University of Southampton, 2025-26

Faculty of Environmental and Life Sciences
School of Geography and Environmental Science

AN ANALYSIS OF THE FINE-SCALE SPATIAL AMBIT AND HABITAT UTILISATION OF FORAGING MINKE WHALES IN NORTHEAST SCOTLAND

STUDENT ID: 33840784

SUPERVISOR: Dr. Victoria Domínguez Almela

A dissertation submitted in partial fulfilment of the degree of
BSc Environmental Science

Word Count: 6,432

Statement of originality

By submitting this thesis, I agree the following:

Except for those parts in which it is explicitly stated to the contrary, this thesis is my own work. It has not been submitted for any degree at this or any other academic or professional institution.

I agree that the thesis may be made available online for reading at the discretion of the Head of the School of Geography and Environmental Science. Permission for anyone other than the author to reproduce any part of the thesis must be obtained from the Head of School who will give his/her permission for such reproduction only to an extent which he/she considers to be fair and reasonable.

Candidate’s ID Number: 33840784

ACKNOWLEDGEMENTS

First, I would like to express my sincere gratitude to Dr Kevin Robinson at the Cetacean Research and Rescue Unit (CRRU) for enabling me to undertake this incredible project, for sharing his extensive knowledge, both in and out of the field, and for his guidance and recommendations throughout this dissertation. I would also like to thank Duncan MacDougall for his invaluable support in the field, assistance with idea generation and technical advice (frequently over a dram of whiskey!), and Jenny Spinou for being an exceptional boat skipper and for her unwavering support during my time at CRRU over the summer. It has been a pleasure to work with you all.

Furthermore, I would like to thank my supervisor, Dr Vicky Domínguez Almela, for her continued guidance throughout the project and for providing both constructive feedback and reassurance throughout the year. Finally, I would like to thank my family and friends for their encouragement and unconditional support during this very intense academic year.

ABSTRACT

Marine Protected Areas (MPAs) are recognised as an essential tool for the management and conservation of marine habitats; however, they have been criticised for a panacea, one-size-fits-all approach that overlooks spatial heterogeneity and differential habitat value within protected areas. Adaptive management seeks to address this limitation by using iterative, research-based conservation that refines management practices within designated areas. This study investigated the fine-scale foraging behaviour and spatial utilisation of minke whales to identify the factors influencing habitat use and inform adaptive management within the Southern Trench MPA. Kernel density estimates were applied to focal follow data to quantify spatial ambit. Juvenile whales were found to forage exclusively inshore, exhibiting larger total foraging areas (KDE 95), whereas adults were found to primarily forage offshore, with larger core foraging areas (KDE 50). Differences in habitat context, foraging tactics and competency, energetics, ontogeny, behavioural plasticity and dietary preferences provide compelling evidence for these spatial differences. The findings identify spatially discrete areas of ecological importance within the MPA and demonstrate how fine-scale spatial analysis can support the implementation of targeted, seasonal management measures. Overall, conclusions highlight the value of spatial analysis for informing adaptive management within heterogeneous MPA landscapes.

Table of Contents

List of Figures and Tables

1. Introduction

Marine Protected Areas (MPAs) are spatially delimited areas of the marine environment that are managed and designated for conservation and restoration purposes to protect biodiversity and associated ecosystem services (Connell and Gillanders, 2007; OSPAR, 2026; McLeod *et al.*, 2009). Despite the success of MPAs worldwide (Halpern and Warner, 2002), they have faced criticism for their panacea, one-size-fits-all approach to marine conservation (Rossiter and Levine, 2014), overlooking the spatial heterogeneity in habitat value across MPAs (Robinson *et al.*, 2023). However, this can be addressed through adaptive management – a flexible approach to policy implementation that refines the broad management objectives of an MPA. This allows conservation to be targeted to the most important areas, both spatially and temporally, through iterative conservation responses informed by ongoing research (Rossiter and Levine, 2014; MacDougall and Robinson, 2025).

Distributional mapping is an essential step in facilitating and designing adaptive management (Hooker *et al.*, 2011), however, these maps fail to consider the spatial ambit of species relative to their life-history strategies and behaviour (Robinson *et al.*, 2023). The success of designated areas depends on more than simply defining boundaries based on presence-absence data; it relies on data availability, an understanding of how animals utilise their habitats, and the factors affecting both distribution and abundance (Wilson *et al.,* 1997). Within this management context, an understanding of the ecological and behavioural factors driving spatial utilisation is further essential to discern the threats facing these animals and, thus, inform the management process.

The Southern Trench MPA, within the Moray Firth in northeast Scotland (Figure 1.1), was designated in 2020, encompassing identified burrowed habitats, areas of oceanographic fronts, shelf deeps, and two geodiversity features, with named, specific conservation benefits including the protection of the coastally occurring minke whale (*Balaenoptera acutorostrata*) (NatureScot, 2025). The common minke whale is the smallest of the baleen (rorqual) whales in the North Atlantic (Thibault *et al.,* 2025; Hoelzel *et al.,* 1989). Within the eastern North Atlantic, stocks are present in the waters of Spitsbergen, the Barents Sea, in Norwegian coastal waters and the North Sea (Monteiro *et al.*, 2025; Folkow *et al.*, 2000). The minke whale is widespread in UK waters, with an estimated 9,000 individuals occurring in the North Sea (Hammond *et al.*, 2017).

During the summer and autumn months, the Moray Firth attracts higher-than-average densities of minke whales compared to adjacent and wider waters (Paxton *et al.,* 2014). The whales mostly occur in shallow shelf waters (20 to 50 meters deep), particularly in areas with pronounced submarine topography, steep slopes, and along dynamic frontal systems (Sivertsen *et al.*, 2006; Naud *et al.*, 2003). These topographic and oceanographic features promote water-column mixing and nutrient upwellings, increasing biological productivity and subsequently affording rich feeding grounds for these whales (Robinson *et al.,* 2009). A spatial preference for sandy gravel sediment types is also exhibited by the whales utilising these waters, providing habitat for high densities of targeted sandeel (Ammodytidae) prey (Naud *et al.*, 2003). This fine-scale habitat selection shown by minkes is driven by the intrinsic link between environmental factors and prey availability (Boer, 2010; Thibault *et al.,* 2025).

Minke whales feed by swimming into prey aggregations with their mouths agape, expelling water through their baleen plates (a continuously growing keratinised structure used for filter feeding), retaining and swallowing their prey (Eerkes-Medrano *et al.,* 2021; Kuker *et al.,* 2005). These small balaenopterids exhibit a variety of foraging methods and feeding techniques. Both 'passive' (bird-associated) foraging and 'active' feeding methods (first described by Hoelzel *et al.,* 1989) are observed in the MPA (Robinson *et al.,* 2023), with increased turning rates and residence time associated with areas of high prey density (MacDougall and Robinson, 2025). Both behavioural and dietary plasticity are exhibited by minkes in response to spatio-temporal environmental heterogeneity, with foraging techniques and prey selection determined by energetics (Lindstrøm and Haug, 2001). However, individual entrapment specialisations are observed in the species (Kuker *et al.,* 2005; Robinson *et al.,* 2023), with preferences shown for small, pelagic schooling fish with high energy density, namely sandeel (*Ammodytes tobianus*), sprat (*Sprattus sprattus*), krill (*Euphausiacea*), capelin (*Mallotus villosus*), herring (*Clupea harengus*), and haddock (*Melanogrammus aeglefinus*). Minke whales typically target a single prey species during individual foraging events and respond to variable prey abundance by prey switching. Prey switching is assumed to occur when targeted prey species surpass a certain density threshold, and when switching to a different prey species becomes more energetically profitable (Robinson *et al.,* 2023). Therefore, the distribution of minke whales is highly correlated with the availability and distribution of prey species, with fine-scale foraging reflecting this trend (Robinson and Tetley, 2007).

Despite their high abundance in UK waters, due to their elusive nature and small size, much still remains unknown about their behaviour, feeding habits, and spatial utilisation (Eerkes-Medrano *et al.,* 2021). This scarcity of information highlights the importance of fine-scale behavioural studies to better understand the spatial ambit of foraging minke whales and the factors influencing their habitat/area use. Concerningly, these coastal waters face a plethora of anthropogenic threats, including ship strikes, entanglement in fishing gear, noise and water pollution, disturbance from whale watching, fisheries and habitat degradation (Leaper and Miller, 2011; Ryan *et al.,* 2016; Risch *et al.*, 2019). These threats can disrupt the natural homeostasis of animals, significantly influencing their life-history strategies, with short-term avoidance elucidating long-term impacts (Lusseau and Bejder, 2007). Impending threats will invariably vary within an MPA across spatial and temporal scales. Accordingly, the following study aims to advance current insights into these whales by improving understanding of fine-scale foraging behaviour, spatial ambit, and the factors influencing habitat use, to inform adaptive management in the Southern Trench MPA.

This BSc study provides the first fine-scale, individual-level analysis examining the spatial foraging of minke whales in the Moray Firth within the Southern Trench MPA. The primary objectives of this investigation were to:

1. Examine the foraging tracks of coastal minke whales collated from dedicated focal follows of the animals in the Moray Firth MPA.

2. Conduct spatial analysis to quantify core and total foraging areas utilised by the whales, employing kernel density estimates to understand their fine-scale habitat utilisation and individual movements.

3. Assess the impact and influence of habitat context (inshore *versus* offshore foraging), age class (adults *versus* juveniles), and dive duration on the fine-scale spatial ambit of individual minkes.

4. Evaluate the implications of the behavioural analysis in the context of conservation management, for the implementation of adaptive management practices (prohibitory exclusion zones for commercial and other vessels) in the Southern Trench MPA.

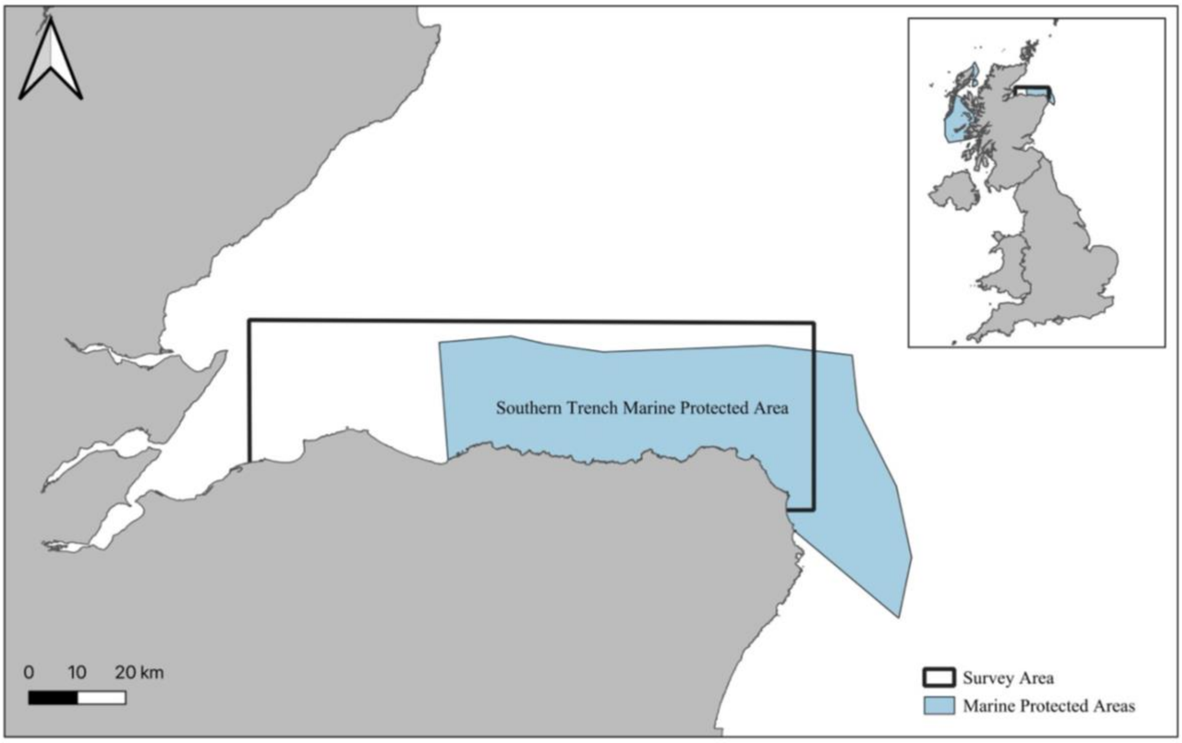


Figure 1.1. The location of the Moray Firth study area (black outline) within which focal follows were conducted, with reference to the boundaries of the Southern Trench MPA (in blue).

2. Methods

2.1. Survey area and locating animals

All data were collected during dedicated boat surveys conducted by the Cetacean Research and Rescue Unit, within a 1980km² survey area along the southern coastline of the Moray Firth in northeast Scotland (Figure 1). All research was conducted under a European Protected Species Licence issued to the Cetacean Research and Rescue Unit (CRRU) by NatureScot under The Conservation (Natural Habitats, &c.) Regulation 1994 (as amended): Regulation 44(2) (a). Surveys were conducted using an 8-metre rigid inflatable boat (RIB) and operated at speeds of 7 to 10 knots while searching for animals, and during favourable sea conditions (≤ 3 Beaufort Sea State, swells >1m and visibility ≥ 1.5 km) (after MacDougall and Robinson, 2025).

Surveys were conducted opportunistically, with routes selected to maximise encounter probabilities, informed by intra-seasonal, wide-scale searches of the study area (Robinson *et al.*, 2023). Comprehensive, 360° visual coverage was ensured during surveys by assigning fixed watch positions to between 2 and 3 trained observers and 6 support observers. Minke whales were located visually, either from direct sightings of travelling or feeding animals, or by the presence of feeding bird rafts. Upon sighting and locating an individual, a focal follow could commence.

2.2. Data collection

Focal follows are a vessel-based study method in marine mammal research, to document the fine-scale behaviour of marine predators and their relationships between habitat use and prey distribution (Friedlaender *et al.*, 2015; Kuhn *et al.*, 2020). Focal follows were conducted only in the presence of a single animal or when an individually distinctive whale could be identified from others by its unique dorsal fin shape/markings, facilitating unambiguous tracking of said animal. Follow data was recorded on a standardised data collection sheet (Figure A1). To minimise disturbance, the vessel was maintained at a distance of 50 to 300 metres from the whale, ensuring the animal had full freedom of movement. An Unmanned Aerial Vehicle (UAV) aircraft or drone was further used to assist the team in tracking the whales, as well as providing further opportunities for observations of foraging behaviours. The UAV was flown at a minimum height of 30 metres to minimise the potential for behavioural disturbance in focal whales, in line with established cetacean best practice guidelines.

During each focal follow, observers continuously tracked the whale, maintaining 360° visual coverage around the vessel to ensure no surfaces were missed. Upon each surfacing event, the bearing and the distance to the whale was recorded, along with the GPS position of the vessel, from which the actual position of the whale was determined via trigonometry. Information on the age of the animal (i.e. adult, dark in colour and >6.5 metres in length, or juvenile, lighter in colour and <6.5 metres in length (Robinson *et al.*, 2023)) was further recorded. The type of surface (i.e. regular surface, dive or feeding strike) and the direction of travel upon surfacing were also recorded for each timed surface interval during a focal follow event.

2.3. Spatial analysis

The recorded coordinates for each surface from each of the focal follows examined were imported into QGIS-LTR (v.3.40.5- Bratislava) for spatial analysis using the British National Grid Projection (CRS ESPG:27700 – OSGB36). Thereafter, the ‘Point to Path’ tool was used to create linear reconstructions of the foraging path for each whale. For each whale, the distance from shore, i.e. the shortest perpendicular distance from each foraging path to the coastline, and the longitudinal extent, i.e. the two most longitudinally separated surface points, were then measured using the ‘Measure (line)’ tool. Distance from shore was used to categorise each follow as either “inshore”, where the shape of the immediate coastline and/or shallow water depth might restrict the observed movements of the whale, or “offshore”, where there were no immediate coastline or water depth impediments.

Kernel Density Estimation (KDE) was subsequently employed to estimate the approximate foraging area used by each whale from the foraging tracks recorded. KDE calculates the probability density of surfaces, thereby identifying the differential affinity and intensity of spatial use. KDE countours, as a measure of utilisation distribution, were calculated at 50% and 95%, representing the core foraging area and total foraging range for each of the respective follows (after Teoh *et al.*, 2023).

The KDEs were resolved in Rstudio (v.2025.09.2+418), using the *kernelUD* function in the *adehabitatHR* package, with a Gaussian (bivariate normal) kernel and reference bandwidth *href* (Calenge, 2006). The spatial output for each whale was then exported as a shapefile for plotting in QGIS. The areas for both KDE 50 and KDE 95 were calculated from their polygons using the field calculator. A 200-metre exclusion buffer was added to each focal follow as a suggested minimum exclusion zone for tour vessels (as per Stevenson, 2019).

2.4. Statistical analysis

All statistical analyses were conducted in Rstudio (v. 2025.09.2+418). A Shapiro-Wilk test for normality was conducted to determine if the results were normally distributed. All data was non–normally distributed, requiring the use of non-parametric tests throughout.

Mann-Whitney U tests were used to assess the influence of foraging location (onshore *vs* offshore) and age (juvenile *vs* adult) on the utilised foraging area. Spearman’s Rank correlations were further used to test associations between dive durations, distance from the shore, and foraging area. A significance threshold of <0.05 was applied to all tests, and all means are given ± 1 standard deviation.

3. Results

Between 2009 and 2025, 27 focal follows were successfully conducted by the CRRU team, from which a total of 12, with durations greater than 20 minutes, were selected for further analysis. Follows were predominantly acquired from adult whales (10 adults *versus* 2 juveniles), with 7 offshore and 5 inshore tracks recorded, respectively (Table 3.1). The collated dataset resulted in a cumulative follow time of 5:49:49 hours, with follows ranging between 20:00 and 51:18 minutes (mean follow time = 29.09 ± 7:55 minutes).

The number of surfacing events (defined as Type 1 surfaces between dives) ranged from 3 to 31 with a median of 21, and intervals ranging from 4 to 59 seconds (mean = 26 ± 14 seconds). Longer (Type 2) dives ranged from 1:00 to 4:34 minutes, with an average dive duration of 1:56 ± 1:03 minutes.

Table 3.1. The individual minke whale focal follow events examined in the present investigation, detailing the age, location, follow duration and surface/dive intervals for each animal selected.

Whale ID	Age	Foraging location	Duration of follow (min)	Average surface interval (min)	Average dive interval (sec)
Ba01	Adult	Offshore	31:28	0:26	2:19
Ba02	Adult	Offshore	21:48	0:36	1:13
Ba03	Adult	Offshore	23:50	0:12	2:43
Ba04	Adult	Offshore	27:23	0:15	2:58
Ba05	Adult	Inshore	31:07	0:44	1:10
Ba06	Juvenile	Inshore	32:05	0:22	2:38
Ba07	Juvenile	Inshore	27:45	0:30	1:40
Ba08	Adult	Inshore	28:10	0:29	2:29
Ba09	Adult	Offshore	28:26	0:29	3:28
Ba10	Adult	Offshore	20:00	0:23	2:09
Ba11	Adult	Offshore	51:18	0:32	1:36
Ba12	Adult	Inshore	26:29	0:27	1:32

The utilisation distribution areas (KDE 50 and KDE 95) determined for the respective whale foraging tracks are shown in Table 3.2. Core (KDE 50) foraging areas ranged from 0.05 km^2 to 3.82 km^2, with an average core area of 0.89 km^2 ± 1.04 km^2. Total (KDE 95) foraging areas ranged from 0.2 km^2 to 26.04 km^2, with a total average area of 2.23 km^2 ± 2.62 km^2.

Table 3.2. The calculated utilisation areas (KDE 50 and KDE 95) for each minke whale foraging track, along with the longitudinal extent of each track and the proximity of the follow to the shore. (*inshore follows)

Whale ID	Age	KDE 50 Area (Km^2)	KDE 95 Area (Km^2)	Longitudinal extent (km)	Proximity to shore (Km)
Ba01	Adult	0.20	0.78	0.86	5.30
Ba02	Adult	0.17	6.77	0.74	5.93
Ba03	Adult	0.48	1.69	1.02	14.36
Ba04	Adult	1.35	5.12	1.82	14.78
Ba05*	Adult	3.82	13.99	1.26	0.31
Ba06*	Juvenile	1.20	4.22	1.61	0.48
Ba07*	Juvenile	0.20	1.09	0.75	0.49
Ba08*	Adult	0.43	1.70	1.10	1.50
Ba09	Adult	1.49	0.60	0.46	12.08
Ba10	Adult	0.05	0.20	0.41	13.77
Ba11	Adult	0.70	0.45	0.46	5.70
Ba12*	Adult	0.53	26.04	0.90	1.40

3.1. Spatial context of foraging

Figure 3.1 illustrates the spatial utilisation and foraging travel paths for an inshore and offshore minke whale, respectively. A Mann-Whitney U test revealed no significant difference between inshore and offshore foraging for KDE 50 ($W = 21.5$, $p = 0.569$) or KDE 95 ($W = 28$, $p = 0.106$). A Spearman's Rank test was further conducted to assess if there was a correlation between the distance from shore and the foraging area, however, no significant correlation was found in either the KDE 50 ($p=0.579$, $\rho = -0.18$, $S = 337.09$) or KDE 95 ($p=0.237$, $\rho = -0.37$, $S = 392$) utilisation areas. Despite the non-significant results, a slight negative correlation was observed for KDE 95, suggesting that foraging closer to shore tends to result in larger total foraging areas. Inshore whales certainly appeared to forage over a larger longitudinal distance than offshore animals (Table 3.2). However, offshore individuals Ba03 and Ba04 were also observed foraging over extensive longitudinal distances; thus, these differences are not necessarily as clear-cut.

Offshore whales were generally found to utilise larger average core foraging areas (KDE 50), whereas inshore whales utilised larger total foraging areas (KDE 95) (Table 3.3). This pattern aligned with the greater spatial variability observed in inshore foraging tracks. The large standard deviation for the inshore KDE 95 was noted, highlighting the variability and inconsistent spatial use of inshore foraging animals. This likely contributed to the insignificant results of the Mann-Whitney U tests, with statistical power limited by the small dataset.

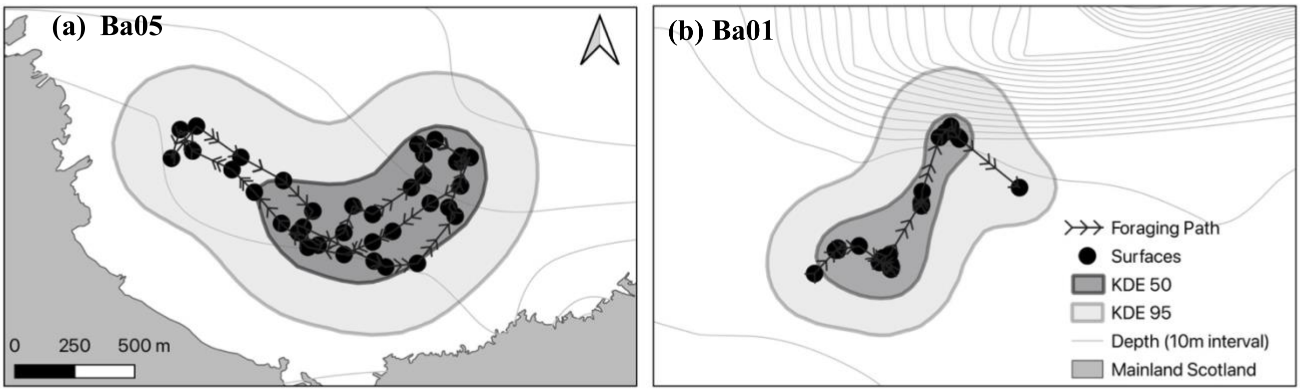


Figure 3.1. Examples showing the travel paths and spatial utilisation of an inshore (a) and offshore (b) foraging minke whale, respectively. (Scale 1:5500)

Table 3.3. Showing the average utilisation areas determined for inshore *versus* offshore foraging.

	Count	Average KDE 50 area (km^2)	Average KDE 95 area (km^2)
Inshore	5	1.23 ± 1.49	9.41 ± 10.64
Offshore	7	2.23 ± 2.62	5.21 ± 2.62

3.2. The effect of age class on foraging utilisation area

Adult whales were found to utilise larger foraging areas than juvenile whales (Table 3.4 and Figure 3.2). However, due to the restrictive sample size, a Mann-Whitney U test revealed no significant effect of age class upon foraging area for either the KDE 50 ($W = 9.5$, $p = 1$) or KDE 95 ($W = 10$, $p = 1$) outputs.

Table 3.4 shows a clear association between spatial foraging utilisation and age class, with adult whales typically foraging further offshore (averaging 7.51 km from shore) than juveniles (averaging 0.49 km from shore). Despite this, a Mann-Whitney U test showed no significant difference in foraging location between adults and juveniles ($W = 18$, $p = 0.107$), although the statistical power of this test was inevitably limited by the small dataset, particularly regarding the small sample size for juveniles ($n = 2$).

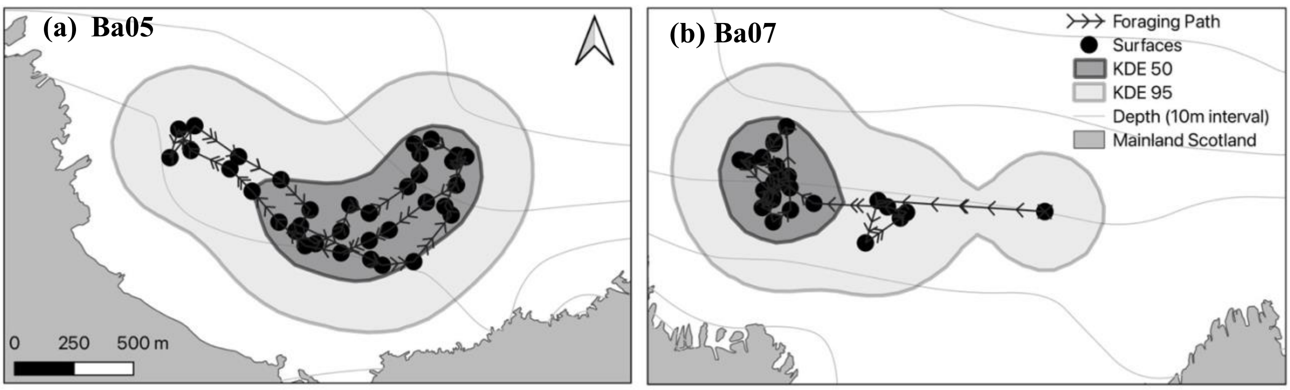


Figure 3.2. Examples showing the travel paths and spatial utilisation of an adult (a) and juvenile (b) foraging minke whale, respectively. (Scale 1:5500)

Table 3.4. Showing the average utilisation areas resolved for adult *versus* juvenile minke whale age classes.

	Count	**Average KDE 50 area km²**	**Average KDE 95 area km²**	**Average proximity to shore (km)**
Adult	10	0.92 ± 1.12	5.73 ± 8.32	7.51 ± 5.73
Juvenile	2	0.70 ± 0.70	2.67 ± 2.21	0.49 ± 0.01

3.3. The effect of dive duration on foraging area

The dive duration showed no significant correlation with the foraging area for either KDE 50 (Spearman's rank: $p = 0.4$, $\rho = 0.23$, $S = 219.8$) or KDE 95 ($p = 0.27$, $\rho = -0.35$, $S = 386$). Despite the absence of statistical significance (attributable to the small sample size), a weak positive correlation was, however, observed between dive duration and core foraging area (KDE 50), suggesting that longer dive durations were associated with larger core foraging areas. Conversely, a weak negative correlation was observed between dive duration and total foraging area (KDE 95), suggesting that shorter dives were consistent with larger foraging ranges.

Figure 3.3 illustrates high-intensity foraging behaviour within a dense prey patch, characterised by tight turns, repeated surfaces, and feeding strikes by the whales. This is reflected in the above findings: foraging whales observed exploiting dense prey aggregations exhibit more focal (smaller) core utilisation areas and shorter dive times. When prey are more spatially distributed, core foraging areas were seen to be larger, and the recorded dive times were longer. Conversely, the negative correlation between KDE 95 and dive interval times suggested that larger total foraging areas are reflected by shorter dive intervals.

Figure 3.3. Photogrammetry progression showing a minke whale's foraging path within a dense prey patch over a 13-second duration. The whale circles tightly to the right before striking and swimming away. Stills taken by a stationary drone at a height of 30 metres.

4. Discussion

The present study aimed to examine the fine-scale spatial utilisation of minke whale foraging using focal follows and kernel density estimates. The influence of habitat context (inshore *versus* offshore), age class, and dive duration on spatial utilisation was investigated. Differential spatial utilisation was observed between inshore and offshore foraging, with inshore individuals tending to utilise larger total foraging areas (KDE 95) and offshore individuals utilising bigger core foraging areas (KDE 50). Juveniles were exclusively observed using inshore habitats, whereas adults primarily foraged offshore, with a few exceptions. Dive duration was associated with variable spatial utilisation of foraging behaviour: longer dives were associated with larger core foraging areas, and shorter dives with larger total foraging areas.

4.1. Spatial context of foraging

4.1.1. Differential inshore *versus* offshore strategies

Minke whales are opportunistic, flexible foragers, and their distribution within known feeding areas is subsequently linked to the distribution and availability of their targeted prey (Lindstrøm and Haug, 2001; Skaug *et al.*, 1997). Marine habitats are complex and heterogeneous over both space and time, which results in the non-random distribution of prey aggregations across fine- and meso- scales (Naud *et al.*, 2003), shaped by fixed, physiographic (e.g., bathymetry, depth, sediment type) and temporal, oceanographic (e.g., water temperature or currents) environmental parameters, that influence prey species and predator behaviour alike (Anderwald *et al.*, 2012; Robinson *et al.,* 2023).

The comparative larger total foraging area (KDE 95) observed for inshore minke whales in the present study may reflect greater spatial heterogeneity in prey availability (e.g. Macleod *et al.*, 2004). Inshore, small eddies and fronts may enhance primary productivity and concentrate prey aggregations (Boer *et al.*, 2014); however, these aggregations are often patchy and short-lived. As a result, inshore minkes may need to conduct extensive exploratory searches over large areas in order to locate optimal prey patches. In contrast, however, the larger core foraging areas observed in offshore waters may reflect the influence of submarine topography (the Southern Trench in the Moray Firth) upon available prey, with oceanic upwellings increasing water-column mixing and resulting in greater biological productivity (Naud *et al.*, 2003). Such conditions evidently support larger, denser prey aggregations through elevated nutrient availability, and the subsequent cascades from phytoplankton to higher trophic levels, which result in the formation of biological hotspots (prey aggregations) that attract intense, core minke whale foraging (e.g. Boer, 2010; Thibault *et al.*, 2025). Within the Moray Firth study area, however, habitat associations are seen to vary temporally with the whales showing strong associations with inshore sandeels during May and June, and with krill and clupeid schooling fish in offshore habitats from June to September (MacDougall and Robinson, 2025; Robinson *et al.,* 2023).

This pattern aligns with the optimal foraging theory, which posits that predators adopt foraging strategies that maximise fitness and energetic gain by balancing the energy expenditure of searching and feeding, relative to prey intake (Pyke *et al.*, 1977). Although bulk filter feeding (minke whales are lunge feeders) incurs high energetic costs, it is energy efficient when prey density is high, and therefore, the primary factor influencing lunge feeding is prey density (Goldbogen *et al.*, 2011). Consequently, inshore foraging may involve individual minkes making a heightened search effort over a larger area before encountering a sought-after prey patch. Conversely, offshore habitats may offer denser and more persistent prey aggregations, supporting a more concentrated and sustained foraging effort, resulting in the larger core foraging area observed in this study.

4.1.2. Spatial variability and proximity to shore

The foraging efficiency of marine predators is closely linked to localised oceanographic conditions (Cox, 2016), with topographic and hydrographic features known to influence cetacean distribution (Bailey and Thompson, 2010; Boer *et al.*, 2014). The greater longitudinal extent of inshore foraging tracks is likely due to the physical constraints imposed by the adjacent coastline, which heavily influences the direction of travel and restricts cross-shore movements. The shallow bathymetry of bays also increases friction and creates turbulence, thereby increasing vertical mixing, limiting water-column stratification, and influencing local productivity. Where the curvature of a headland creates a bay, tidal patterns are enforced by the curved profile, which also promotes the retention of phytoplankton and small nekton and influences fine-scale prey movements (Cox, 2016). As a result, the greater longitudinal extent observed in the inshore movements by foraging animals was likely a reflection of 'along-shore' search behaviour, as minkes logically tracked the spatially constrained prey aggregations within bays. However, offshore foraging was found to be less linear and more circular or oval in form, reflecting an area-restricted search, in which movements shifted from directional exploration to a more focused search, with circular, looping tracks, as commonly observed in fine-scale foraging behaviour (e.g. Fauchald and Tveraa, 2003).

4.2. Individual variability and behavioural plasticity

Considerable variability was observed in the foraging tracks between individual whales, with this behavioural plasticity consistent with results from previous studies in the Moray Firth (e.g. MacDougall and Robinson, 2025; Robinson *et al.,* 2023). This was suggestive of the intra-population phenotypic variation observed by Robinson *et al.* (2023), manifested through behaviour in the observed foraging paths and spatial utilisation of individual whales, such that no single dominant or consistent foraging strategy was resolved. This variation and plasticity likely reflect heterogeneous resource use attributed to a combination of abiotic tolerance, microhabitat use, prey preferences and/or predation (after Dall *et al.*, 2012).

In the present investigation, it was difficult to demonstrate individual foraging specialisation, *per se,* as specialisation is defined as the 'consistent use' of a specific foraging pattern by an individual (Hoelzel *et al.,* 1989). However, pronounced inter-individual variability and behavioural plasticity appeared to explain the lack of commonality between recorded events. The individual differences in spatial utilisation are clearly visible in Figures 3.1, 3.2, and Appendix Figure A2, with markedly different spatial ambits being observed in both the core and total foraging areas and foraging paths, despite the close spatial proximity and broadly similar abiotic and biotic conditions between each foraging event. The individual variation may be explained by a wide combination of determinants, such as the age/experience of the whale, its body size (competitive ability), nutritional state/level of hunger, and, of course, the proximate abundance and type of prey (Anderwald *et al.*, 2012; Robinson *et al.,* 2023; *Bird et al.*, 2024).

Minke whales evidently exhibit opportunistic, flexible foraging and exploit a wide variety of prey species (Robinson and Tetley, 2007). The spatial variation in prey abundance is thus reflected in the diets of the minke whale, which will inevitably influence observed behaviour. This suggests that individual whales are not purely *inshore* or *offshore* strategists, but instead respond to spatial and temporal factors affecting the distribution and abundance of their prey. The structured surfacing pattern observed in travelling minke whales is thought to minimise the cost of transport – minke whales have a remarkably low energy expenditure of just 80 kJ per day (Blix and Folkow, 1995) – allowing them to exploit environmental conditions over larger spatial scales. However, when prey densities surpass a certain threshold that is energetically profitable for them, prey switching will occur (Robinson *et al.,* 2023).

4.3. Effect of age class on foraging

Prey accessibility for minke whales will invariably result from their ability to exploit suitable habitats which enable effective location, capture and consumption of prey (Bird *et al.*, 2024). Minke whales in the Moray Firth have been shown to exhibit age-class-related niche separation in fine-scale foraging and habitat partitioning, as well as ontogenetic shifts in their foraging tactics. The results of this study showed that whereas adults potentially foraged offshore and exhibited larger core foraging areas, juveniles exclusively foraged inshore and displayed larger total foraging areas. These findings were consistent with previous studies of minke and other baleen whales, demonstrating ontogenetic shifts in both foraging location and tactics, and suggest that foraging behaviour and habitat use are not uniform across age classes (Robinson *et al.,* 2023; Bird *et al.*, 2024; Fisheries, 2025). However, since the juvenile sample in the present study comprised only two individuals, further studies would benefit from a much larger sample to support this hypothesis.

Previous research has found that the spatial occurrence of adult minkes is best predicted by factors including the distance from shore (offshore) and high relief benthic slope, whilst in juvenile whales, sediment type, proximity to shore (inshore), and low relief benthic slope are the most important predictors (Robinson *et al.,* 2023). These predictions are complemented by the present results, which suggest that adults exhibit a wider range of foraging habitat use than juveniles. Indeed, juvenile whales are thought to be less efficient foragers than adults (Robinson *et al.,* 2009) and thus might be displaced from more optimal offshore feeding areas by their larger conspecifics, forcing them to forage closer inshore. The observed differences in the spatial utilisation of adult minkes (using larger core foraging areas) and juveniles (showing larger total foraging area use) are therefore likely the result of a combination of energetic constraints, foraging skills and competency and dietary preferences.

4.3.1. Energetic constraints

Optimal foraging theory posits that foraging animals aim to maximise energy benefits and minimise energy expenditure to maximise fitness gained from foraging (Mead, 2004). The utilisation of inshore habitats by juvenile whales, where locomotion incurs lower energetic costs, enables greater exploratory movement to locate patchy prey resources, thereby resulting in the larger overall foraging area observed. Since the energetic costs of locomotion increases with body mass (Bird *et al.*, 2025), movement will be more costly for adult minke whales. In the present study, adult minkes were found to exhibit targeted foraging in areas of high prey density, resulting in the smaller observed core foraging areas, which aligns with those energetic constraints.

4.3.2. Foraging skills and competency

Foraging skills and competency are developed over the course of a lifetime as the result of both learning and the inherent changes to in physiology (Patterson *et al.,* 2016). Thus, the ontogenetic scaling of foraging capacity may have profound consequences for the foraging capacity of organisms and the differing competitive ability between age classes (e.g. Persson *et al.*, 1998). Juvenile minkes will have lower competitive ability than adults, which may inevitably result in competitive exclusion from the optimal foraging area. Consequently, adults target rich, dense prey aggregations; however, juveniles forage between more patchy prey aggregations, due to competitive exclusion, resulting in a larger total foraging area.

4.3.3. Dietary preferences

Dietary preferences have also contributed to the differential spatial utilisation observed between adults and juveniles in the present study. Juvenile minke whales are found to primarily forage on inshore sandeels (Ammoditydae) (Robinson and Tetley, 2007; Robinson *et al.,* 2023), however, adults display greater dietary plasticity, typically foraging on offshore shoaling fish such as sprat (*Sprattus sprattus)* and herring (*Clupea harengus*) (Robinson *et al.,* 2023). Therefore, the smaller core foraging area observed in adult minke whales may reflect their focal foraging on more dense, predictable shoaling prey aggregations, whereas the larger total foraging area observed by juveniles may reflect the greater exploratory search required to locate patchier inshore sandeel prey.

However, while age-class is a potential explanation for the spatial distribution of minke whales, several studies suggest that the spatial distribution is more closely associated with environmental variables and prey availability (Anderwald *et al.*, 2012; Thibault *et al.,* 2025; and Macleod *et al.*, 2004), with no evidence of the effect of age class on spatial dynamics.

4.4. Relationships between spatial utilisation and dive duration

The dive performance of marine mammals is invariably influenced by body mass and metabolic rate (Schreer and Kovacs, 1997; Halsey *et al.,* 2006). However, dive-time budgets (the duration between surfaces) may also result from ecological aspects which cannot be explained by physiology alone (e.g. Doniol-Valcroze *et al.*, 2011). Predators aim to maximise resource acquisition by adapting their foraging strategies as a response to prey density and distribution (Heerah *et al.*, 2014). As a result, dive duration provides insights into the depth and density of targeted prey species, and has been used to examine the spatial utilisation of foraging minke whales (Eide, Rikardsen and Freitas, 2025).

The results of this study show that longer dive durations were associated with larger core foraging areas (KDE 50) and smaller total foraging areas (KDE 95). The dive duration of marine mammals tends to increase with habitat richness and prey depth, which may reflect the additional time required for prey search and ingestion (Christiansen *et al.*, 2015). The increased dive time may also reflect deeper, more widespread searches to locate prey. This aligns with the central-place foraging theory (as minke whales repeatedly return to the surface to breathe), balancing the energetic costs of travel and foraging to maximise net energy gain (Bell, 1990). However, Florko *et al.* (2023) highlighted that the time spent on a prey patch and dive duration may be misleading, as longer durations can also reflect greater search effort in poorer foraging conditions, characterised by less-dense prey aggregations.

In addition, shorter dive durations were associated with smaller core foraging areas (KDE 50) and larger total foraging areas (KDE 95). Two potential explanations for this pattern exist. Firstly, short dive durations within small core foraging areas might be attributable to intense feeding on a dense prey aggregation, as shown in Figure 3.3. Active foraging is employed, aggregating prey through corralling, active pursuit and multi-directional surfacing at the air-water interface – the observed whales swimming in tight, spiralling, elliptical patterns before striking through the centre of the formed bait ball (Kuker *et al.,* 2005). This behaviour would result in spatially concentrated foraging behaviour and short dive durations. Conversely, this could also be alternatively attributable to low prey density, in which dives are terminated prematurely due to low prey encounters (Christiansen *et al.*, 2015). Herein, the larger total foraging areas observed reflect the more extensive spatial search required to locate the ephemeral patches of distributed prey.

Despite the lack of statistical significance found, the observations made in the present investigation do provide insight into the behavioural trade-offs between search behaviour and patch exploitation that minke whales make in response to prey density and availability. That said, the conflicting interpretations of this behaviour highlight conflicts in the present literature, and therefore, no concrete assumptions can be made about the correlation between dive duration and spatial utilisation without further research.

4.5. Management implications

This fine-scale spatial and behavioural analysis of minke whale habitat use has direct management implications, providing the empirical evidence required for the iterative conservation responses in adaptive management (Rossiter and Levine, 2014). The larger total foraging area (KDE 95) associated with inshore habitats, along with their exclusive use by juvenile whales, underscores the importance of these areas from a management perspective. The risk of entanglement in fishing gear is higher inshore; thus, juvenile whales are more susceptible to fatal entanglements due to their exclusive use of coastal habitats, with their small size further increasing their risk of in situ drowning (Rayner *et al.*, 2024).

Adults primarily foraged offshore with smaller core foraging areas (KDE 50), indicating the continued exploitation of localised prey patches, and consequently the potential greater exposure to whale-watching activities, due to the ease with which these vessels can operate. The chronic and cumulative effects of disturbance from whale watching are a concern for these whales (Lusseau and Bejder, 2007; New *et al.*, 2015), with vessel-based whale watching for minke whales occurring on both the east and west coasts of Scotland (Woods-Ballard *et al.*, 2003). Whale watching increases metabolic demands and energy expenditure, with individuals increasing the frequency of heading changes and sinuous turns to try to confuse the 'predator', thereby affecting their energy budgets and potentially resulting in an energy imbalance (Christiansen *et al.,* 2013; Senigaglia *et al.*, 2016).

Therefore, identifying ecologically important habitats and understanding how they are utilised provides a clear spatial basis for adaptive management. In particular, the results support the implementation of targeted no-approach zones for vessels around actively foraging whales, alongside the potential introduction of seasonal or spatial restrictions to fisheries in areas of importance. These measures would reduce entanglement risk to inshore juveniles and disturbance to offshore foraging minkes.

4.6. Limitations and future studies

The present study provides valuable, long-term insights into the fine-scale spatial ambit and behaviours of foraging minke whales. However, several limitations exist and should be considered when interpreting the findings. Firstly, by excluding any of the focal follows shorter than 20 minutes, the sample size available for subsequent analyses was substantially reduced. This minimum follow duration was established to ensure that all focal follows were of sufficient length to produce robust spatial utilisation estimates, as shorter follows would be less reliable for kernel density estimates. Field studies with minke whales are subject to inherent logistical challenges; thus, the selected threshold is consistent with those used in comparable research (Christiansen *et al*., 2015; Pirotta *et al*., 2016). However, applying this threshold significantly reduced the number of juvenile follows, thus limiting the statistical power and significance of the present results.

A further point for consideration is that the very presence and proximity of the research vessel may have resulted in behavioural changes in the whale, which may have consequently altered its spatial utilisation. Although efforts were taken to limit disturbance by maintaining vessel distances and operating the UAV at a minimum elevation of 30 metres, behavioural responses may still have occurred and could not be excluded. This study treated each focal follow as an independent observation and a different minke whale. However, due to the lack of systematic photo-identification within the data, and the inherent difficulties of identifying minke whales, it is possible that the same whale could have been followed twice during the 16-year sample period. Minke whales often lack long-term, stable, distinctive markings compared to other cetacean species, thus making identification challenging (Bertulli *et al.,* 2016; Bertulli *et al.,* 2013). Repeated sampling of the same individuals violates the assumption of independence and might subsequently result in bias.

Future research should focus on continued data collection to increase the sample size of viable focal follows (>20 minute duration) and improve the robustness of statistical analysis. In addition to this, the study would greatly benefit from the integration of prey identification data, and either direct or proxy measures of prey availability and key environmental variables, such as, water temperature, depth, and tidal state, for example, as applied in previous studies (e.g. MacDougall and Robinson, 2025; Lechwar *et al.*, 2023; Anderwald *et al.*, 2012; Smout and Lindstrøm, 2007). This would reduce the degree of inference needed in this research when interpreting the dynamics of foraging and spatial utilisation. Incorporating both environmental and prey-related covariates would allow for a more holistic understanding of the fine-scale spatial variability in minke whale foraging and its related drivers.

5. Conclusion

In conclusion, this study aimed to advance knowledge of minke whales by improving understanding of fine-scale foraging behaviour, spatial ambit, and factors influencing habitat use, to inform adaptive management in the Southern Trench MPA. The present study demonstrates that the fine-scale behaviour and spatial utilisation of minke whales within the Southern Trench MPA is heterogeneous and context-dependent, reinforcing the notion that uniform, static MPA design oversimplifies the biological complexity of habitats and overlooks ecological heterogeneity within protected areas (Benedetti-Cecchi *et al.*, 2003; Harborne, 2009; Robinson *et al.,* 2023). Currently, protective measures in the Southern Trench MPA are broad management objectives (MacDougall and Robinson, 2025); therefore, the results of this dissertation can provide an empirical basis for informing and facilitating the implementation of adaptive principles within the Southern Trench MPA, accounting for spatial, behavioural, and life-history factors.

Anthropogenic threats and disturbances vary across MPAs, with individual minke whales exhibiting a high propensity for context-specific responses (Lusseau and Bejder, 2007). Therefore, adaptive management, a flexible, iterative conservation approach informed by ongoing research, is essential for targeting spatially discrete areas of ecological importance (Rossiter and Levine, 2014; Rouphael Tony, 2020). Thus, understanding when and how minkes utilise habitats, and how these overlap with anthropogenic activities, is crucial for conservation (Davis *et al.*, 2020). These findings could inform dynamic, targeted seasonal protections for high-value habitat areas, such as restrictions on fishing gear or the establishment of vessel no-approach zones, while conceivably lessening restrictions in less ecologically important areas. Implementing adaptive management strategies at a micro-management level (site-specific) enables close monitoring to inform and assess the effectiveness of implemented measures, with the potential scaling of successful measures to meso- (national) or macro- (international) level policies (Higham *et al.,* 2008).

Ultimately, the application of fine-scale adaptive management in the Moray Firth could serve as a model for national and international minke whale conservation, underscoring the value of evidence-based management and the importance of continued research to support future conservation in dynamic, heterogeneous environments.

6. References

1. Anderwald, P. *et al.* (2012) 'Spatial scale and environmental determinants in minke whale habitat use and foraging', *Marine Ecology Progress Series*, 450, pp. 259–274. Available at: https://doi.org/10.3354/meps09573.

2. Bailey, H. and Thompson, P. (2010) 'Effect of oceanographic features on fine-scale foraging movements of bottlenose dolphins', *Marine Ecology Progress Series*, 418, pp. 223–233. Available at: https://doi.org/10.3354/meps08789.

3. Bell, W.J. (1990) 'Central place foraging', in W.J. Bell (ed.) *Searching Behaviour: The behavioural ecology of finding resources*. Dordrecht: Springer Netherlands, pp. 171–187. Available at: https://doi.org/10.1007/978-94-011-3098-1_12.

4. Benedetti-Cecchi, L. *et al.* (2003) 'Implications of spatial heterogeneity for management of marine protected areas (MPAs): examples from assemblages of rocky coasts in the northwest Mediterranean', *Marine Environmental Research*, 55(5), pp. 429–458. Available at: https://doi.org/10.1016/S0141-1136(02)00310-0.

5. Bertulli, C.G., Rasmussen, M.H. and Rosso, M. (2016) 'An assessment of the natural marking patterns used for photo-identification of common minke whales and white-beaked dolphins in Icelandic waters', *Journal of the Marine Biological Association of the United Kingdom*, 96(4), pp. 807–819. Available at: https://doi.org/10.1017/S0025315415000284.

6. Bertulli, C.G., Rasmussen, M.H. and Tetley, M.J. (2013) 'Photo-identification rate and wide-scale movement of common minke whales (Balaenoptera acutorostrata) in the coastal waters of Faxaflói and Skjálfandi Bays, Iceland', *J. Cetacean Res. Manage.*, 13(1), pp. 39–45. Available at: https://doi.org/10.47536/jcrm.v13i1.553.

7. Bird, C.N. *et al.* (2024) 'Growing into it: evidence of an ontogenetic shift in grey whale use of foraging tactics', *Animal Behaviour*, 214, pp. 121–135. Available at: https://doi.org/10.1016/j.anbehav.2024.06.004.

8. Bird, C.N. *et al.* (2025) 'Size and body condition drive the energetic cost of a baleen whale foraging in shallow habitat', *PeerJ*, 13, p. e20247. Available at: https://doi.org/10.7717/peerj.20247.

9. Blix, A.S. and Folkow, L.P. (1995) 'Daily energy expenditure in free living minke whales', *Acta Physiologica Scandinavica*, 153(1), pp. 61–66. Available at: https://doi.org/10.1111/j.1748-1716.1995.tb09834.x.

10. Boer, M.N. de (2010) 'Spring distribution and density of minke whale Balaenoptera acutorostrata along an offshore bank in the central North Sea', *Marine Ecology Progress Series*, 408, pp. 265–274. Available at: https://doi.org/10.3354/meps08598.

11. Boer, M.N. de *et al.* (2014) 'The Influence of Topographic and Dynamic Cyclic Variables on the Distribution of Small Cetaceans in a Shallow Coastal System', *PLOS ONE*, 9(1), p. e86331. Available at: https://doi.org/10.1371/journal.pone.0086331.

12. Christiansen, F., Rasmussen, M. and Lusseau, D. (2013) 'Whale watching disrupts feeding activities of minke whales on a feeding ground', *Marine Ecology Progress Series*, 478, pp. 239–251. Available at: https://doi.org/10.3354/meps10163.

13. Christiansen, F. *et al.* (2015) 'Structure and Dynamics of Minke Whale Surfacing Patterns in the Gulf of St. Lawrence, Canada', *PLOS ONE*, 10(5), p. e0126396. Available at: https://doi.org/10.1371/journal.pone.0126396.

14. Connell, S.D. and Gillanders, B.M. (eds) (2007) *Marine ecology*. South Melbourne, Vic: Oxford Univ. Press. Available at: https://www.researchgate.net/profile/R-Babcock/publication/284222610_Marine_protected_areas/links/57eaf01508aeafc4e88a5864/Marine-protected-areas.pdf?ref=sparrow [Accessed: 12 February 2026]

15. Cox, S.L. (2016) 'The role of physical oceanography on the distributions and foraging behaviours of marine mammals and seabirds in shelf-seas'. Plymouth University. Available at: https://doi.org/10.24382/3273.

16. Dall, S.R.X. *et al.* (2012) 'An evolutionary ecology of individual differences', *Ecology Letters*, 15(10), pp. 1189–1198. Available at: https://doi.org/10.1111/j.1461-0248.2012.01846.x.

17. Davis, G.E. *et al.* (2020) 'Exploring movement patterns and changing distributions of baleen whales in the western North Atlantic using a decade of passive acoustic data', *Global Change Biology*, 26(9), pp. 4812–4840. Available at: https://doi.org/10.1111/gcb.15191.

18. Doniol-Valcroze, T. *et al.* (2011) 'Optimal foraging theory predicts diving and feeding strategies of the largest marine predator', *Behavioral Ecology*, 22(4), pp. 880–888. Available at: https://doi.org/10.1093/beheco/arr038.

19. Eerkes-Medrano, D., Aldridge, D.C. and Blix, A.S. (2021) 'North Atlantic minke whale (Balaenoptera acutorostrata) feeding habits and migrations evaluated by stable isotope analysis of baleen', *Ecology and Evolution*, 11(22), pp. 16344–16353. Available at: https://doi.org/10.1002/ece3.8224.

20. Eide, S., Rikardsen, A. and Freitas, C. (2025) ‘Comparative diving patterns of two minke whales (Balaenoptera acutorostrata) and two fin whales (Balaenoptera physalus) in Northern Norway’, *Animal Biotelemetry*, 13(1), p. 40. Available at: https://doi.org/10.1186/s40317-025-00432-2.

21. Fauchald, P. and Tveraa, T. (2003) ‘Using First-Passage Time in the Analysis of Area-Restricted Search and Habitat Selection’, *Ecology*, 84(2), pp. 282–288. Available at: https://www.jstor.org/stable/3107884 (Accessed: 1 February 2026).

22. Fisheries, N. (2025) *Minke Whale | NOAA Fisheries*, *NOAA*. Available at: https://www.fisheries.noaa.gov/species/minke-whale (Accessed: 4 February 2026).

23. Folkow, L.P. *et al.* (2000) ‘Estimated food consumption of minke whales Balaenoptera acutorostrata in Northeast Atlantic waters in 1992-1995’, *NAMMCO Scientific Publications*, 2, pp. 65–80. Available at: https://doi.org/10.7557/3.2972.

24. Florko, K.R.N. *et al.* (2023) ‘Linking movement and dive data to prey distribution models: new insights in foraging behaviour and potential pitfalls of movement analyses’, *Movement Ecology*, 11(1), p. 17. Available at: https://doi.org/10.1186/s40462-023-00377-2.

25. Friedlaender, A.S. *et al.* (2015) ‘Feeding performance by sympatric blue and fin whales exploiting a common prey resource’, *Marine Mammal Science*, 31(1), pp. 345–354. Available at: https://doi.org/10.1111/mms.12134.

26. Goldbogen, J.A. *et al.* (2011) ‘Mechanics, hydrodynamics and energetics of blue whale lunge feeding: efficiency dependence on krill density’, *Journal of Experimental Biology*, 214(1), pp. 131–146. Available at: https://doi.org/10.1242/jeb.048157.

27. Halpern, B.S. and Warner, R.R. (2002) ‘Marine reserves have rapid and lasting effects’, *Ecology Letters*, 5(3), pp. 361–366. Available at: https://doi.org/10.1046/j.1461-0248.2002.00326.x.

28. Hammond, P. *et al.* (2017) ‘Estimates of cetacean abundance in European Atlantic waters in summer 2016 from the SCANS-III aerial and shipboard surveys’. Available at: http://hdl.handle.net/10261/327814

29. Harborne, A.R. (2009) ‘First among equals: why some habitats should be considered more important than others during marine reserve planning’, *Environmental Conservation*, 36(2), pp. 87–90. Available at: https://doi.org/10.1017/S0376892909005487.

30. Hazen, E.L., Friedlaender, A.S. and Goldbogen, J.A. (2015) ‘Blue whales (Balaenoptera musculus) optimize foraging efficiency by balancing oxygen use and

energy gain as a function of prey density', *Science Advances*, 1(9), p. e1500469. Available at: https://doi.org/10.1126/sciadv.1500469.

31. Heerah, K. *et al.* (2014) 'A New Method to Quantify within Dive Foraging Behaviour in Marine Predators', *PLoS ONE*, 9(6), p. e99329. Available at: https://doi.org/10.1371/journal.pone.0099329.

32. Higham, J.E.S., Bejder, L. and Lusseau, D. (2008) 'An integrated and adaptive management model to address the long-term sustainability of tourist interactions with cetaceans', *Environmental Conservation*, 35(4), pp. 294–302. Available at: https://doi.org/10.1017/S0376892908005249.

33. Hoelzel, A.R., Dorsey, E.M. and Stern, S.J. (1989) 'The foraging specializations of individual minke whales', *Animal Behaviour*, 38(5), pp. 786–794. Available at: https://doi.org/10.1016/S0003-3472(89)80111-3.

34. Hooker, S. *et al.* (2011) 'Making protected area networks effective for marine top predators', *Endangered Species Research*, 13(3), pp. 203–218. Available at: https://doi.org/10.3354/esr00322.

35. Kuhn, C. *et al.* (2020) 'Test of unmanned surface vehicles to conduct remote focal follow studies of a marine predator', *Marine Ecology Progress Series*, 635, pp. 1–7. Available at: https://doi.org/10.3354/meps13224.

36. Kuker, K.J., Thomson, J.A. and Tscherter, U. (2005) 'Novel Surface Feeding Tactics of Minke Whales, *Balaenoptera acutorostrata*, in the Saguenay-St. Lawrence National Marine Park', *The Canadian Field-Naturalist*, 119(2), pp. 214–218. Available at: https://doi.org/10.22621/cfn.v119i2.109.

37. Leaper, R. and Miller, C. (2011) 'Management of Antarctic baleen whales amid past exploitation, current threats and complex marine ecosystems', *Antarctic Science*, 23(6), pp. 503–529. Available at: https://doi.org/10.1017/S0954102011000708.

38. Lechwar, A. *et al.* (2023) 'Habitat preference of common minke whale (Balaenoptera acutorostrata) in Skjálfandi Bay, Iceland', *J. Cetacean Res. Manage.*, 24, pp. 29–46. Available at: https://doi.org/10.47536/jcrm.v24i1.388.

39. Lindstrøm and Haug (2001) 'Feeding strategy and prey selectivity in common minke whales (Balaenoptera acutorostrata) foraging in the southern Barents Sea during early summer', *Journal of Cetacean Rescue and Management*, 3(3). Available at: https://journal.iwc.int/index.php/jcrm/article/download/876/596.

40. Lusseau, D. and Bejder, L. (2007) 'The Long-term Consequences of Short-term Responses to Disturbance Experiences from Whale watching Impact Assessment',

International Journal of Comparative Psychology, 20(2). Available at: https://doi.org/10.46867/ijcp.2007.20.02.04

41. MacDougall, D.A.I. and Robinson, K.P. (2025) 'Following the Food: Dynamic, Seasonal Changes in the Fine-Scale Distribution of Foraging Minke Whales Within a Scottish Marine Protected Area (MPA)', *Oceans*, 6(1), p. 18. Available at: https://doi.org/10.3390/oceans6010018.

42. McLeod, E. *et al.* (2009) 'Designing marine protected area networks to address the impacts of climate change', *Frontiers in Ecology and the Environment*, 7(7), pp. 362–370. Available at: https://doi.org/10.1890/070211.

43. Macleod, K. *et al.* (2004) 'Seasonal distribution of minke whales Balaenoptera acutorostrata in relation to physiography and prey off the Isle of Mull, Scotland', *Marine Ecology Progress Series*, 277, pp. 263–274. Available at: https://www.jstor.org/stable/24867742 (Accessed: 27 January 2026).

44. Mead, J.V. (2004) 'Food Capture, Energy Costs of', pp. 705–717. Available at: https://doi.org/10.1016/B0-12-176480-X/00064-4.

45. Monteiro, S.S. *et al.* (2025) 'What's on the menu? Diet of common minke whales (*Balaenoptera acutorostrata*) stranded on the Atlantic Iberian coast', *Marine Environmental Research*, 205, p. 107024. Available at: https://doi.org/10.1016/j.marenvres.2025.107024.

46. NatureScot (2025) 'Conservation and Management Advice - Southern Trench'. Available at: https://www.nature.scot/sites/default/files/nature-conservation-mpa/10477/conservation-and-management-advice.pdf

47. Naud, M.J. *et al.* (2003) 'Influences of underwater bottom topography and geomorphology on minke whale (Balaenoptera acutorostrata) distribution in the Mingan Islands (Canada)', *Journal of the Marine Biological Association of the United Kingdom*, 83(4), pp. 889–896. Available at: https://doi.org/10.1017/S0025315403008002h.

48. New, L.F. *et al.* (2015) 'The modelling and assessment of whale-watching impacts', *Ocean & Coastal Management*, 115, pp. 10–16. Available at: https://doi.org/10.1016/j.ocecoaman.2015.04.006.

49. OSPAR (2026) *Marine Protected Areas*, *OSPAR Commission*. Available at: https://www.ospar.org/work-areas/bdc/marine-protected-areas (Accessed: 12 February 2026).

50. Patterson, E.M., Krzyszczyk, E. and Mann, J. (2016) 'Age-specific foraging performance and reproduction in tool-using wild bottlenose dolphins', *Behavioral Ecology*, 27(2), pp. 401–410. Available at: https://doi.org/10.1093/beheco/arv164.

51. Paxton, C. G.M., Scott-Hayward, L.A.S. and Rexstad, E. (2014) 'Statistical approaches to aid the identification of Marine Protected Areas for minke whale, Risso's dolphin, white-beaked dolphin and basking shark'.

52. Pirotta, V. *et al.* (2016) 'Migrating humpback whales show no detectable response to whale alarms off Sydney, Australia', *Endangered Species Research*, 29(3), pp. 201–209. Available at: https://doi.org/10.3354/esr00712.

53. Persson, L. *et al.* (1998) 'Ontogenetic Scaling of Foraging Rates and the Dynamics of a Size-Structured Consumer-Resource Model', *Theoretical Population Biology*, 54(3), pp. 270–293. Available at: https://doi.org/10.1006/tpbi.1998.1380.

54. Pyke, G.H., Pulliam, H.R. and Charnov, E.L. (1977) 'Optimal Foraging: A Selective Review of Theory and Tests', *The Quarterly Review of Biology*, 52(2), pp. 137–154. Available at: https://www.jstor.org/stable/2824020 (Accessed: 29 January 2026).

55. Rayner, J. *et al.* (2024) 'Minke whale entanglement in static fishing gear: identifying consistent areas of high risk in Western Scotland', *Journal of the Marine Biological Association of the United Kingdom*, 104, p. e15. Available at: https://doi.org/10.1017/S0025315423000930.

56. Risch, D. *et al.* (2019) 'Common and Antarctic Minke Whales: Conservation Status and Future Research Directions', *Frontiers in Marine Science*, 6. Available at: https://doi.org/10.3389/fmars.2019.00247.

57. Robinson, K.P. *et al.* (2023) 'Ecological habitat partitioning and feeding specialisations of coastal minke whales (Balaenoptera acutorostrata) using a recently designated MPA in northeast Scotland', *PLOS ONE*, 18(7), p. e0246617. Available at: https://doi.org/10.1371/journal.pone.0246617.

58. Robinson, K.P., Tetley, M.J. and Mitchelson-Jacob, E.G. (2009) 'The distribution and habitat preference of coastally occurring minke whales (Balaenoptera acutorostrata) in the outer southern Moray Firth, northeast Scotland', *Journal of Coastal Conservation*, 13(1), pp. 39–48. Available at: https://doi.org/10.1007/s11852-009-0050-2.

59. Robinson, K.P. and Tetley, M.J. (2007) 'Behavioural observations of foraging minke whales (*Balaenoptera acutorostrata*) in the outer Moray Firth, north-east Scotland', *Journal of the Marine Biological Association of the United Kingdom*, 87(1), pp. 85–86. Available at: https://doi.org/10.1017/S0025315407054161.

60. Rouphael Tony, A.B. (2020) ‘Adaptive management in context of MPAs: Challenges and opportunities for implementation’, *Journal for Nature Conservation*, 56, p. 125864. Available at: https://doi.org/10.1016/j.jnc.2020.125864.

61. Rossiter, J.S. and Levine, A. (2014) ‘What makes a “successful” marine protected area? The unique context of Hawaii′s fish replenishment areas’, *Marine Policy*, 44, pp. 196–203. Available at: https://doi.org/10.1016/j.marpol.2013.08.022.

62. Ryan, C., Leaper, R., Evans, P.G., Dyke, K., Robinson, K.P., Haskins, G.N., Calderan, S., van Geel, N., Harries, O., Froud, K. and Brownlow, A., 2016, June. Entanglement: an emerging threat to humpback whales in Scottish waters. In *Scientific Committee Meeting of the International Whaling Commission*(pp. 17-19).

63. Schreer, J.F. and Kovacs, K.M. (1997) ‘Allometry of diving capacity in air-breathing vertebrates’, *Canadian Journal of Zoology*, 75(3), pp. 339–358. Available at: https://doi.org/10.1139/z97-044.

64. Senigaglia, V. *et al.* (2016) ‘Meta-analyses of whale-watching impact studies: Comparisons of cetacean responses to disturbance’, *Marine Ecology Progress Series*, 542. Available at: https://doi.org/10.3354/meps11497.

65. Sivertsen, S.P. *et al.* (2006) ‘Prey partitioning between cod (Gadus morhua) and minke whale (Balaenoptera acutorostrata) in the Barents Sea’, *Marine Biology Research*, 2(2), pp. 89–99. Available at: https://doi.org/10.1080/17451000600670952.

66. Skaug, H.J. *et al.* (1997) ‘Do Minke Whales (*Balaenoptera acutorostrata*) Exhibit Particular Prey Preferences?’, *Journal of Northwest Atlantic Fishery Science*, 22, pp. 91–104. Available at: https://doi.org/10.2960/J.v22.a8.

67. Smout, S. and Lindstrøm, U. (2007) ‘Multispecies functional response of the minke whale Balaenoptera acutorostrata based on small-scale foraging studies’, *Marine Ecology Progress Series*, 341, pp. 277–291. Available at: https://doi.org/10.3354/meps341277.

68. Stevenson, H. (2019) ‘Wildlife (Marine Mammals) Regulations 2019’, *Marine Mammals*, (001). Available at: https://dolphinswims.com.au/wp-content/uploads/2025/09/Wildlife-Marine-Mammals-Regulations-2019.pdf [Accessed on: 03/12/25]

69. Teoh, Z.Y. *et al.* (2023) ‘Movement, ranging patterns and habitat use of Indo-Pacific humpback dolphins (Sousa chinensis) in the Langkawi Archipelago and adjacent Perlis-Kedah coastal waters, Malaysia’, *Aquatic Conservation: Marine and Freshwater Ecosystems*, 33(12), pp. 1552–1570. Available at: https://doi.org/10.1002/aqc.4002.

70. Thibault, R., Methion, S. and Díaz López, B. (2025) 'Fine-scale habitat selection of minke whales (Balaenoptera acutorostrata) in Northwest Iberian Peninsula waters', *Marine Biology*, 172(2), p. 27. Available at: https://doi.org/10.1007/s00227-024-04586-0.

71. Wilson, B., Thompson, P.M. and Hammond, P.S. (1997) 'Habitat Use by Bottlenose Dolphins: Seasonal Distribution and Stratified Movement Patterns in the Moray Firth, Scotland', *Journal of Applied Ecology*, 34(6), pp. 1365–1374. Available at: https://doi.org/10.2307/2405254.

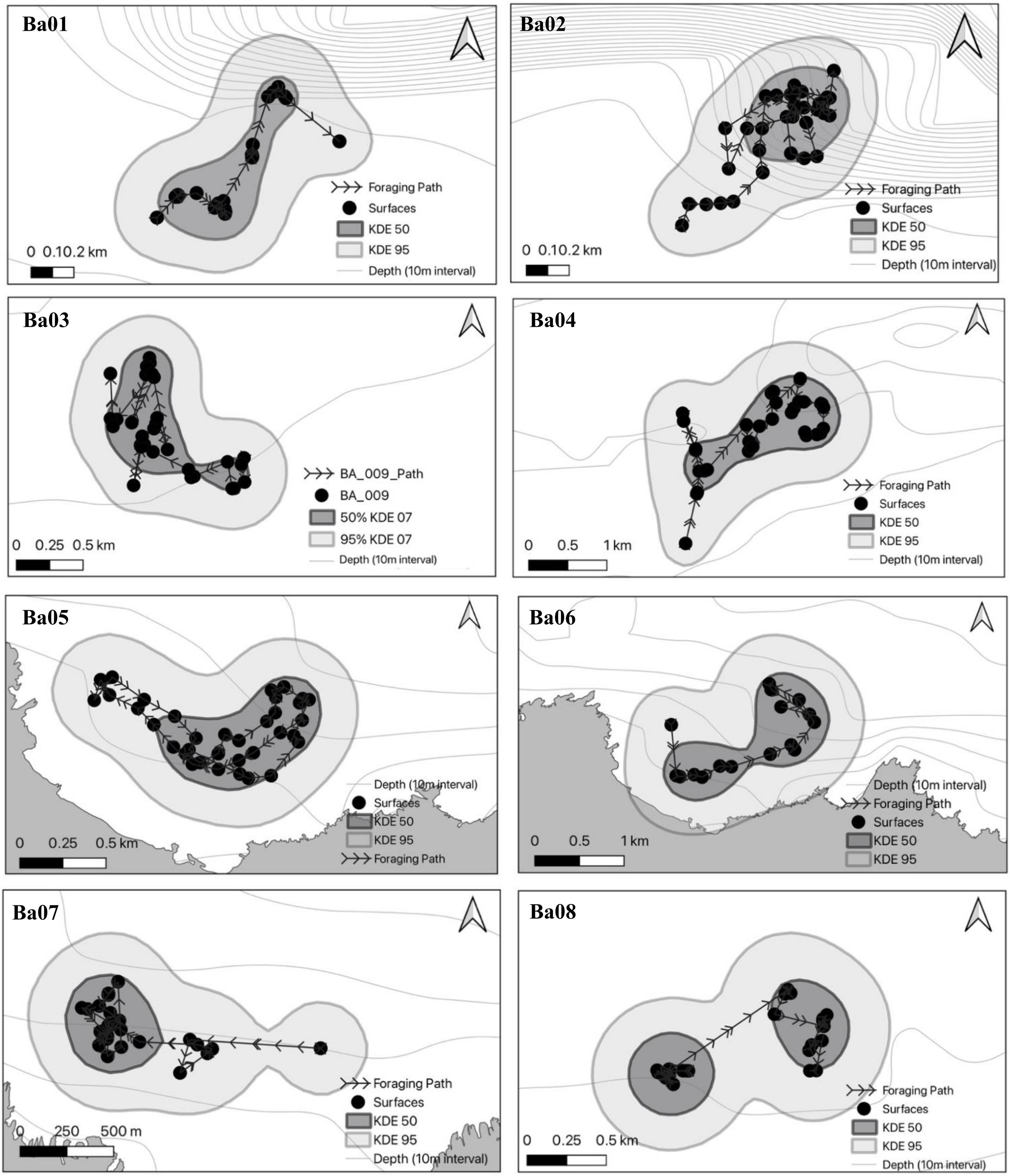
72. Woods-Ballard, A.J. *et al.* (2003) 'The Sustainability of Whale-watching in Scotland', *Journal of Sustainable Tourism*, 11(1), pp. 40–55. Available at: https://doi.org/10.1080/09669580308667192.

7. Appendix

Figure A1. The standardised data collection sheets for focal follows.

DATE [DD/MM/YY]			**TIME START / END [HH:MM 24 HRS]**				**SAMPLE #**	
BOAT			**AGE [JUVENILE OR ADULT]**				**WAYPOINTS**	
	TIME (MINS:SECS)	**SURFACE BEHAVIOUR** (**S**urface; **F**eeding **S**trike; **H**ead **S**lap; **D**epth **C**harge)	**DIRECTION OF TRAVEL**	**BIRD ASSOC (Y/N)**	**BEARING (DEGREES)**	**DISTANCE (M)**	**NOTES**	
e.g.	*1:55*	*FS R*	*NE*	Y	*270°*	*80 M*	*e.g. Unusual behaviour etc*	
1	0:00							
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								

Figure A2. The compiled GIS kernel density estimates for focal follows used in the spatial analysis.



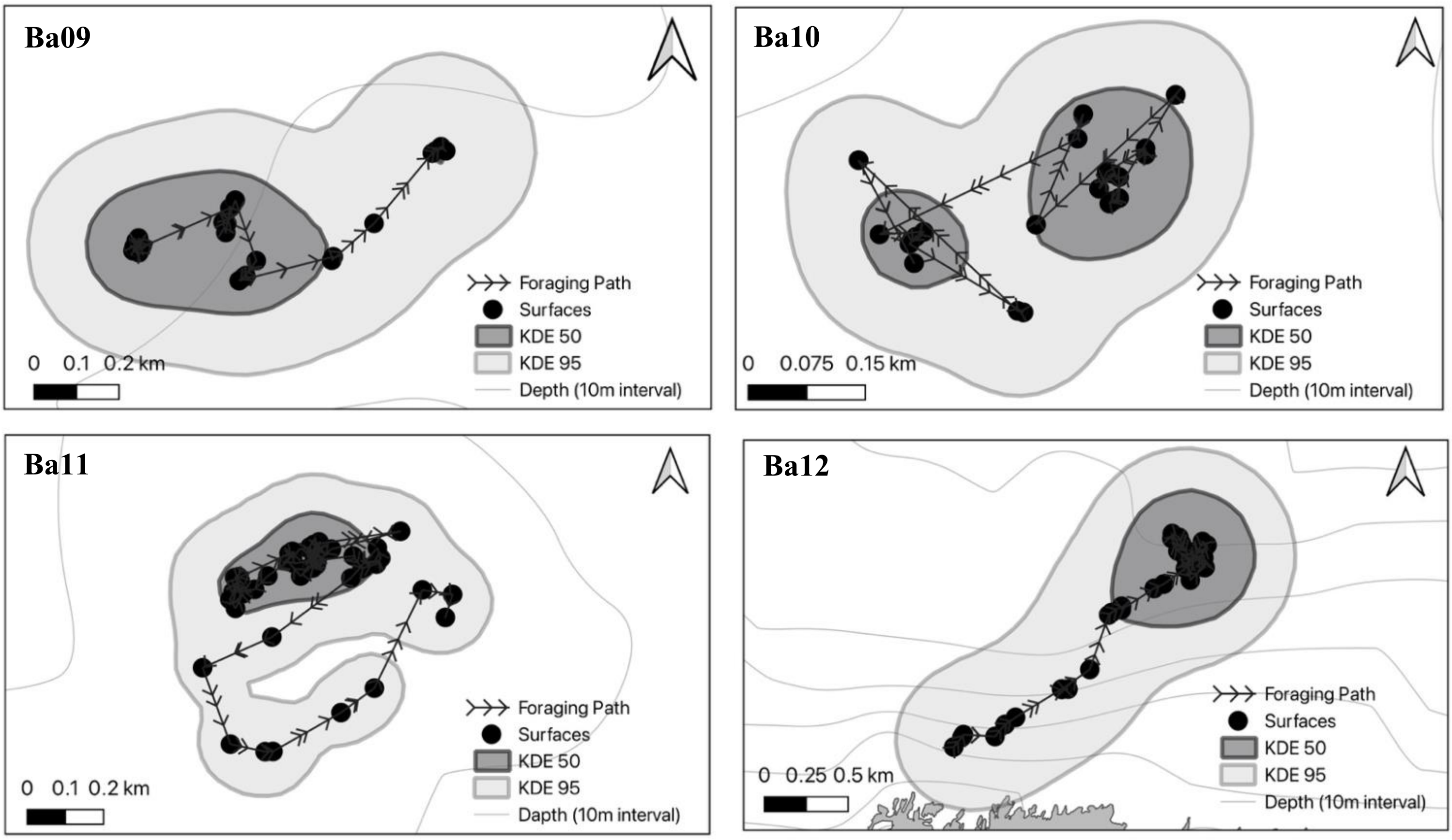

Ba09
Foraging Path
Surfaces
KDE 50
KDE 95
Depth (10m interval)
0 0.1 0.2 km
Ba10
Foraging Path
Surfaces
KDE 50
KDE 95
Depth (10m interval)
0 0.075 0.15 km
Ba11
Foraging Path
Surfaces
KDE 50
KDE 95
Dapth (10m interval)
0 0.1 0.2 km
Ba12
Foraging Path
Surfaces
KDE 50
KDE 95
Depth (10m interval)
0 0.25 0.5 km

Figure A3. The projects ERGO application, comprising the CRRU boat risk assessment and ethics (primary, secondary and animal).

Risk Assessment for operation of CRRU research boat

Date	15/06/2021
Boat name	Hermes
Assessor's name	Dr Kevin Robinson, Director, CRRU

Liability insurance cover provided by ANSVAR (Endsleigh Business Insurance Services); Policy Type: SMALL CHARITY CONNECT no. SCW2280924.

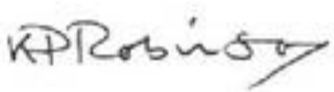
What are the hazards?	Likelihood of hazard occurring (1-5)	Who might be harmed and how?	What are the current control measures and are they sufficient?	What additional control measures are needed?
Slipping/falling on the boats	2	Crew members - twisted ankles or sprained wrists; bad fall could result in head injury.	Anti-slip flooring to prevent slips. Anti-slip protectors on the sides of the vessel for entry/exit of the vessel. Hand-rails on all and harnesses (all crew required to be seated during transit). Offshore (MCA-required) first aid kits onboard.	Full "Safety at Sea" training provided every 2 weeks for all crew. All CRRU staff first aid trained (Basic Offshore Safety Induction and Emergency Training mandatory) for minor treatment. Evacuation procedures for any serious injuries in place (see CRRU Emergency Response Plan – Location 2).

Electrical fire onboard	1	Crew members may suffer minor burns. Boat immobilised requiring evacuation procedures.	2 x fire extinguishers onboard and offshore first aid kit. Fuel cargo under the hull (no exposure fuel tanks).	All CRRU staff first aid trained (Basic Offshore Safety Induction and Emergency Training mandatory) for minor treatment and fully trained in evacuation procedures for any serious injuries (details also provided in the CRRU Emergency Response Plan – Location 2).
Man overboard (MOB)	1	Crew members – accidental fall into the water. Possible hypothermia or drowning.	ALL crew provided with a fully-protective/waterproof immersion/Drysuit, with an all-in-one woolly-bear underneath for warmth. ALL crew provided with a Crewsaver 190N offshore life-jacket, equipped with a hydrostatic self-activating inflation trigger, plus whistle, light and spray hood. Wet boots and wet gloves and protective helmets also provided. Each member of crew also has access to an emergency foil blanket.	Identification of weak or non-swimmers on the vessel. All CRRU staff first aid trained (Basic Offshore Safety Induction and Emergency Training mandatory) and trained in MOB protocols for such a situation.

			The vessel is further equipped with 2 x throw lines and 2 x life buoys with lights.	
Immobilisation of vessel, Vessel sinking or capsizing	1	Crew members required to abandon vessel may be in the water whilst awaiting rescue and may become hypothermic. Crew members may be physically injured during a capsize.	The vessel is a multichambered RHIB with a reinforced double-lined hull which is designed to minimise the possibility of sinking due to collisions at sea. The twin outboard engines also provide a back-up engine should one engine fail or if a propeller is fouled. In the case of any imminent life-threatening situation, it has a DSC VHF radio to call for help, plus an additional handheld radio, a 406MHz Emergency Position Radio Indicating Beacon (EPIRB) plus charging points to ensure mobile phones are fully charged. The EPIRB is fitted additional to MCA requirements, and can be activated manually, as required, or is automatically triggered if submerged in water (in the very unlikely case of a capsize).	At least 1 x licensed VHF radio radio operator must be onboard. VHF radios and EPIRB registered with OffCom. All crew members are trained to carry out MayDay calls, and know how to correctly give the vessels position in an emergency situation. All crew members must also be provided with the contact number for the Aberdeen coastguard. All crew members are trained how to tie knots and deploy drift anchors and weighted anchors as required. Full training is provided on deployment and operation of the 8-man life-raft.

			In addition, the vessel is equipped with 2 x orange hand flares, 2 x red hand flares and 2 x rocket flares (as per MCA 3 coding). In the case of evacuation, the vessel is equipped with an 8-man life-raft. ALL crew provided with a fully-protective/waterproof immersion/Drysuit, with an all-in-one woolly-bear underneath for warmth. ALL crew provided with a Crewsaver 190N offshore life-jacket, equipped with a hydrostatic self-activating inflation trigger, plus whistle, light and spray hood. Wet boots and wet gloves and protective helmets also provided.	
Flat battery, engine failure or propeller damage	2		The vessel is equipped with a dual battery system as per MCA 3 coding. All electrical equipment is operated by the starboard battery, such that if this battery power fails, the port	All crew members are trained to carry out PanPan or MayDay calls, and know how to correctly give the vessels position in an emergency situation. All crew members must also be provided with the

			battery can be used to start the starboard battery. In the case of an engine failure, the second engine is sufficient to get the vessel safely back to port. Should the vessel become immobilised, a drift anchor is available for deployment whilst awaiting assistance from the coastguard or other nearby vessels.	contact number for the Aberdeen coastguard. All crew members are trained how to tie knots and deploy drift anchors and weighted anchors as required. Full training is provided on deployment and operation of the 8-man life-raft.

Signed and dated:  15/06/2021

Assessor’s name and position: Dr Kevin P Robinson, Director, Cetacean Research & Rescue Unit (CRRU)

ERGO II Ethics application form – FELS

1. Applicant Details

1.1 Applicant name	Mia Wake
1.2 Supervisor	Dr Vicky Dominguez Almela
1.3 Other researchers / collaborators (if applicable): *Name, address, email*	Dr Kevin Robinson **Cetacean Research & Rescue Unit (CRRU)** 48 Seatown Gardenstown Banff AB45 3YQ Aberdeenshire kev.robinson@crru.org.uk

2. Study Details

2.1 Title of study	***Foraging behaviour of coastal minke whales (Balaenoptera acutorostrata) in a Marine Protected Area***
2.2 Type of project (e.g. undergraduate, Masters, Doctorate, staff)	**Undergraduate**

2.3 Briefly describe the rationale for carrying out this project and its specific aims and objectives.

Rationale

The highly productive waters of the Moray Firth in northeast Scotland attract above-average densities of minke whales *(Balaenoptera acutorostrata) relative to adjacent and wider Scottish waters, providing rich feeding grounds for the species during the summer and autumn months.*

Aims

1. To examine the swim paths of foraging minke whales, to better understand the behavioural mechanics and spatial ambit of the species in the Southern Trench Marine Protected Area (MPA) in the Moray Firth in northeast Scotland.
2. To inform the adaptive management practices within the newly designated MPA for the implementation of prohibitory exclusion distances for commercial tour boats operating in the region.

Objectives

1. To better understand the swim paths of foraging minke whales in the Moray Firth
2. To identify patterns/trends in the foraging behaviour of the species
3. To inform the adaptive management processes within the newly designated MPA. The implementation of prohibitory exclusion distances for commercial tour boats operating in the region may also be implemented based on findings.

2.4 Provide a brief outline of the basic study design. Outline what approach is being used and why.

This study will use a combination of archived data (2015 to 2024) and primary research (conducted in the summer of 2025 by the project student) consisting of non-invasive

observations during dedicated boat-based surveys. Focal follows will be used to track the whale's swim paths, and a drone will be used to capture surface behaviour and aid tracking of the subject species. Both primary and secondary data will be compiled. Basic stats will be run using R and spatial analysis of swim paths etc will be executed in QGIS. These combined approaches will facilitate a comprehensive understanding of the foraging behaviour of these coastal whales whilst avoiding any disturbance.

2.5 What are the key research question(s)? Specify hypotheses if applicable.
<u>Primary research question:</u> What parameters can be established to define and describe in the swim paths and beahviours of foraging minke whales, and how can these be used to inform effective management practices? <u>Sub questions:</u> How do the spatial and temporal patterns of foraging behaviour inform adaptive management practices in the Southern Trench MPA? Can prohibitory vessel exclusion distances be established for commercial tour boats to minimise/prevent disruption to foraging minke whales?

3. **Sample and setting**

3.1 Who are the proposed participants and where are they from (e.g. fellow students, club members)? List inclusion / exclusion criteria if applicable.
N/A

3.2. How will the participants be identified and approached? Provide an indication of your sample size. If participants are under the responsibility of others (e.g., parents/carers, teachers) state if you have permission or how you will obtain permission from the third party).
N/A

3.3 Describe the relationship between researcher and sample. Describe any relationship e.g., teacher, friend, boss, clinician, etc.
N/A

3.4 How will you obtain the consent of participants? (*please upload a copy of the consent form if obtaining written consent***) NB A separate consent form is not needed for online surveys where consent can be indicated by ticking/checking a consent box (normally at the end of the PIS). Other online study designs may still require a consent form or alternative procedure (for example, recorded verbal consent for online interviews).**
N/A

3.5 Is there any reason to believe participants may not be able to give full informed consent? If yes, what steps do you propose to take to safeguard their interests?
N/A

4. **Research procedures, interventions and measurements**

4.1 Give a brief account of the procedure as experienced by the participant. Make it clear who does what, how many times and in what order. Make clear the role of all assistants and collaborators. Make clear the total demands made on participants, including time and travel. *Upload copies of questionnaires and interview schedules to ERGO.*
N/A

4.2 Will the procedure involve deception of any sort? If yes, what is your justification?
N/A

4.3. Detail any possible (psychological or physical) discomfort, inconvenience, or distress that participants may experience, including after the study, and what precautions will be taken to minimise these risks to ensure the well-being, health, and safety of the participants. **Health & Safety policies and resources are available here: https://sotonac.sharepoint.com/teams/HealthSafetyRisk?e=1%3Af902a94a6c14407fbe44e40e5066cb91** **If the study involves lone working please state the risks and the procedures put in place to minimise these risks (please refer to the lone working policy). Please seek advice from your local Health and Safety contact if there are significant wellbeing or safety considerations.**
N/A

4.4 Detail any possible (psychological or physical) discomfort, inconvenience, or distress that YOU as a researcher may experience, including after the study, and what precautions will be taken to minimise these risks and ensure health and safety. **Health & Safety policies and resources are available here: https://sotonac.sharepoint.com/teams/HealthSafetyRisk?e=1%3Af902a94a6c14407fbe44e40e5066cb91** **If the study involves lone working please state the risks and the procedures put in place to minimise these risks (please refer to the lone working policy). Please seek advice from your local Health and Safety contact if there are significant wellbeing or safety considerations.**
Falling overboard. • Constant wear of a Crewsaver 190N offshore lifejacket equipped with a hydrostatic self-activating inflation trigger, plus whistle, light and spray hood and a fully protective /waterproof immersion/drysuit, with an all-in-one woolly-bear underneath for warmth, helmet and wet boots and gloves (ALL provided by the host organisation). • Vessel equipped with throw lines and life buoys with lights. • Highly experienced and qualified boat team.

Slipping/falling on the boat • Anti-slip flooring on boat • Anti-slip protectors on sides of the vessel for entry/exit • Offshore first aid kit onboard • Experienced first aiders onboard Sea sickness • Take sea sickness tablets if nausea starts during survey (also available in offshore first aid kit) Full CRRU operational risk assessment in place.

4.5 Explain how you will care for any participants in 'special groups' e.g., those in a dependent relationship, are vulnerable or are lacking mental capacity), if applicable:
N/A

4.6 Please give details of any payments or incentives being used to recruit participants, if applicable:
N/A

5. Access and storage of data

5.1 How will participant confidentiality be maintained? Confidentiality is defined as non-disclosure of research information except to another authorised person. Confidential information can be shared with those already party to it and may also be disclosed where the person providing the information provides explicit consent. Consider whether it is truly possible to maintain a participant's involvement in the study confidential, e.g. can people observe the participant taking part in the study? How will data be anonymised to ensure participants' confidentiality?
N/A

5.2 How will personal data and study results be stored securely during and after the study. Who will have access to these data?
N/A

5.3 How will it be made clear to participants that they may withdraw consent to participate? Please note that anonymous data (e.g. anonymous questionnaires) cannot be withdrawn after they have been submitted. If there is a point up to which data can be withdrawn/destroyed e.g., up to interview data being transcribed please state this here.
N/A

6. Additional Ethical considerations

6.1 Are there any additional ethical considerations or other information you feel may be relevant to this study?
Potential disturbance to whales will be minimised by: • Ensuring boat-based focal follows maintain appropriate speed and distance from the animal (established protocols already in place with host organisation) • Monitor whale behaviour for signs of avoidance/stress. Activity will be ceased if these are observed.

Use of the drone:

- Any drone use will be fully supervised with all training provided by the host organisation.
- Drones will be operated at a minimum (established) altitude of 30 metres, to avoid any disturbance of the study animals.
- The drone is licenced and registered with the UK Civil Aviation Authority – ALL guidelines will be adhered to – and the project student is also possesses a registered drone user licence (attached).

Use of data archives

- Full permission from the original data collector to use the secondary data. The project student will follow all data sharing agreements.

ERGO II Ethics application form for secondary data analysis

Please consult the 'Guidance on the use of secondary data for research purposes' (downloadable via ERGO II) before completing and submitting your application.

ERGO Number: **103934**

1. **Name(s):** Mia Wake
2. **Current Position:** Undergraduate BSc Environmental Science Student
3. **Contact Details:** mw2n23@soton.ac.uk
   Division: Environmental Science
   Email: mw2n23@soton.ac.uk
   Phone: 07769206035
4. **Is your research being conducted as part of an education qualification?**
   Yes ☒ **No** ☐
5. **If Yes, please give the name of your supervisor:**
   Dr Vicky Dominguez Almela
6. **Title of your research project/study:**

Understanding the foraging behaviour of coastal minke whales in a Marine Protected Area

7. **Briefly describe the rationale, aims, design and research questions of your research**

Rationale

The highly productive waters of the Moray Firth in northeast Scotland attract above-average densities of minke whales *(Balaenoptera acutorostrata)* relative to the adjacent and wider Scottish waters, providing rich feeding grounds for the species during the summer and autumnal months. This study aims to better understand and describe the foraging behaviours of minke whales in a recently established Marine Protected Area (MPA) for the species, the outcomes of which will be used to provide the evidence-base to inform and advance adaptive management strategies.

Aims

3. To examine the swim paths of foraging minke whales to better understand the behavioural mechanics and spatial ambit of the species in the Moray Firth MPA.
4. To inform adaptive management practices within the newly established MPA, for the implementation of prohibitory exclusion distances for commercial tour boats operating in the region.

Study design
This study will use a combination of archived data (2015 to 2024) and primary research (conducted in the summer of 2025 by the project student) consisting of non-invasive observations during dedicated boat-based surveys. Focal follows will be used to track the whale's swim paths, and a drone will be used to capture surface behaviour and aid tracking of the subject species. Both primary and secondary data will be compiled. Basic stats will be run using R and spatial analysis of swim paths etc will be executed in QGIS. These combined approaches will facilitate a comprehensive understanding of the foraging behaviour of these coastal whales whilst avoiding any disturbance.

Research question
What parameters can be established to define and describe the swim paths and behaviours of foraging minke whales, and how can these be used to inform effective management practices?

8. Describe the data you wish to analyse and how this will be completed

The secondary, quantitative data will be obtained from the Cetacean Research & Rescue Unit (CRRU) from their long-term, dedicated studies. This data has been collected during boat-based work under licence from NatureScot and applying the best ethical guidelines and practices. Data analysis will involve spatial analysis, using GIS, to map the movements and swim paths of the foraging minkes and the use of R to conduct basic statistics. Handling will ensure that sensitive spatial information will not be publicly available to protect the species accordingly.

I also wish to analyse data from NOAA that will inform on variables such as sea surface temperature, bathymetry, water depth, etc (open access). This will be used in R to understand correlations between environmental variables, and how the whales may be impacted by changing temperatures.

9. What are the terms and conditions around the use of the data? Did data subjects give consent for their data to be re-used? If not, on what basis is re-use of the data justified?

A confidentiality agreement will be provided by the host organisation and all data will be made available for the student project and for potential publication thereafter. All archived data has been collected under licence from NatureScot. The re-use of this data is justified because it hasn't been analysed in this way before; therefore, it will enable a greater understanding of the minke whale foraging paths and, thus, potential exclusion zones.

The NOAA data is open-access data. The data can be freely accessed, used and redistributed without restriction if they are not misrepresented. The NOAA data-sharing policy ensures that datasets are made openly accessible for scientific, educational and policy-related purposes. The re-use of this data is justified because of its designation as a public domain service, aligning with its mission to support scientific research. The data is provided with no legal or ethical restrictions on their use, provided they are properly attributed and not used in a misleading way.

10. Do you intend to use personal data (https://ico.org.uk/for-organisations/uk-gdpr-guidance-and-resources/personal-information-what-is-it/what-is-personal-data/what-is-personal-data/) or sensitive personal data (https://ico.org.uk/for-organisations/uk-gdpr-guidance-and-resources/lawful-basis/a-guide-to-lawful-basis/special-category-data/) as defined by the Data Protection Act (even if the data are publicly available)? or data relating to a person's criminal convictions, even if such data are publicly available and/or have been pseudonymised? (https://ico.org.uk/for-organisations/uk-gdpr-guidance-and-resources/lawful-basis/criminal-offence-data/what-are-the-rules-on-criminal-offence-data/)

Yes ☐ **No** ☒

If YES, please specify what personal data will be included and why.

11. Do you intend to link two or more datasets?

Data linkage refers to merging of information from two or more sources of data to consolidate facts concerning an individual or an event that are not available in any separate record. Please note that for the purposes of research ethics we are not interested in the merging of different waves of a particular survey, or the merging of data from different countries for the same survey.

Yes ☐ **No** ☒

If YES, please give details of which datasets will be linked and for what purposes.

12. How will you store and manage the data before and during the analysis? What will happen with the data at the end of the project?

Access to the data will be restricted to the research team and my supervisor, adhering to permissions from CRRU, the owner of the data. During the analysis, the data will be stored on a password-protected computer. Data will be organised thoroughly in files and structured accordingly.

13. How will you minimise the risk/ maintain participant anonymity and/or confidentiality that data subjects (individuals or organisations) could be identified in your presentation of results?

N/A

14. What other ethical risks are raised by your research, and how do you intend to manage these?

The greatest ethical risk in using this secondary dataset is the publication of raw data containing precise locations of whale sightings. This could potentially increase vessel disturbance by potentially attracting tourist/leisure boats. This will be managed by not publishing any raw data. Data will be published in more generalised formats. This will ensure that the use of the data will only aid conservation and not contribute in any negative way to the study species in focus.

15. Please outline any other information that you feel may be relevant to this submission.

None

Guidance on applying for ethics approval for secondary data analysis

Service Evaluations and Audits within the NHS which involve the review of clinical data do not fall within the scope of this guidance and should be submitted using the appropriate ethics application form on ERGO II.

Researchers who are unsure whether their study uses secondary data should contact their FREC or the REGO office (rgoinfo@soton.ac.uk) for advice.

If your research PURELY involves the following, it may not require ethics review- however still requires submission to ERGO II:

- literature reviews or reviews/analyses of reports, policies, documents, meeting minutes, newspaper articles, films.
- Systematic reviews
- meta-analyses (i.e. the analysis of studies);
- analysis of <u>aggregated</u> data on individuals or organisations (e.g. GDP, labour force participation rates, fertility rates) where data cannot be linked to an individual or their geographical location
-

<u>Filling in the SDA online submission form on ERGO II:</u>

- Please give your application a title that includes ‘SDA’ (Secondary Data Analysis).

<u>Additional Forms:</u>
If your study PURELY involves secondary analysis of data, you only need to fill in the ‘Ethics Application Form for Secondary Data Analysis.’
If your study is a mixed-method study involving secondary data analysis AND some component of data collection (e.g. interviews, online survey), then you also need to include (if applicable):

a. Ethics Application Form for Research Involving Human Participants
b. The questionnaire or details on your research questions*
c. Any communication that you will be using to recruit participants, including emails, posters, flyers, tweets, etc. d. Letters/ emails of permission from any relevant third parties and any text that you will ask them to send to participants on your behalf.
e. A participant information sheet**
f. Consent form**
g. Risk assessment

*If you are issuing a questionnaire, you must include in your submission the specific questions you will be asking participants. If you are conducting more informal interviews, you must provide information concerning your research questions and methods.

**For internet questionnaires or surveys, you should choose the ‘combined internet participant sheet and consent form’ instead of using two separate documents.

<u>If applicable:</u> If your study requires **full** Cultural Heritage ethics review, you will need to submit the following documents (note: applications that **do not contain** all the documents will be sent back for revision):

a. Ethics Application Form for Research Involving Cultural Heritage
b. Any other documentation that is needed to assess the ethics of your project

However, most applications involving Cultural Heritage will not require full ethics review. See the section on Cultural Heritage in the FAH Ethics Approval Process Guidance Documents for details.

If your research involves both Cultural Heritage and Human Participants, you will have to fill in the Human Participant form too).

<u>Please note:</u>

- <u>You must not begin data analysis until ethical approval has been obtained</u>.
- It is your responsibility to follow the University of Southampton's Ethics Policy and any relevant academic or professional guidelines in the conduct of your research. This includes ensuring confidentiality in the storage and use of data.
- It is your responsibility to provide <u>full and accurate information</u> in completing this form.

<u>ERGO II Animal ethics application form</u>

All mandatory fields are marked (M*). Applications without mandatory fields completed are likely to be rejected by reviewers. Other fields are marked "if applicable". Help text is provided, where appropriate, in italics after each question.

1. APPLICANT DETAILS

1.1 (M*) Applicant name and email:	**Mia Wake <u>mw2n23@soton.ac.uk</u>**
1.2 (M*) Supervisor name and email:	**Vicky Dominguez Almela <u>v.dominguez-almela@soton.ac.uk</u>**
1.3 Other researchers/collaborators and external personnel involved in study (if applicable): ***Name, address, email, telephone***	**Dr Kevin Robinson** Cetacean Research & Rescue Unit (CRRU) **48 Seatown** **Gardenstown** **Banff AB45 3YQ** **Aberdeenshire** **<u>kev.robinson@crru.org.uk</u>** **07875 105506**

2. STUDY DETAILS

2.1 (M*) Title of study:	BSc Environmental Science
2.2 (M*) Type of study (*e.g. Undergraduate, Doctorate, Masters, Staff*):	Undergraduate

2.3 i) (M*) Proposed start date (allow at least 1 month):	June 2025
2.3 ii) (M*) Proposed end date:	March 2026

2.4 (M*) What are the aims of this study?
To examine the swim paths of foraging minke whales to better understand the behavioural mechanics and spatial ambit of the species in the Moray Firth and advance management.

2.5 (M*) What are the objectives of this study?
1. Understand the swim paths of foraging minke whales in the Moray Firth 2. Identify patterns/trends in foraging behaviour both spatially and temporally 3. Use results to inform adaptive management processes within the newly designated Southern Trench Marine Protected Area. The implementation of prohibitory exclusion distances for commercial tour boats operating in the region may also be implemented based on findings.

2.6 (M*) Background to study (*a detailed and thorough rationale for conducting the study, listing all relevant publications*):
The highly productive waters of the Moray Firth in northeast Scotland attract above-average densities of minke whales relative to adjacent and wider Scottish waters (Paxton *et al.* 2014), affording rich feeding grounds for these mammals during the summer and autumn months (Robinson & Tetley 2007, Robinson *et al.* 2009). Observed feeding strategies in this location may be "passive" (bird-associated) or "active", such that individuals employ a wide range of predatory behaviours and show inter- and intra-seasonal plasticity in their diet (e.g. Robinson & Tetley 2007, Kuker *et al.* 2005, Robinson *et al.* 2024). This study aims to examine the swim paths of foraging minke whales in the Moray Firth to better understand the behavioural mechanics and spatial ambit of the species. Results aim to inform adaptive management practices within the newly designated Southern Trench Marine Protected Area (MPA) for the implementation of prohibitory exclusion distances for commercial tour boats operating in the region.

2.7 (M*) Has this work been done before? If so, what are you adding to previously published work?
No, this work hasn't been conducted before, and we expect to be able to publish the results in a peer-reviewed journal.

2.8 (M*) What are the benefits of this study?
To provide recommendations for adaptive management strategies within the MPA and inform on prohibitory exclusion distances for commercial tour boats to minimise disturbance to the whale.

2.9 (M*) Study design and detailed protocol (*Give a clear detailed protocol*) *Outline what approach is being used, why certain methods have been chosen and include statistical design.*
This study will use a combination of archived data (2015 to 2024) and primary research (conducted in the summer of 2025) consisting of non-invasive observations during dedicated boat-based surveys. Focal follows will be used to track the whale's swim paths, and a drone will be used to capture surface behaviour and aid tracking of the subject species. Both primary and secondary data will be compiled. Basic stats will be run using R and spatial analysis of swim paths etc will be executed in QGIS. These combined approaches will facilitate a comprehensive understanding of the foraging behaviour of these coastal whales whilst avoiding any disturbance.

3. SAMPLE AND SETTING

3.1 (M*) State numbers (or predicted numbers) to be used for study:
Up to 20 focal follows

3.2 (M*) What species is the proposed sample and where is it located (e.g private land, university land, overseas, specific location)?
Minke whale (*Balaenoptera acutorostrata*). Moray Firth, northeast Scotland (57º 41′ N, 2º 40′ W)

3.3 (M*) Are endangered or protected species involved (intentionally or possibly inadvertently)
Common minke whales are difficult to assess globally due their diffuse distribution. However, they are designated as Least Concern under the IUCN Red List for threatened species, due primarily to the fact that they were less depleted by commercial whaling than other baleen whale species.

3.4 (M*) If so has relevant permission and licence been obtained?
All field work by CRRU is carried out under licence from NatureScot.

3.4 (M*) Please list and upload licences required and name of person holding it.
NatureScot animal licence number 211865, Dr Kevin Robinson, Cetacean Research & Rescue Unit (CRRU)

3.5 (M*) Which laws apply?
The Conservation (Natural Habitats, &c.) Regulations 1994 (as amended): Regulation 44 (2) (a)

3.6 (M*) What is the relationship between researchers and external funding organisation if any?
None

4. RESEARCH PROCEDURES, INTERVENTIONS AND MEASUREMENTS

4.1 (M*) Give a brief account of the procedure as experienced by the participant *(Make clear who does what, how many times and in what order. Make clear the role of all assistants and collaborators.*
Working within an experienced team, during dedicated boat surveys, once whales have been spotted and deemed to be “approachable”, feeding/foraging individuals, the boat handler will very sensitively position the boat within 50 or so metres of the whale(s) so that the behaviour of the animal(s) can be observed and recorded. For each surface, the geographical position and orientation/direction of travel will be recorded by the project student along with the surfacing/diving durations. In ideal conditions, a drone will also be launched to better track the whale and record its swim path and behaviour. A team of up to 8 trained spotters with assist the project student in tracking the whale through its surfacing movements, covering 360 degrees around the vessel to ensure no surfaces are missed. This will all be carried-out alongside additional data collection (photo-identification etc) by the remaining boat team.

5. ANIMAL WELFARE

5.1 (M*) Will the animal be exposed to psychological or physical discomfort and/or distress?
No

5.2 (M*) Explain how you intend to alleviate any psychological or physical discomfort and/or distress that may arise? (if applicable)
Monitoring animal behaviour. If the animal shows obvious signs of adaptive behaviour/stress/avoidance, any activity will be ceased. Ensuring boat based focal follows maintain appropriate distance/speed from the animal (as well practised by highly experienced CRRU team)

5.3 Explain how you will care for any living organisms in the study (if applicable)?
N/A

5.4 What is the fate of the organisms at the end of the study?
N/A

5.5 Have you undertaken any animal handling training (if applicable)?
N/A

5.6 (M*) How will data from this study be used? *Researchers should be aware of, and compliant with, the Data Protection policy of the University. You must be able to demonstrate this in respect of handling, storage and retention of data.*
Data will be used to map the foraging paths of minke whales using QGIS to understand spatial and temporal minke whale foraging patterns. Subsequent analysis will be performed in R to conduct basic stats. Archived data will be used with permission from the original owner, with data sharing agreements closely adhered to.