecchi, W.A., Chapdelaine, G., Rail, J.F. & Hedd, A. (2007). Contrasting foraging tactics by northern gannets (Sula bassana) breeding in different oceanographic domains with different prey fields. Marine Biology, 151, 687-694.

Giacoma, C., Papale, E., & Azzolin, M. (2013). Are land based surveys a useful tool for managing marine species of coastal protected areas? *Diversity*, *5*(1), 15–25. http://doi.org/10.3390/d5010015

Grecian, W. J., Inger, R., Attrill, M. J., Bearhop, S., Godley, B. J., Witt, M. J., & Votier, S. C. (2010). Potential impacts of wave-powered marine renewable energy installations on marine birds. *Ibis*.

Hamer, K., Phillips, R., Hill, J., Wanless, S. & Wood, A. (2001). Contrasting foraging strategies of gannets Morus bassanus at two North Atlantic colonies: Foraging trip duration and foraging area fidelity. Marine Ecology Progress Series, 224, 283-290.

Hart, K. M., & Hyrenbach, K. D. (2010). Satellite telemetry of marine megavertebrates: The coming of age of an experimental science. *Endangered Species Research*.

Heath, M., Edwards, M., Furness, R., Pinnegar, J. & Wanless, S. (2009). A view from above: Changing seas, seabirds and food sources. In: Marine Climate Change Ecosystem Linkages Report Card 2009 (Eds. Baxter, J.M., Buckley, P.J. & Frost M.T.)

Holm, K. J., & Burger, A. E. (2002). Foraging Behavior and Resource Partitioning by Diving Birds During Winter in Areas of Strong Tidal Currents. *Waterbirds*, *25*(3), 312–325.

Hunt, G. L., Harrison, N. M., & Cooney, R. T. (1990). The influence of hydrographic structure and prey abundance on foraging of least auklets. *Studies in Avian Biology*, (14), 7–22.

Jones, A. R., Hosegood, P., Wynn, R. B., De Boer, M. N., Butler-Cowdry, S., & Embling, C. B. (2014). Fine-scale hydrodynamics influence the spatio-temporal distribution of harbour porpoises at a coastal hotspot. *Progress in Oceanography*, *128*, 30–48.

King, D. A. (2004). Climate change Science: Adapt, mitigate or Ignore. *Science* Vol. 303, Issue 5655, pp. 176-177.

Kruse G.H., Livingston P., Overland, J.E., Jamieson, G.S., McKinnell, S., Perry, R.I. (eds) (2006). Report of the PICES/NPRB workshop on integration of ecological indicators of the North Pacific with emphasis on the Bering *Sea. North Pacific Marine Science Organization (PICES)*, Sidney, BC, PICES Scientific Report 33.

Kuepfer, A. (2012). Foraging patterns and home-ranges of breeding razorbills (Alca torda) from two colonies in North Wales, UK, as revealed by GPS-tracking in the seasons of 2011 and 2012. MSc thesis, University of Bangor. p. 83.

Langhamer, O. (2012). Artificial Reef Effect in relation to Offshore Renewable Energy Conversion: State of the Art. *The Scientific World Journal*, *2012*, 1–8.

Langton, R., Davies, I. M. & Scott, B. E. (2011). Seabird conservation and tidal stream and wave power generation: Information needs for predicting and managing potential impacts. Marine Policy, 35, 623-630.

Mitchell, I., Newton, S.F, Ratcliffe, N. & Dunn T.E. (Eds.) (2004). Seabird Populations of Britain and Ireland: results of the Seabird 2000 census (1998-2002). T and A.D. Poyser, London.

Montevecchi, W. A. (2006). Influences of Artificial Light on Marine Birds. Ecological Consequences of Artificial Night Lighting (eds C. Rich & T. Longcore), pp. 94- 113. Island Press, Washington, D.C.

Montevecchi, W. A., Benvenuti, S., Garthe, S., Davoren, G. K. & Fifield, D. (2009). Flexible foraging tactics by a large opportunistic seabird preying on forage- and large pelagic fishes. Marine Ecology Progress Series, 385, 295-306.

Robbins, A., Thaxter, C., Cook, A., Furness, T., Daunt, F., Masden, E. (2014). A Review of Marine Bird Diving Behaviour: Assessing Underwater Collision Risk with Tidal Turbines [Presentation]. Presented at the Environmental Impact of Marine Renewables 2014, Stornoway, Scotland, UK.

Ross, O. N., & Sharples, J. (2007). Phytoplankton motility and the competition for nutrients in the thermocline. *Marine Ecology Progress Series*, *347*, 21–38.

Scott, B. E., Webb, A., Palmer, M. R., Embling, C. B., & Sharples, J. (2013). Fine scale bio-physical oceanographic characteristics predict the foraging occurrence of contrasting seabird species; Gannet (Morus bassanus) and storm petrel (Hydrobates pelagicus). Progress in Oceanography, 117, 118-129.

Scottish Natural Heritage (2016) ‘Assessing collision risk between underwater turbines and marine wildlife’. SNH guidance note.

Sharples, J. (2008). Potential impacts of the spring-neap tidal cycle on shelf sea primary production. *Journal of Plankton Research*, *30*(2), 183–197.

Sparling, C., Lonergan, M., McConnell, B. (2017). Harbour seals (Phoca vitulina) around an operational tidal tur- bine in Strangford Narrows: no barrier effect but small changes in transit behaviour. Aquatic Conserv: Mar Freshw Ecosyst. 1–11.

Stone, C., Webb, A. & Tasker, M. (1995). The distribution of auks and procellariiformes in north-west European waters in relation to depth of sea. Bird Study, 42, 50-56.

Waggitt, J. J., & Scott, B. E. (2014). Using a spatial overlap approach to estimate the risk of collisions between deep diving seabirds and tidal stream turbines: A review of potential methods and approaches. *Marine Policy*, *44*, 90–97.

Waggitt, J. J., Bell, P. S., & Scott, B. E. (2014). An evaluation of the use of shore-based surveys for estimating spatial overlap between deep-diving seabirds and tidal stream turbines. *International Journal of Marine Energy*, *8*, 36–49.

Waggitt, J. J., Cazenave, P. W., Torres, R., Williamson, B. J., & Scott, B. E. (2016). Predictable hydrodynamic conditions explain temporal variations in the density of benthic foraging seabirds in a tidal stream environment. *ICES Journal of Marine Science*, *73*(10), 2677–2686.

Waggitt, J. J., Cazenave, P. W., Torres, R., Williamson, B. J., & Scott, B. E. (2016). Quantifying pursuit-diving seabirds' associations with fine-scale physical features in tidal stream environments. *Journal of Applied Ecology*, *53*(6), 1653–1666.

Waggitt, J. J., Robbins, A. M. C., Wade, H. M., Masden, E. A., Furness, R. W., Jackson, A. C., & Scott, B. E. (2017). Comparative studies reveal variability in the use of tidal stream environments by seabirds. *Marine Policy*, *81*(Supplement C), 143–152.

Weimerskirch, H., Pinaud, D., Pawlowski, F., & Bost, C. (2007). Does Prey Capture Induce Area-Restricted Search? A Fine-Scale Study Using GPS in a Marine Predator, the Wandering Albatross. *The American Naturalist*, *170*(5), 734–743.

Willsteed, E., Gill, A. B., Birchenough, S. N. R., & Jude, S. (2017). Assessing the cumulative environmental effects of marine renewable energy developments: Establishing common ground. *Science of the Total Environment*.

Zamon, J. E. (2001). Seal predation on salmon and forage fish schools as a function of tidal currents in the San Juan Islands, Washington, USA. *Fisheries Oceanography*, *10*(4), 353–366.

Zamon, J. E. (2002). Tidal changes in copepod abundance and maintenance of a summer Coscinodiscus bloom in the southern San Juan Channel, San Juan Islands, USA. *Marine Ecology Progress Series*, *226*, 193–210.

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