Social Structures and Ecological Drivers of Risso's Dolphins *(Grampus griseus)* in the Irish Sea.

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Executive Summary

Risso's dolphins (*Grampus griseus*) are a common inhabitant within the Irish Sea and around the British Isles, where their preferences of environmental factors can be found. Favoured prey of cephalopods, like deep-diving squid and octopus, can also be seen within these waters. Non-invasive techniques of photo-ID and sightings data from Sea Watch Foundation (SWF) were used. Nine locations within and around Welsh waters from 2004-2022 allowed 314 individuals to be identified. Sightings around Anglesey were more densely recorded due to this area being the main research area for the SWF. From 52 encounters, 67 (16%) of the individuals returned. This showed a low fidelity rate within this data set, similar to those who have used this data previously within these areas. Environmental factor data was analysed using R-Studio. The results suggest that depth, sediment type and temperature were not significant. These parameters were found to not be directly correlated with Risso's dolphins' distribution patterns in the Irish Sea. Higher phytoplankton presence was found with increasing oxygen temperatures, as seen in other research. Despite this, some associations with site fidelity and environmental factors on Risso's dolphins dispersal were identified and show they do play a role, but they are not the sole influence.

Key words: Risso's dolphin, Irish Sea, Social structure, Ecological drivers, Distribution, Site fidelity

1 | Introduction

The Risso's dolphin *Grampus griseus* (G. Cuvier, 1812) is a widely distributed cetacean that prefers offshore continental slopes in temperate and subtropical waters of all oceans (Amano and Miyazaki, 2004). This common odontocete occurs in coastal to oceanic waters, preferably warmer than 12°C but no less than 10°C, and is classified as an elusive species (Evans, 2013). This is due to their patchy distribution which is because of its long dive times and rare advancements to boats (Luna *et al.*, 2022). They are relatively slow swimmers, roughly between 4-12km/h, that can be regularly seen engaging in surface behaviours such as breaching, tail-slapping and communal diving (Evans, 2008; Evans, 2013).

Risso's have a teuthophagous diet, with a preference for deep-diving squids, octopus and cuttlefish; this has been observed from analysing their stomach contents, where remains such as beaks and teutholoid statoliths have been found (Blanco, Raduán and Raga, 2006). Over 80% of odontocete species commonly include cephalopods in their diet, where 60 cephalopod species have been widely recorded within stomach content analyses (Clarke, 1996).

The heads of Risso's dolphins are distinctively formed. They feature a broad, squarish contour with a longitudinal furrow that produce sonar rays with unusual angles (Bearzi *et al.*, 2011). Along with this, they have distinctive morphological features that allow them to be easily identified against other cetaceans, such as a lack of beak, a V-shaped cleft and a tall dorsal fin (Gaspari, 2004). Another identifiable feature is the scarring that conspecifics leave on each other during behaviours such as mating or fighting, caused by their teeth (Marini *et al.*, 2016).

1.1 | Environmental factors

This predator's trophic habitat preference has been linked to their cephalopod preys, specifically larger squids at deeper depths (Luna *et al*., 2022). Clarke (1996) discovered that Risso's dolphins had a high concentration of mesopelagic and deep-water cephalopods in their stomachs. The 'Central Place Foraging' theory predicts that predators will only swim away from the sea surface to find high quality food and increased prey densities (Arranz *et al.*, 2018). Risso's use this theory as they must consider the availability and nutritional value of deep-water cephalopods, as well as the journey of returning to the surface for oxygen intake is worth the risk (Arranz *et al.*, 2018; Visser *et al.*, 2021). Prey abundance can be influenced by current strength and direction, leading Risso's dolphins to change feeding habitats and patterns (Ballance, Pitman and Fiedler, 2006).

Risso's display a strong preference for mid-temperate waters near deep offshore waters around the continental shelf (roughly 50-100m depth in UK waters) where there are strong bathymetric features like submarine canyons, seamounts and oceanic trenches (Evans, 2008; Jefferson *et al.*, 2013; Luna *et al*., 2022). Higher numbers of cetaceans have been recorded near upwellings and frontal systems due to the increased presence of phytoplankton, fish and cephalopods within these areas (Baumgartner, 1997). Anthropogenic activities, like fishing, paired with ongoing climate change have been thought to alter dispersal patterns (Azzellino *et al*., 2016). It is thought, however, that by-catch is relatively low in the British Isles, but could also be under-recorded (Evans, 2013).

1.2 | Social Dynamics

Underwater noise pollution has been shown to impact this species as well as their sonar projections due to the exposure of high-intensity frequencies (Azzellino *et al.*, 2016). Risso's dolphins use echolocation, an acoustic bisonar sensory system, to communicate with conspecifics, detect predators and in foraging ecology (Au and Simmons, 2007). They have bisonar clicks of short duration (30 μsec) signals with peak frequencies around 40 kHz (Madsen, Kerr and Payne, 2004).

Due to their preferences and wide distribution, it has been found that there is no evidence of exchange between populations in different areas when comparing genetic material, for example in UK waters and the Mediterranean Sea (Gaspari, 2004; Hartman, Visser and Hendriks, 2008). Despite these genetic disparities from differing waters, it is seen in photo-ID studies that individuals from the UK that range up and down the west coast from the Isle of Man, Wales and Cornwall (Stevens, 2014; Mandlik, 2021). Risso's have been reported in group sizes ranging from one to several hundreds and have even been spotted with clusters of other cetacean species (Hartman, Visser and Hendriks, 2008).

A fission-fusion society, based on age and sex, has been commonly linked with Risso's as they are known to make some strong individual bonds (Santacesaria *et al*., 2022). These bonds, in multiple studies, have been associated with long-term stable pairs and clusters, with some differentiation by age and sex classes, affecting the make-up of these groupings (Hartman, Visser and Hendriks, 2008). Adults are predominantly observed in pairs that form subunits of larger changeable groups that adapt based on the environmental variables and resource availability (Azzellino *et al*., 2016). In UK waters, this gregarious species is commonly seen in group sizes between 6-12 but have been recorded in temporary aggregations of hundreds (Evans, 2008).

As for locations of these groupings, site fidelity is commonly reported for this species (Carlucci *et al*., 2020). This residency pattern allows further understanding of critical habitats for species as well as the reasons they return to these locations (Carlucci *et al*., 2020). These reasons include food exploitation, lower movement costs and reduced predation risk (Morrison *et al*., 2021). This information in turn aids in conservation actions for not only Risso's but other cetacean and marine mammal species. This behaviour is typically associated with demographic processes like feeding, breeding and calving (Hartman *et al*., 2015).

1.3 | Aims and Hypothesis

The overarching aim of this study is to further understand the Risso's dolphins' social structure and the effects of this, as well as ecological drivers on their distribution. Populations vary greatly, which yield different results between studies and locations. Insight into their group dynamics and overall social organisation can be gained by examining their behavioural ecology and patterns, which will also provide knowledge of their social dynamics within their populations.

In this study, it is hypothesised that the frequency of individuals and groups will be dependent on environmental factors, such as slope gradients and temperature (H1). It is theorised that Risso's will be present at greater depths and higher oxygen concentrations due to their preference in deep-dwelling cephalopods. Whilst looking at this, phytoplankton abundance will be theorised to have a higher presence in the sighting areas, due to the images being collected throughout their blooming season. The preferences of Risso's dolphins have been shown to be consistent across multiple sites in earlier investigations. With the ever-changing environment, due to climate and physical changes, it is likely that this will have an impact on their presence and behaviour.

Another hypothesis within this study is that the individuals' observed will display a recurring pattern of returning to the same previously documented areas (H2). Population studies from across the world indicate that this species has a high site fidelity to certain regions, suggesting that it is within this species' natural biology to return to the same location. Notes on whether single dolphins were seen with other adults or calves were made in order to make assumptions on their social aspects. This is because they form strong relationships with at least one other conspecific, and the movements of the group depend on their classes and pairings within pods and their behaviour.

2 | Materials and Methods

Despite this study utilising data from Risso's sightings across the UK coastal waters, the Irish Sea was the main focus of this study (Figure 1). Three separate aspects were examined: i) photo-identification of Risso's dolphins, ii) testing for patterns of site fidelity patterns and determining home ranges and iii) discovering what environmental factors affect these patterns and why.

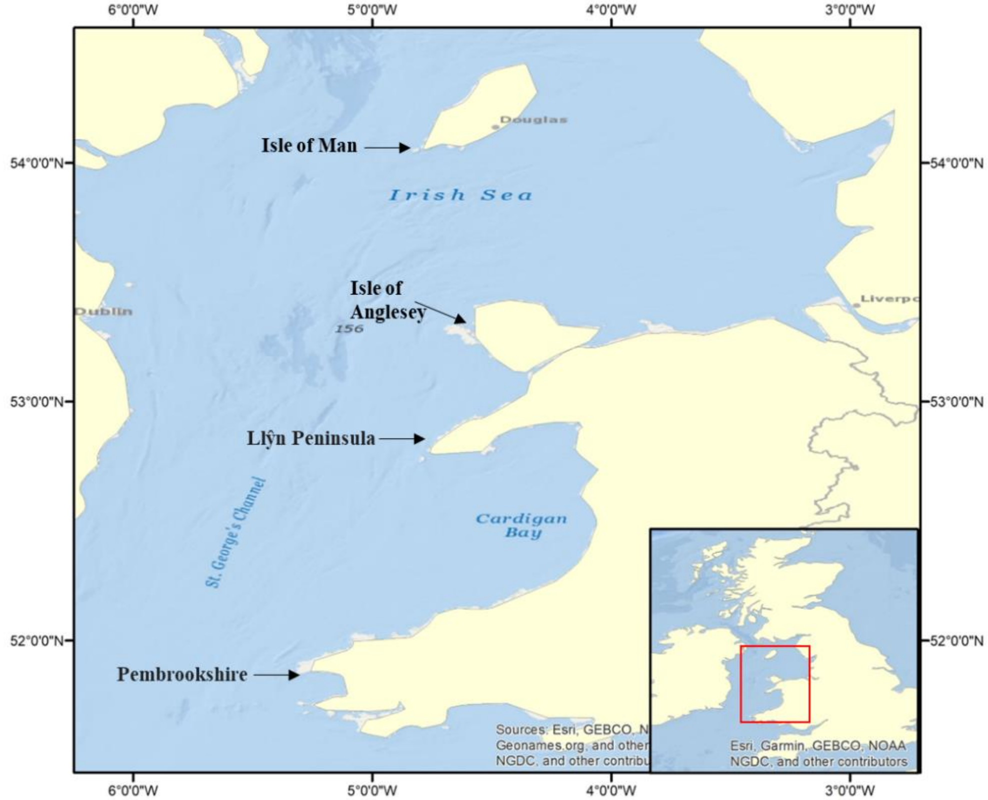

Figure 1. A map of North Wales and the Irish Sea showing the focal point of photo-identification in the UK (indicated by the red square) and environmental variable data, including the locations of data collection.

Photo-ID of individuals

After receiving ID images of Risso's dolphins from the Sea Watch Foundation (SWF), they were sorted through and the photos that were clear and good quality for identification were placed into folders by year, location and photographer. Photographs were from encounters made between 2004-2022. The free image editor software Windows Paint was used in order to crop the photos and edit things, such as the lighting, to allow easier and more precise identification. As for re-naming the images, the following code was used: YYMMDD_EEE_NNN_###_S, where: YY = year, MM = month, DD: day, EEE = encounter number (starting 001), NNN = photographer name (e.g., Peter Evans: PGHE), ### = picture consecutive numbers and S = number of individuals in the image. An example of this is 070905_001_PGHE_001a_3. Also, if a calf was present, a lowercase 'c' was added. Although calves were not individually identified in this study, they were helpful for the behavioural aspects of this study.

Once the images had been cropped and renamed, a catalogue was created. The catalogue name ###_YY was used, where ### began at 001 and continued increasing throughout the years. This code was added to the beginning of the renamed images, for example 028_05_070905_001_PGH_001a_3 (Table 1). Within the catalogue, the individual's catalogue name, year first seen, renamed image name, marking description, marking type and the image in which the individual was first seen were recorded. An excel spreadsheet was created to show a condensed list of the encounters seen on these dates and to take notes of any re-sightings across the years. This process was used in order to understand the Risso's dolphin population's ranging movements across the Irish Sea. As well as this, their site fidelity and patterns of movement were also established for each encounter.

Table 1. An example of the catalogue tables including the image / individual and catalogue name, the marking description of the dorsal fin and the date first seen.

Catalogue name	084_08
Year first seen	2008
Image name	080710_001_TFE_003_1
Marking description	Circular notch missing in middle of dorsal fin, scratches along both sides of dorsal fin
Marking type	Notch and scratches
First seen photo	10th July 2008
	

Mapping Data

To create a visual representation of the Risso's dolphins' sightings, ArcGIS Map 10.8 was used. The locations were West Wales, Isle of Man, Anglesey, Pembrokeshire, Llyn Peninsula, Amlwch, Cemaes, Wylfa, Point Lynas and Bull Bay. The distribution of the encounters was then plotted in their correct locations using different colour markers to represent the year of the sightings. Then, the website European Marine Observation and Data Network (EMODnet) was used in order to find the depth of water and sediment type for each location. Other geomorphological features and anthropogenic information were also found by using this website from looking throughout the catalogue and highlighting the focal areas within this paper.

Copernicus Marine Service was another website that was used to collect data on the geological and ecological factors of the sighting locations. The oxygen (mg/L), phytoplankton (mmol/m^3), chlorophyll-a

(mg/m^3) concentration, sea surface temperature (°C) and salinity (10^{-3}) data were collected from this database. This was completed by adding different layers to the map generated and selecting the specific location and date for each of the sightings. Data from this database was then added to the excel sheet that will be used for analysis.

Data Analysis

As soon as the database catalogue was completed, and additional data collected, an excel sheet comprising the collated figures was loaded into R-Studio 4.2. Within this analysis, correlational graphs were created alongside statistical tests, such as an ANOVA and paired t-test to look for statistical differences between the means. A Shapiro-Wilk normality test was also used to see whether the data follows a normal distribution. In addition, a linear regression analysis was used to help predict values of another variable. These tests were conducted in order to compare the different parameters to understand the relationship between them and how they correlate with the distribution patterns of the Risso's dolphin sightings. A Q-Q plot was created to visually show the correlation between the number of individuals and the normal distribution.

Then, for the fidelity rate (FR) the equation of "Number of sightings of an individual in a specific area/Total number of sightings of the individual" was used (Labach *et al.*, 2015). This was done by looking at each of the sightings and noting each individual, their sighting date and location. The equation in Labach *et al.* (2015) was then used to calculate their fidelity rate.

3 | Results

The sighting data from the SWF showed that a total of 314 individuals were identified between the years 2004-2022 within the nine locations plotted in the Irish Sea (Figure 2). There was a total number of 421 dolphin sightings with 16% (67) of individuals returning across the 52 encounters. As well as this, six of those were observed returning in more than one year. However, the data from 2004 and 2005 were from an unknown location, so the data was removed from any calculations. The mean and standard deviation were calculated for each of the environmental factors (Table 2).

A map of the sighting locations was created to look at the Risso's dolphin distribution, where it can be seen in figure 2, that locations near the top of Anglesey were more concentrated in effort. The favoured sediment amongst the sightings was sandy gravel, the substrate described in EMODnet, along with a mean depth of –38.2m and temperature of 12.7°C (Table 2).

The fidelity rate was then calculated (Table 3). For this, only individuals that had three or more sightings were used in order to provide a more reliable ratio, resulting in only six being used. The highest number of sightings overall was six for two dolphins, four for one individual and three for three individuals. From the 421 sightings, only six dolphins were re-sighted three or more times, meaning that support for the hypothesis (H2) is low.

Table 2. Mean and standard deviation (SD) of the numerical parameters.

	Depth (m)	**Oxygen (mg/L)**	**Phytoplankton Concentration ($mmol/m^3$)**	**Temperature (°C)**	**Chlorophyl a (mg/m^3)**	**Salinity (10^{-3})**
Mean	-38.264	255.39	3.647	12.767	1.117	33.878
SD	11.666	21.648	1.7603	0.301	0.144	0.373

Table 3. Fidelity Rate (FR) for 6 individuals that had three or more sightings.

Individual Name	Fidelity Rate (FR)
137_15	0.5 (3/6)
178_18	0.66 (4/6)
046_07	0.33 (1/3)
127_11	0.66 (2/3)
150_17	1 (3/3)
144_15	0.75 (¾)

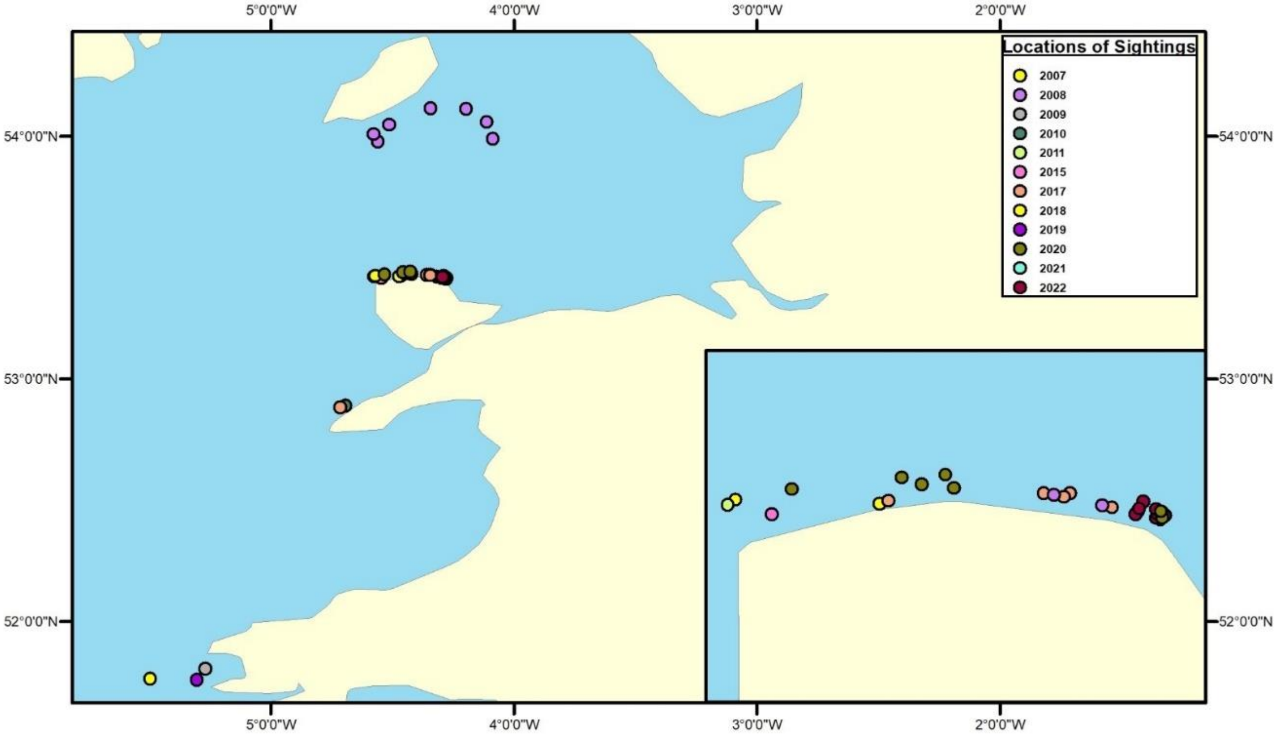

Figure 2. A map indicating the sighting distributions within the Irish Sea, including a key in the top right displaying each year's identification. A closer image of North Anglesey is provided in the bottom right corner.

Whilst reviewing the number of individuals in each location, the bathymetry feature of depth and ecological features of oxygen, temperature and phytoplankton concentration were also considered. A one-way ANOVA was conducted for each factor and revealed that for depth (Fig. 3A) there was a statistically significant difference ($P \leq 0.05$) between at least two groups ($F(9,35) = 58.1$, $p = <2e-16$). Temperature (Fig. 3C) ($F(9,35) = 3.056$, $p = 0.008$) and phytoplankton concentrations (Fig. 3D) ($F(9, 35) = 3.844$, $p = 0.002$) can also be classified as statistically significant. However, oxygen (Fig. 3B) ($F(9,35) = 1.58$, $p = 0.16$) was not statistically significant as its p-value was not $P \leq 0.05$.

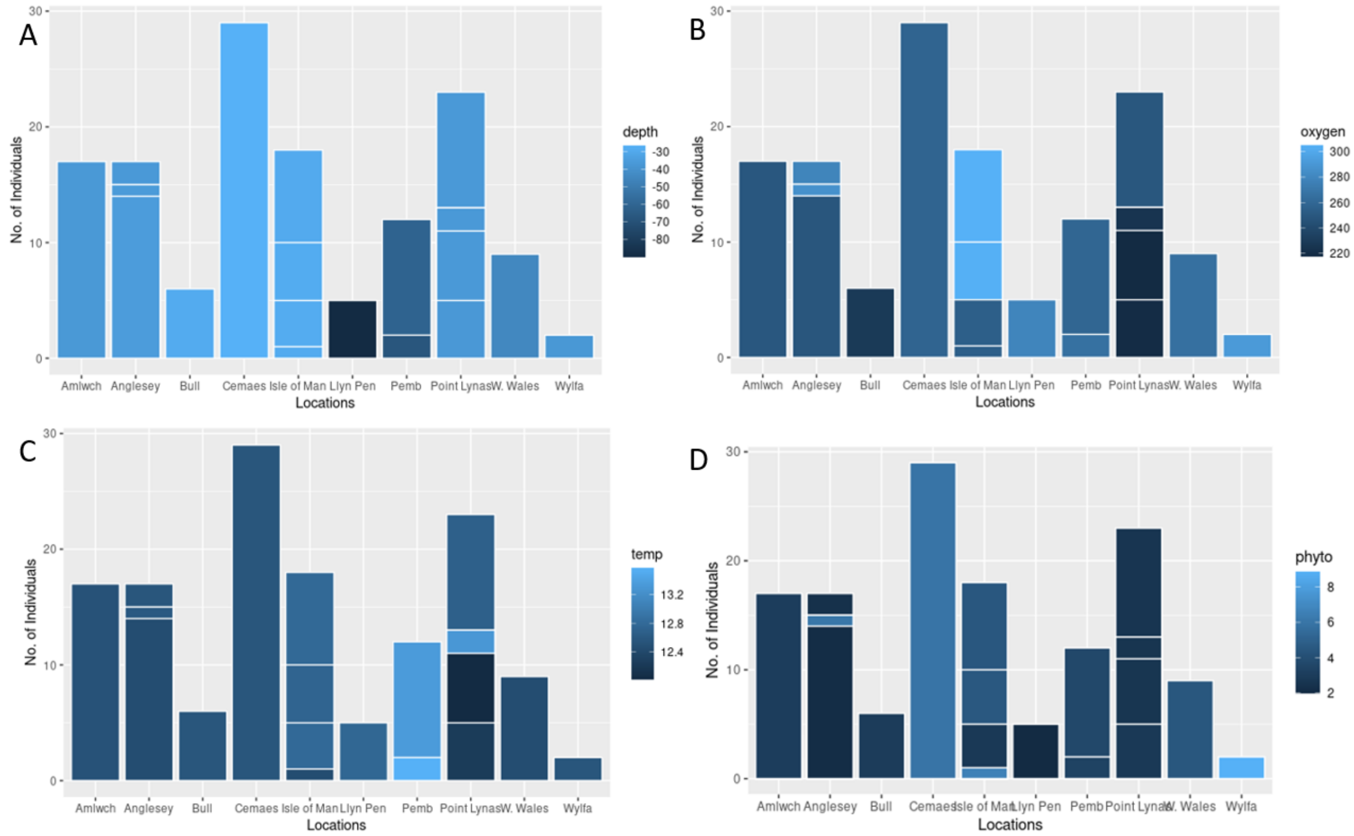

Figure 3. The number of individuals in each location with the white bars showing each sighting and A) Depth, B) Oxygen, C) Temperature and D) Phytoplankton Concentration being indicated in each sighting by the colour chart indicated on the right of each graph.

A Kruskal-Wallis test was used to determine the significant differences between the independent variable (location) and the temperature in those areas ((H1 = 67.22, P= 2.428e-16), (Chi-square test, X9 = 17.978, P = 0.035)). As both P-values are ≤ 0.05, making the results significant, the alternative hypothesis (H1) was confirmed, rejecting the null hypothesis. A boxplot was then made to visually summarise the data as well as highlight any outliers within the data set that could have altered the overall results (Fig. 4). The majority of the boxes (apart from Point Lynas) are short, meaning that the data is less dispersed. Also, the box plot points are mostly left-skewed in distribution, meaning that the median is greater than the mean in this data set.

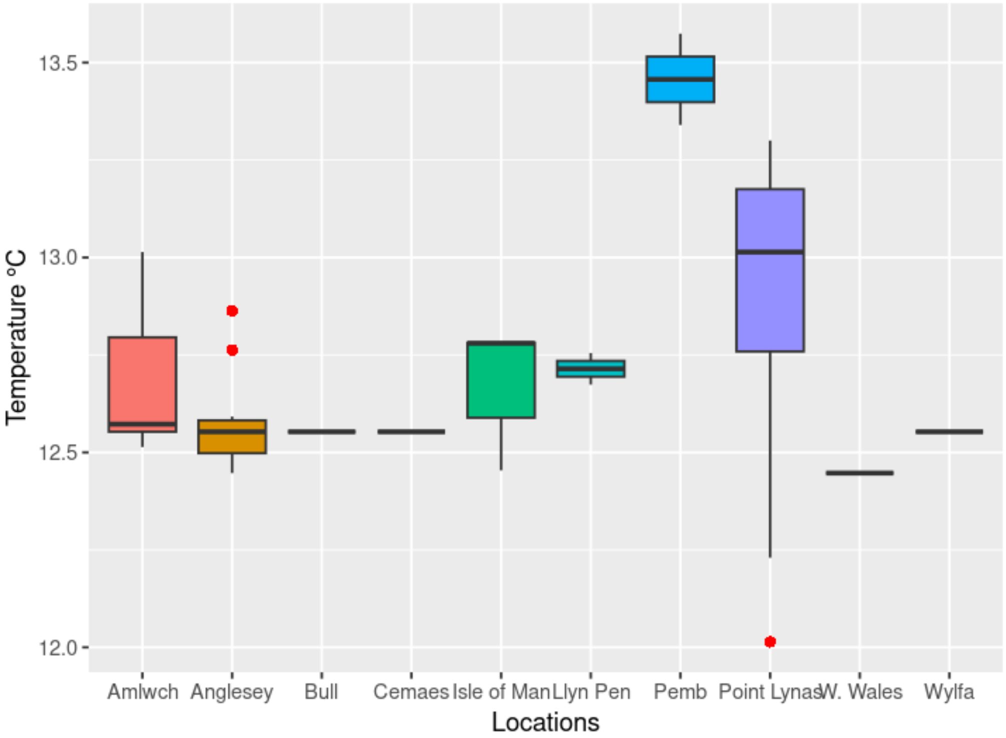

Figure 4. Box plot showing the temperature (°C) against the different sighting locations. These boxes show the lowest and highest scores (whiskers) and present the median marks surrounded by the 25% scores that fall on either end of this number (inter-quartile range).

Then, a Shapiro-Wilk test of normality was conducted to determine whether the number of individuals was normally distributed. From this, it can be stated that the alternative hypothesis (H1) is accepted for the number of individuals in the dataset (p = 0.0009) and one can conclude that the data is significantly different from normal distribution and can assume the normality. To further assess normality, a Q-Q plot was created (Fig. 5) where the majority of points fell within the confidence bands, which means that a normal distribution can be assumed.

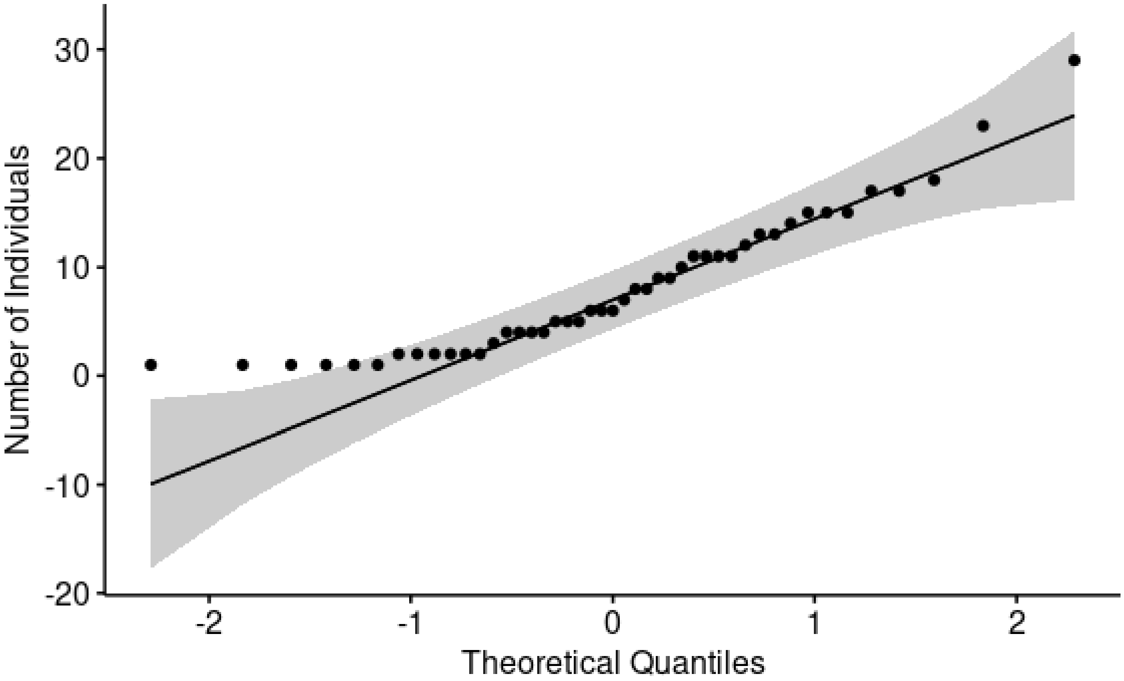

Figure 5. A Q-Q plot showing the correlation between number of individuals with a confidence band surrounding a 45-degree reference line plotted.

A linear regression was used to test if increasing depth significantly predicted a rise in phytoplankton abundance. The fitted regression model was Y = a + bX. The regression was not statistically significant (R2 = 0.045, F(1, 43) = 2.014, p = 0.163). It was found that there was no correlation between increasing depth with increasing phytoplankton concentrations and the alternative hypothesis (H1) was rejected (β = 0.212, p = 0.163).

A two-sample t-test and a one-way ANOVA were then used to compare the means between the number of individuals against the concentration of phytoplankton. There was no significant difference in means between the number of dolphins (M = 8.13, SD = 6.497) and phytoplankton concentration (M = 3.647, SD = 1.78); t(44) = 4.302, p = 0.314). The ANOVA (F(1, 43) = 1.309, p = 0.312) also showed that the data was not statistically significant as the P-value was ≤ 0.05. Figure 6 provides a visual representation of the data. There is an anomaly at 6mmol/m^3 at 29 individuals. The trend-line shows a weak negative correlation between the data points, indicating that the data was not significant.

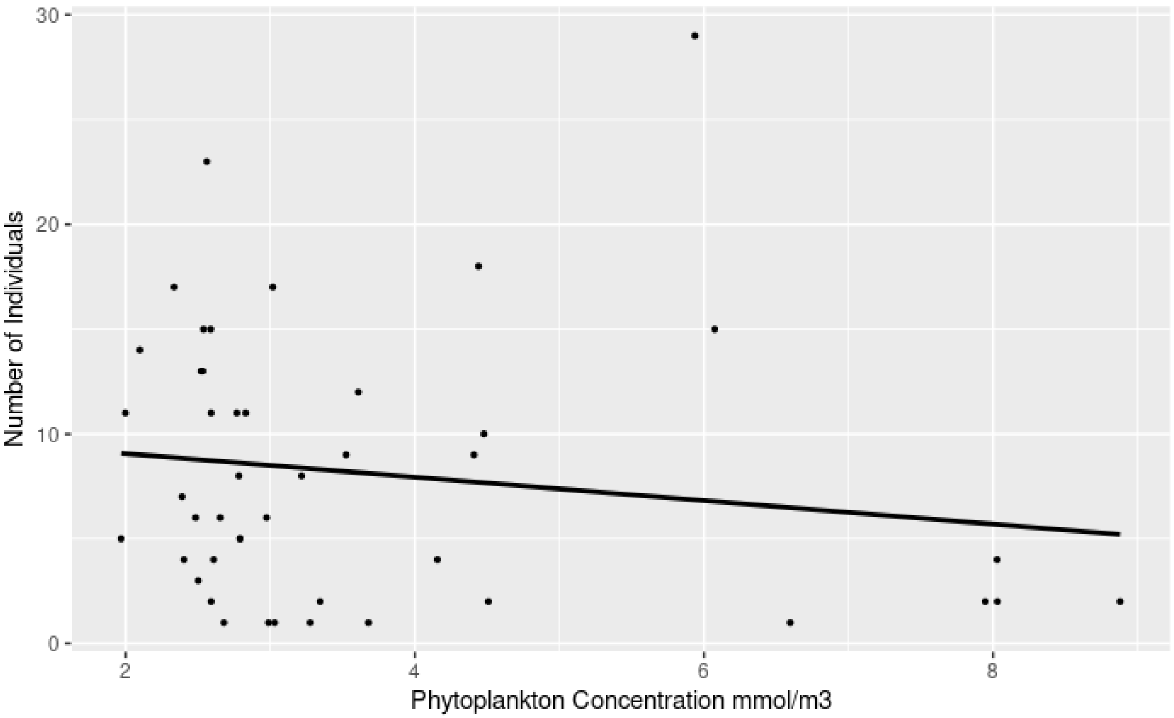

Figure 6. Scatter plot showing the number of individuals against the phytoplankton concentration (mmol/m^3) with a line of best fit indicating the trend.

Following this, a two-sample t-test was performed to compare the means in the phytoplankton concentration and temperature. There was no significant difference in means between phytoplankton concentration (M = 3.647, SD = 1.780) and temperature (M = 12.508, SD = 1.736); t(44) = -24.610, p = 0.710). To further test the significance between these two variables, a one-way ANOVA was used. It was shown that for phytoplankton against temperature (Fig. 7A) there was no statistically significant difference between them (F(1, 43) = 0.183, p = 0.671). This agreed with the paired t-test and further supports the rejection of the hypothesis (H1).

An ANOVA was performed to examine the relationship between phytoplankton concentration with oxygen concentration (F(1, 43) = 8.18, p = 0.006). The data was statistically significant, meaning that the null hypothesis will be rejected, and the alternative hypothesis (H1) accepted. A scatter plot (Fig. 7B) was then produced in R-Studio to highlight the spread of the data. There was a weak positive correlation in the data with some outliers, but the majority of the data was close to the trend-line.

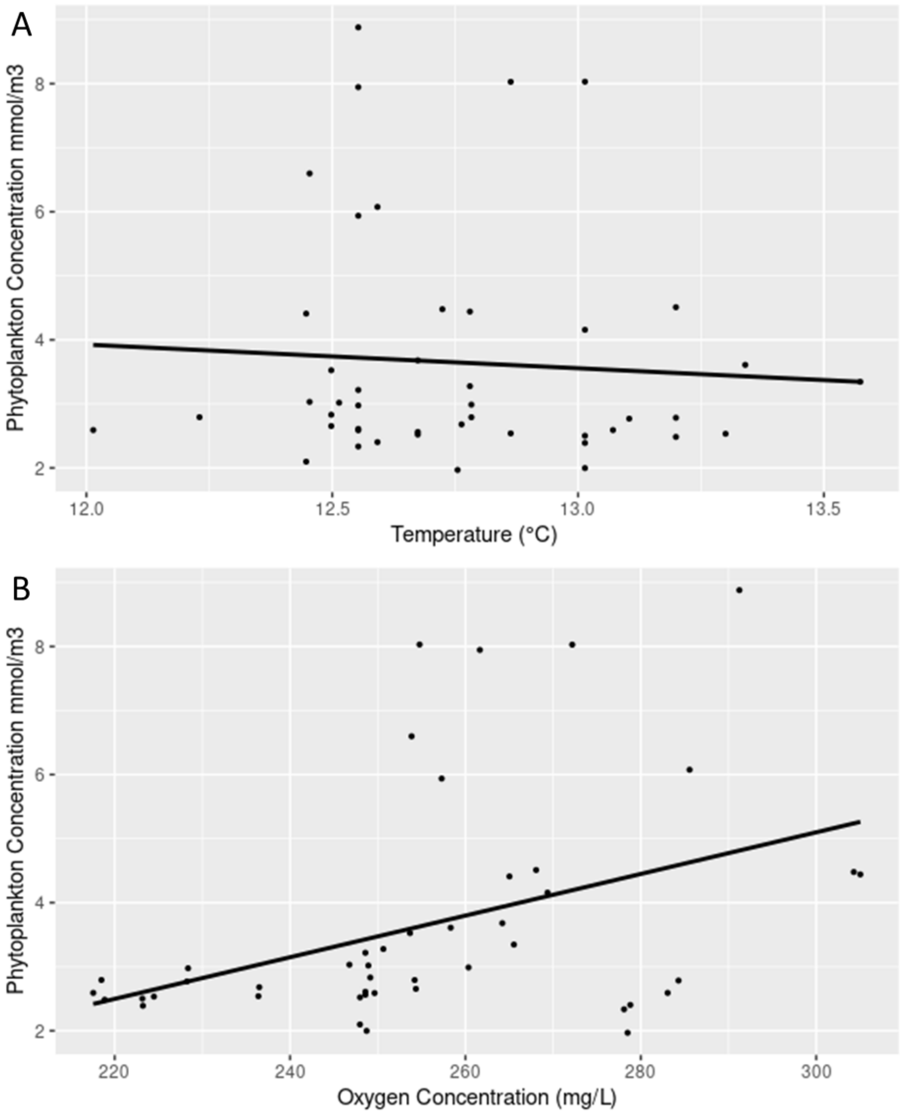

Figure 7. Scatterplot showing the relationship between phytoplankton concentrations (mmol/m^3) and A) temperature (°C) with a weak negative trend-line and B) oxygen concentration (mg/L) with a weak positive trend line.

4 | Discussion

From this study, some insights into Risso's dolphin social structure and the influence of environmental factors on their distribution were found. The number of individuals was deemed normally distributed, which indicates that all the sightings within each location lacked extreme values and describes the spread of data as natural and normal.

Looking at the features around the location of sightings is crucial in understanding the organisation of Risso's dolphins in the Irish Sea, and how environmental factors influence them. From this analysis, the number of single dolphins did not seem to have an effect on an increased concentration of phytoplankton. It was theorised that they would be influenced due to an increased phytoplankton concentration, suggesting a higher population of cephalopods as they are a known food source. Phytoplankton are at the base of most marine food webs as they can form large blooms that are nutritionally advantageous for the taxa consuming them (Not *et al*., 2012). However, the relationship between phytoplankton concentration with an increased oxygen concentration was still analysed, due to phytoplankton being a known producer of oxygen as a by-product of photosynthesis (Diaz and Plummer, 2018). This relationship correlated positively, meaning that the higher the oxygen concentration, the higher the phytoplankton presence, which agrees with other published literature findings.

As for depth, this correlated positively with the locations of sightings which was predicted due to the Risso's dolphins' preference for deep waters beyond continental shelves. This area is known as a transition zone between two different ecosystems, where Risso's dolphins can feed on both neritic and oceanic cephalopods (Baumgartner, 1997). This behaviour has been recorded in the Mediterranean and Azores populations where food availability, as well as protection from differing predators, is associated with these deep geomorphological features (Baumgartner, 1997; Maglietta *et al*., 2018; Visser *et al*., 2011). Also, the preference of sandy gravel further relates to the presence of cephalopods, the Risso's favoured food source. This is because squids are known to form a depression and bury themselves in sandy sediments on the sea floor, where they cover themselves in sand to hide from prey (Brocco, 1971). Within both Baumgartner (1997) and Maglietta *et al*. (2018) the effects of anthropogenic behaviour, such as fishing and merchant traffic, affecting the Risso's distribution and overall conservation status was considered. As anthropogenic activities impact the ecosystem physically, chemically and acoustically, the movement of Risso's dolphins and other taxa from those areas is not unheard of. Despite this, the presence of Risso's with increasing depth was not significant and went against the hypothesis and other published papers, suggesting that Risso's can occur in shallower waters than theorised. Nevertheless, it could be argued that during these periods of sightings, the Risso's were not feeding as they are known to feed at night, corresponding with cephalopod circadian vertical movements (Bearzi *et al*., 2011).

Temperature was the final environmental factor that was analysed. It had a positive relationship with the sighting locations, as the average temperature in each area was similar to those in other Risso's dolphin research (Kruse *et al*., 1999; Baird, 2002). Each location had similar environmental data, all of which aligned with other studies that have specifically researched Risso's dolphins within these waters. However, the analysis showed a decrease in phytoplankton with rising temperatures. The temperature in this study (12-14°C) conforms to other recorded temperatures (6-14°C) that phytoplankton are commonly found blooming in (Trombetta *et al*., 2019). Also, Trombetta *et al.* (2019) states that phytoplankton abundance tends to increase when temperatures reach 12-14°C, which was not observed in this paper. Despite the majority of data being collected during peak blooming seasons, the results do not support other findings. A reason for this might be due to the depth and upwellings, as sightings were only in shallower waters. Silva *et al.* (2021) discusses the effect of depth upon phytoplankton abundance, as well as the variability in nutrient availability and its impact on phytoplankton biomass within the blooms.

Overall, the results of this analyses support the acceptance of the null hypothesis 'The frequency of individuals and groups will not be dependent on environmental factors, and rejection of the alternative hypothesis (H1). Kanaji and Gerrodette, (2020) suggest that the change in abundance trends may not be due to an actual increase or decrease in single dolphins, but rather individuals changing habitat. This could be due to long-term environmental changes, recovery from previous human exploitation or competition with other species within the area. Due to the paper's lack of concentration, it is not possible to draw a direct connection between group movements and environmental changes, but it is likely that several movements can be attributed to alterations in the environment. However, seasonal variations also need to be considered as oceanographic conditions, such as currents and tidal patterns, as this has been linked to reproductive constraints on distribution and migration patterns (Ballance, Pitman and Fiedler, 2006).

Within Risso’s dolphin research, fidelity rate is a recurring topic and a trait that has been associated with this species. It is also crucial to locate frequently visited areas to understand any drivers or preferred conditions that alter this species distribution and movement patterns. This study did not present high fidelity, as only a small number of independent dolphins were sighted returning to the areas of observation. Those six individuals did show site fidelity, consistently returning to similar areas within the Irish Sea over several years. Mandlik (2021), who previously worked on this data set, had a total of 105 identified individuals with a 16.2% re-sighting rate. This study found that there was a low site fidelity of individuals in the Irish Sea, and considered the correlation with ample foraging opportunities and summer migrations and the time these sightings were captured. As for Stevens (2014), who also previously worked on this data set, had a total of 144 identified individuals from 30 sightings events and 12.5% of individuals were resighted. They also found a low site fidelity and suggested that this was due to their large-scale movement patterns up and down the west coast of the British Isles. Eisfeld-Pierantonio and James (2018) also found some degree of site fidelity, despite it being low, showing that Risso’s dolphins within Welsh waters are returning across the years.

As well as this, a pair of Risso’s dolphins were seen together across four different years as well as multiple dolphins returning with similar pods. This also supports other research, such as Hartman, Visser and Hendriks (2008), where pair formation within group clusters is commonly related to Risso’s dolphins. It suggests that there is a hierarchy and social structure within pods, as the groups are altered by pairings and their contribution to activities, such as hunting and avoiding predators. Also, there was a total of 15 individuals that were seen with a calf where they were mostly in clusters. This suggests that Risso’s dolphins in pods will protect the calves within their group, and that clusters with calves are most likely found in safer areas with a higher population of prey. This is because the chances of the calf surviving to adulthood is higher within these parameters.

Once again, the acceptance of the null hypothesis that ‘individuals' studied will not display a recurring pattern of returning to the same previously documented areas’, and rejection of the alternative hypothesis (H2). Despite re-occurrence of some dolphins, there was not a high enough percentage of return rates to fully accept the alternative hypothesis. Other studies, such as Stevens (2014) have suggested that populations in the Irish Sea may be part of the same population that have a pathway through the waters. Individual 046_07 can be found in both Isle of Man and off Bull Bay across the years, which supports this theory. However, the other returning individuals were seen returning to similar locations, which further infers the use of site fidelity in Risso’s dolphins.

Further Research

Further research into cephalopod abundance and ecological importance needs to be considered, as a lot of the research is on their role in fisheries and their economic impact. As mentioned in Lordan, Burnell and Cross (1998), their role in the ecosystem was considered and the need to reduce fishing exploitation in Irish waters was emphasised. This is due to their seasonal migrations into shelf waters to spawn, where the Risso’s dolphins have been regularly seen, as the locations within this study are all on or near a shelf edge. Many of the papers on Risso’s dolphins focus heavily on either their feeding habits or dive tracking, rather than their overall movement patterns. This research would be helpful in future understanding of this species, as it will help to further understand their social structure and spatial distribution, as well as how environmental and physical factors affect this. Finally, further investigation into calf presence in Irish waters would be beneficial. This is because, in theory, the female Risso’s dolphins will take their calves to the most ideal ecosystem, where there is a high abundance of food and preferred environmental conditions. The presence of calves was noted within this paper, but no further research into pod size, specific environmental conditions or movement patterns was considered. This could facilitate additional knowledge on Risso’s dolphins' social structure, as well as their overall organisation and movement patterns.

Limitations

As for limitations within this study, human error can be highlighted as one of the main factors. This is because there were many images and data points that needed to be sorted through in a thorough routine and misidentification of individuals could have occurred. As there were three people sorting through these data files, there could have been a miscommunication or misunderstanding in any aspect of the identification process. This means that the processes could have been done slightly differently, which could have altered the results. Also, as some of the images were out of focus or from a difficult-to-identify angle, these images were not used, meaning some identifications may have been missed. As well as this, not all individuals had photos from both sides of their dorsal fin, making identification difficult if they did not have prominent nicks or other markings that were visible from both angles.

Another challenge was that some markings can disappear over time, making it hard to identify from past images, as they sometimes covered or removed identifiable markings that were being used before. Finally, there were some issues when it came to the photographing style and bias with locations. Some of the images were not usable due to the angle of the photo, meaning that some dolphins were not identified and therefore excluded from the study. As for the location, there was not an even distribution in specific areas and locations within them, which would have enabled a more accurate reporting of their site fidelity and dispersal patterns and routes. However, this is due to Anglesey being the main research area for the SWF and not because of bias.

Conclusions

Conclusive evidence for the effects of ecological drivers and the frequency of high site fidelity was not found within this analysis. Despite this, some conclusions can be drawn from this study. Environmental factors can influence Risso’s dispersal patterns, but it is not the sole reasoning for their spatial distribution, as other factors such as predation risk, and effects of anthropogenic activity such as vessel disturbance can also impact this. Also, the occurrence of site fidelity, as well as patterns in social structures – like pairings, can be observed within this set of data, even if it is not as frequent as predicted. Risso’s dolphins are not as well studied as other cetaceans, and the occurrence of more sighting and data collection in the future will allow more concrete statements and understandings to be made.

Acknowledgements

A massive thank you to the supervisors Peter Evans (SWF and Bangor University) and James Waggitt (Bangor University) for aiding in the completion of this study through guidance and recommendations of sources and programmes. Also, thank you to the Sea Watch Foundation (SWF) who, over a period of years and many locations, collected and produced the Risso’s dolphin dorsal fin photos and data used throughout this paper. Finally, thank you to the fellow students who took part in generating the general catalogue of individuals and spreadsheet of sightings, which allowed any data analysis within this study to be performed. Without this help, this paper would not have been able to be completed.

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Appendix:

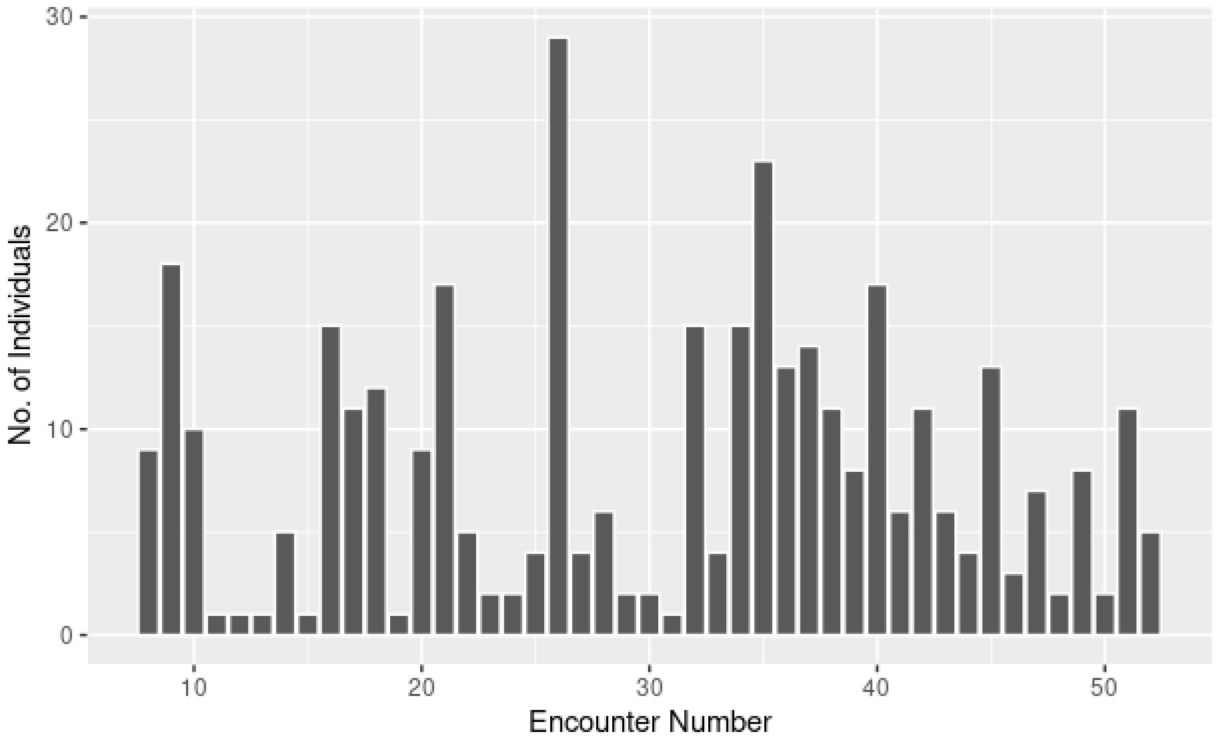

Figure 8. Bar plot showing of number of individuals within each encounter number (starting from encounter 8).

Table 4. Individuals resighting table including the dates they were sighted.

INDIVIDUAL	137_15	178_18	046_07	127_11	150_17	144_15
DATE FIRST SEEN	04/10/15	10/05/18	07/09/07	15/09/11	26/09/17	04/10/15
SECOND VISIT	12/09/17	09/08/20	24/03/08	26/09/17	27/09/20	26/09/17
THIRD VISIT	26/09/17	06/09/20	27/09/20	20/08/21	25/09/21	18/08/20
FOURTH	10/05/18	27/09/20	x	x	X	20/08/21
FIFTH	18/08/20	25/09/21				x
SIXTH	20/08/21	25/09/21				
SEVENTH	x	x				

Table 5. Table of overall data and sightings. Environmental data for each location was used.

Date	*LAT*	*LONG*	*Location*	*Depth (m)*	*Oxygen*	*Phytoplankton Concentration mmol/m³*	*Sediment type*	*Temperature (°C)*	*chlorophyl a mg/m³*	*Salinity 10⁻³*	*Encounter Number*	*Individuals*
18/04/2004	-	-	UNK	-	-	-	-	-	-	-	1	7
09/05/2004	-	-	UNK	-	-	-	-	-	-	-	2	4
15/06/2004	-	-	UNK	-	-	-	-	-	-	-	3	5
06/12/2005	-	-	UNK	-	-	-	-	-	-	-	4	23
09/12/2005	-	-	UNK	-	-	-	-	-	-	-	5	1
05/09/2007	-	-	UNK	-	-	-	-	-	-	-	6	8
07/09/2007	-	-	UNK	-	-	-	-	-	-	-	7	7

28/08/2007	51.763631	-5.494973	West Wales	-44.6	265.02	4.4091	Sand	12.447	1.3036	33.743	8	9
22/03/2008	54.11712	-4.340701	Isle of Man	-29.6	305.03	4.4408	Sandy Gravel	12.78	1.0662	33.72	9	18
24/03/2008	54.114624	-4.194748	Isle of Man	-28.98	304.29	4.478	Sandy Gravel	12.724	1.0672	33.445	10	10
21/04/2008	54.04937	-4.511978	Isle of Man	-29.54	260.35	2.988	Sandy Gravel	12.783	1.0662	34.043	11	1
07/08/2008	54.061462	-4.109604	Isle of Man	-29.42	246.77	3.031	Sandy Gravel	12.454	1.2061	33.828	12	1
07/09/2008	53.98159	-4.55867	Isle of Man	-31.19	250.64	3.276	Sandy Gravel	12.78	1.0662	33.509	13	1
07/10/2008	53.992894	-4.084885	Isle of Man	-28.79	254.21	2.7908	Sandy Gravel	12.783	1.0662	33.186	14	5
17/07/2008	54.009845	-4.576523	Isle of Man	-29.19	253.86	6.5972	Sandy Gravel	12.454	1.2061	33.914	15	1
09/11/2008	53.429643	-4.351303	Anglesey	-37	249.64	2.5879	Sandy Gravel	12.553	1.1147	33.801	16	15
13/10/2008	53.422278	-4.318344	Anglesey	-37.3	249.15	2.8302	Rock	12.498	1.1147	33.831	17	11
27/09/2009	51.80501	-5.269983	Pembrokeshire	-61.65	258.32	3.6086	Sand	13.34	0.83148	34.019	18	12
31/08/2010	52.891582	-4.691861	Llyn Peninsula	-68.36	264.21	3.6792	Sandy Gravel	12.674	1.0719	33.28	19	1
15/09/2011	53.422623	-4.575286	Anglesey	-38.1	253.68	3.5246	Rock	12.498	1.1147	34.713	20	9
10/04/2015	53.416076	-4.545073	Anglesey	-36.9	278.09	2.3347	Sandy Gravel	12.553	1.1147	34.652	21	17
05/12/2017	52.884546	-4.71285	Llyn Peninsula	-89.97	278.49	1.9681	Sandy Gravel	12.755	1.0719	33.699	22	5
20/08/2017	53.420641	-4.311478	Amlwch	-30.94	254.77	8.0298	Sandy Gravel	13.014	1.0719	33.778	23	2
31/08/2017	53.430461	-4.35817	Amlwch	-31.2	261.65	7.9453	Sandy Gravel	12.553	1.1147	33.772	24	2
09/12/2017	53.430461	-4.340317	Amlwch	-31.28	278.8	2.4028	Sandy Gravel	12.592	1.212	33.299	25	4
26/09/2017	53.42514	-4.465086	Cemaes / Holyhead Harbour	-26.69	257.29	5.9372	Rock	12.553	1.1147	33.595	26	29
11/08/2017	53.427944	-4.344365	Amlwch	-29.89	272.18	8.0276	Sandy Gravel	12.863	1.1147	33.7	27	4
05/10/2018	53.425897	-4.569792	Anglesey	-31.45	254.35	2.6537	Sandy Gravel	12.498	1.1147	33.95	28	6
08/06/2018	53.423287	-4.471067	Wylfa	-37.63	291.24	8.8785	Sandy Gravel	12.553	1.1147	33.093	29	2
15/02/2019	51.759867	-5.303428	Pembrokeshire	-67.96	265.53	3.3449	Sand	13.574	1.0893	34.492	30	2
06/09/2020	53.433261	-4.53134	Anglesey	-37.7	236.49	2.6798	Rock	12.763	1.1147	33.882	31	1
08/09/2020	53.436533	-4.442076	Anglesey	-37.59	236.39	2.5389	Rock	12.863	1.1147	33.866	32	15
18/08/2020	53.434079	-4.420104	Anglesey	-36.96	248.59	2.6088	Rock	12.553	1.1147	33.769	33	4
09/06/2020	53.441441	-4.455809	Anglesey	-36.42	285.56	6.0746	Rock	12.592	1.212	33.889	34	15
15/09/2020	53.417813	-4.277395	Point Lynas	-36.97	248.59	2.5612	Rock	12.674	1.0719	34.033	35	23
19/09/2020	53.413289	-4.277124	Point Lynas	-36.9	247.98	2.521	Rock	12.674	1.0719	34.234	36	13
27/09/2020	53.443077	-4.425597	Anglesey	-35.78	247.97	2.0976	Rock	12.447	1.3036	33.74	37	14
29/09/2020	53.417975	-4.277937	Point Lynas	-32.84	248.73	1.9976	Rock	13.014	1.0719	33.914	38	11
14/08/2021	53.422278	-4.323837	Amlwch	-38.2	248.59	3.2168	Sandy Gravel	12.553	1.1147	33.795	39	8
20/08/2021	53.420641	-4.355423	Amlwch	-37.27	248.93	3.0178	Sandy Gravel	12.514	1.0714	34.037	40	17
25/09/2021	53.421306	-4.366143	Bull Bay	-29.3	228.37	2.975	Sandy Gravel	12.553	1.1147	33.551	41	6
25/09/2021	53.419267	-4.296102	Point Lynas	-39	228.24	2.7689	Rock	13.104	1.0719	34.138	42	11
13/10/2021	53.424437	-4.292848	Point Lynas	-38.43	218.86	2.4838	Rock	13.199	1.0719	34.017	43	6
28/07/2022	53.412319	-4.278208	Point Lynas	-38.08	269.36	4.1563	Rock	13.014	1.0719	33.856	44	4
25/08/2022	53.415389	-4.274955	Point Lynas	-37.12	224.48	2.5329	Rock	13.3	0.74521	34.098	45	13
27/09/2022	53.42476	-4.289866	Point Lynas	-37.59	223.16	2.5016	Rock	13.014	1.0719	33.903	46	3
28/09/2022	53.417975	-4.293797	Point Lynas	-38.04	223.22	2.39	Rock	13.014	1.0719	33.903	47	7
10/01/2022	53.415928	-4.295524	Point Lynas	-38.37	283.06	2.5909	Rock	13.071	1.0719	34.066	48	2
10/02/2022	53.413268	-4.281105	Point Lynas	-38.27	284.3	2.783	Rock	13.199	1.0719	34.086	49	8

10/07/2022	53.416338	-4.28059	Point Lynas	-38.94	268.06	4.5091	Rock	13.199	1.0719	34.086	50	2
10/11/2022	53.419714	-4.281276	Point Lynas	-37.02	217.56	2.5909	Rock	12.014	1.8376	33.509	51	11
13/10/2022	53.41997	-4.292778	Point Lynas	-37.5	218.49	2.792	Rock	12.912	1.3377	35.1	52	5