Analysis of The Crown Estate aerial survey data for marine mammals for the FTOWDG

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Introduction

The Crown Estate (TCE) commissioned a series of aerial surveys of offshore wind farm sites during 2009-2010 around the UK. The Scottish Territorial Waters and Round 3 sites within the Firths of Forth and Tay were surveyed during summer 2009 and winter 2009-2010. The surveys employed standard visual aerial survey methods to record seabirds and marine mammals with a view to these data contributing to the baseline information required to inform the Environmental Impact Assessments for each of the lease areas.

The purpose of this document is to report on analyses carried out on the marine mammal data collected on these surveys. Legislation requires developers to assess the local density and abundance of marine mammals within development sites – these data were suitable for doing this for three species (harbour porpoise, white-beaked dolphin and 'all seals').

Methods and Results

Data files were first validated to eliminate issues such as the use of multiple codes for the same species. Any further queries we had about the data, including potentially erroneous values, were confirmed as being correct, or corrected, through dialogue with WWT Consulting who carried out the surveys.

Survey effort

Surveys were carried out on 24 days between the 28th of May 2009 and the 20th of March 2010 inclusive. Effort was recorded separately by the two observers. Because the total length of transect observed by each observer was similar (Table 1), the length of each on effort transect was calculated for the port observer (P) and used when analyzing data collected by each observer.

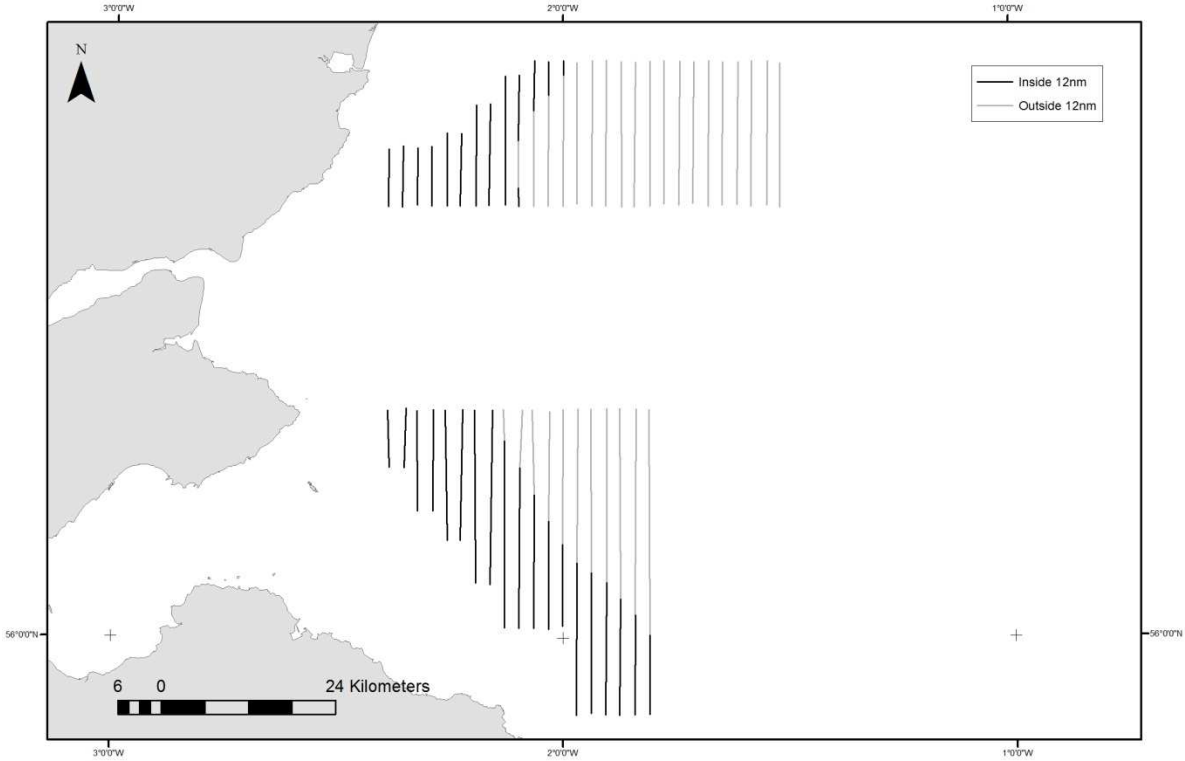
Between 5 and 48 sections of transects were flown in any one survey day; observed track length per day varied from 341.89 to 1116.21km. The whole survey area (all 45 transects, numbered from 13 to 57) was never covered in a single day. Figure 1 shows the observed track length (by the P observer) for one day in May 2009 as an example.

Categories which had been pre-defined for analysis were summer and winter, and inside and outside 12nm. Summer was classed as surveys carried out between 28/05/09 and 6/8/09 (2 survey days in May, 3 in June, 3 in July and 1 in August = 9 survey days). Winter was classed as surveys carried out between 4/11/09 and 20/3/10 (4 survey days in November, 4 in December, 2 in January, 4 in February and 1 in March = 15 survey days). Transects 13-26 were completely inside the 12nm zone. Transects 27-41 crossed the 12nm line. Transects 42-57 were completely outside the 12nm zone.

Table 1. Comparison of total on effort transect length for the two observers.

Observer	Total length of track observed (km)
Port (P)	17864.56
Starboard (S)	18318.46
Difference in total track length observed by P and S	453.9 (equivalent to approx. 2.5%)

Figure 1. Example of the observed transects (by the port observer) flown on a single day (the 28th of May 2009).



Marine mammal sightings

In inshore waters (inside 12nm), seven species of marine mammal were positively identified (bottlenose dolphin, common dolphin, grey seal, harbour porpoise, killer whale, minke whale and white-beaked dolphin; see Table 2 and Table 3). Of these, the harbour porpoise was most common, especially during the summer months. Other marine mammals were identified as far as possible (i.e. to genus, family or order level). 'All seals' were grouped together *post hoc* due to the small number of positive identifications of each species and the large number of seal sp. sightings. The fact that no distinction has been made between the two different species of seal may be a problem when assessing impacts, particularly given the very different status of the local populations of the two species. 'All seals' were also commonly recorded.

In offshore waters (outside 12nm), seven species were also positively identified (bottlenose dolphin, grey seal, harbour porpoise, harbour seal, long-finned pilot whale, minke whale and white-beaked dolphin). Again, harbour porpoise and 'all seals' (especially during the summer months) were most common (and white-beaked dolphin in the summer; see Table 2 and Table 3).

Table 2. Summer.

Species	Number of sightings		Number of individuals		Mean group size (range)	
	Inside 12nm	Outside 12nm	Inside 12nm	Outside 12nm	Inside 12nm	Outside 12nm
Bottle-nosed Dolphin		1		1		1 (1-1)
cetacean sp.	3	15	7	24	2 (1-4)	2 (1-5)
dolphin sp.	2	13	6	24	3 (1-5)	2 (1-6)
Grey Seal		5		5		1 (1-1)
Harbour Porpoise	31	130	36	161	1 (1-3)	1 (1-3)
Killer Whale	1		1		1 (1-1)	
large cetacean sp.	3	4	3	4	1 (1-1)	1 (1-1)
Minke Whale	1	6	1	7	1 (1-1)	1 (1-2)
seal sp.	29	194	60	204	2 (1-30)	1 (1-5)
small cetacean sp.	18	53	22	68	1 (1-3)	1 (1-4)
White-beaked Dolphin	8	41	20	94	3 (1-5)	2 (1-5)
Total	**96**	**462**	**156**	**592**		
All seals	29	199	60	209	2 (1-30)	1 (1-5)

Table 3. Winter.

Species	Number of sightings		Number of individuals		Mean group size (range)	
	Inside 12nm	Outside 12nm	Inside 12nm	Outside 12nm	Inside 12nm	Outside 12nm
Bottle-nosed Dolphin	2		3		2 (1-2)	
cetacean sp.		3		3		1 (1-1)
Common Dolphin	1		1		1 (1-1)	
dolphin sp.	1	5	1	25	1 (1-1)	5 (1-15)
Grey Seal	3	6	3	6	1 (1-1)	1 (1-1)
Harbour Porpoise	19	50	25	72	1 (1-4)	1 (1-6)
Harbour Seal		4		4		1 (1-1)
large cetacean sp.	1	1	1	1	1 (1-1)	1 (1-1)
Long-finned Pilot Whale		2		8		4 (4-4)
Minke Whale		1		1		1 (1-1)
seal sp.	39	68	39	68	1 (1-1)	1 (1-1)
small cetacean sp.	4	17	6	24	2 (1-2)	1 (1-3)
White-beaked Dolphin		15		35		2 (1-6)
Total	**70**	**172**	**79**	**247**		
All seals	42	78	42	78	1 (1-1)	1 (1-1)

Distribution

Distribution maps for each species (harbour porpoise, white-beaked dolphin), family (dolphin species) and order (cetaceans – large and small, seals) positively identified are presented. In addition, separate maps showing sightings made during summer and winter are also presented. Sightings of similar but uncommon species (bottlenose dolphin and common dolphin; killer whale, long-finned pilot whale and minke whale) have been displayed on the same maps.

Whilst distribution maps are useful for showing which species were recorded where at the time of each survey, they should be interpreted with care as the amount of survey effort is an important factor in determining the distribution of sightings and can greatly influence 'apparent density'. However, the following generalisations can be made.

Harbour porpoises were distributed across the survey area, but there were a greater number of sightings offshore (Figure 2). Sightings were more common in summer (Figure 3) than in winter (Figure 4). Porpoises were most often seen singly although group size ranged from one to six individuals (Figure 2; Table 2; Table 3).

White-beaked dolphins were almost always sighted offshore (Figure 5). Sightings were more common in summer (Figure 6) than in winter (Figure 7). White-beaked dolphins were most often seen in groups of two or three although group size ranged from one to six individuals (Figure 5; Table 2; Table 3).

'Seals' were distributed across the survey area (Figure 8) although they appeared to be more common offshore in summer (Figure 9). Sightings were more common in summer than in winter (Figure 10) in general. Seals were most often sighted singly although a group of 30 individuals was sighted on Transect 20 near the Bell Rock, an area where seals are known to 'congregate' (Table 2; Table 3).

'Dolphins' were distributed across the survey area (Figure 11). Sightings were more common in summer than in winter, and more common offshore than inshore in summer (Figure 12; Figure 13). Dolphins were most often seen in small groups although group size ranged from one to 15 individuals (Table 2; Table 3).

'Large cetaceans' were generally sighted offshore (Figure 14). There were fewer sightings in winter (Figure 16) than summer (Figure 15). Large cetaceans were most often seen singly although two groups of four long-finned pilot whales were seen at the same time (in different distance bands) by the starboard observer on one of the November surveys (Table 2; Table 3).

Figure 2. Harbour porpoise – group size – all seasons

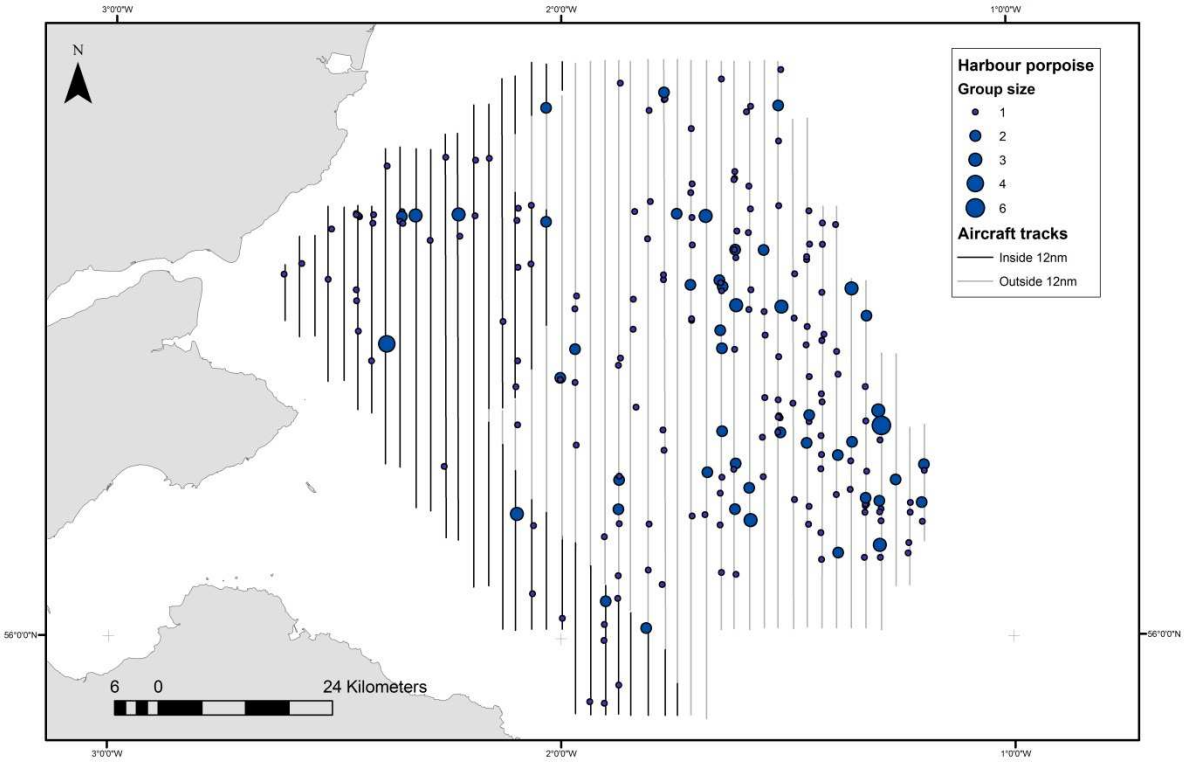


Figure 3. Harbour porpoise – summer

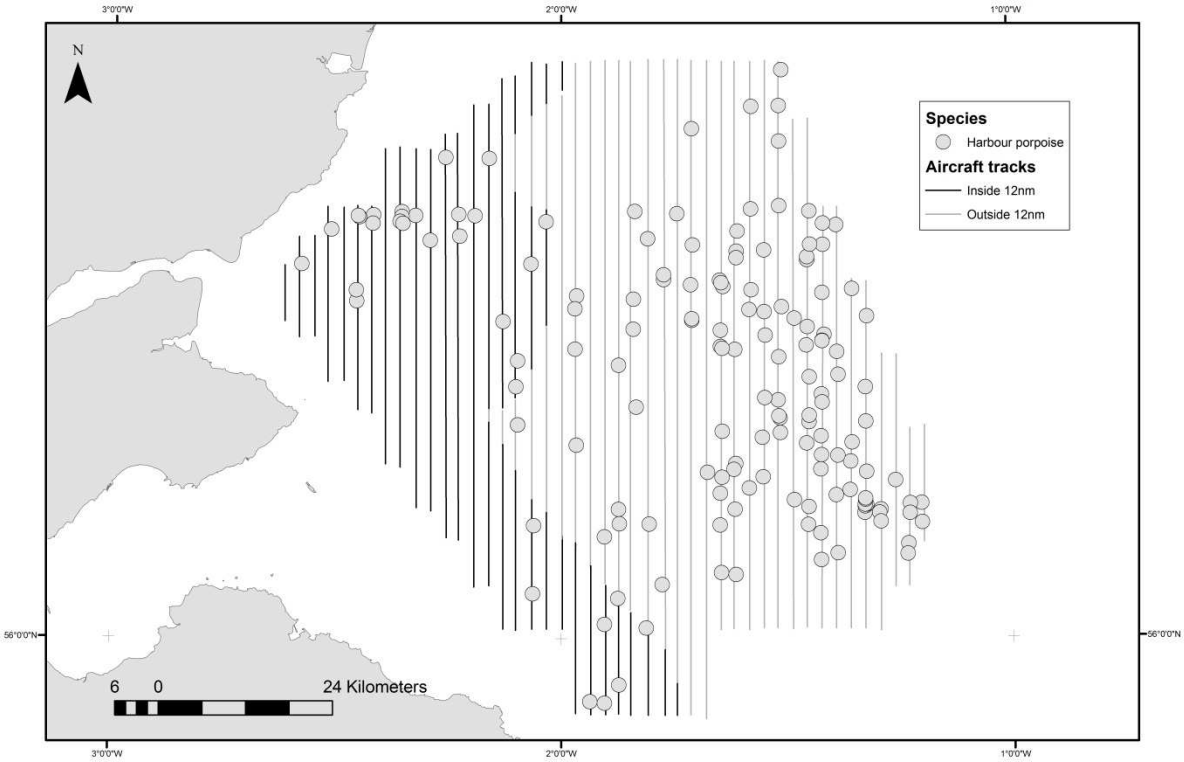


Figure 4. Harbour porpoise – winter

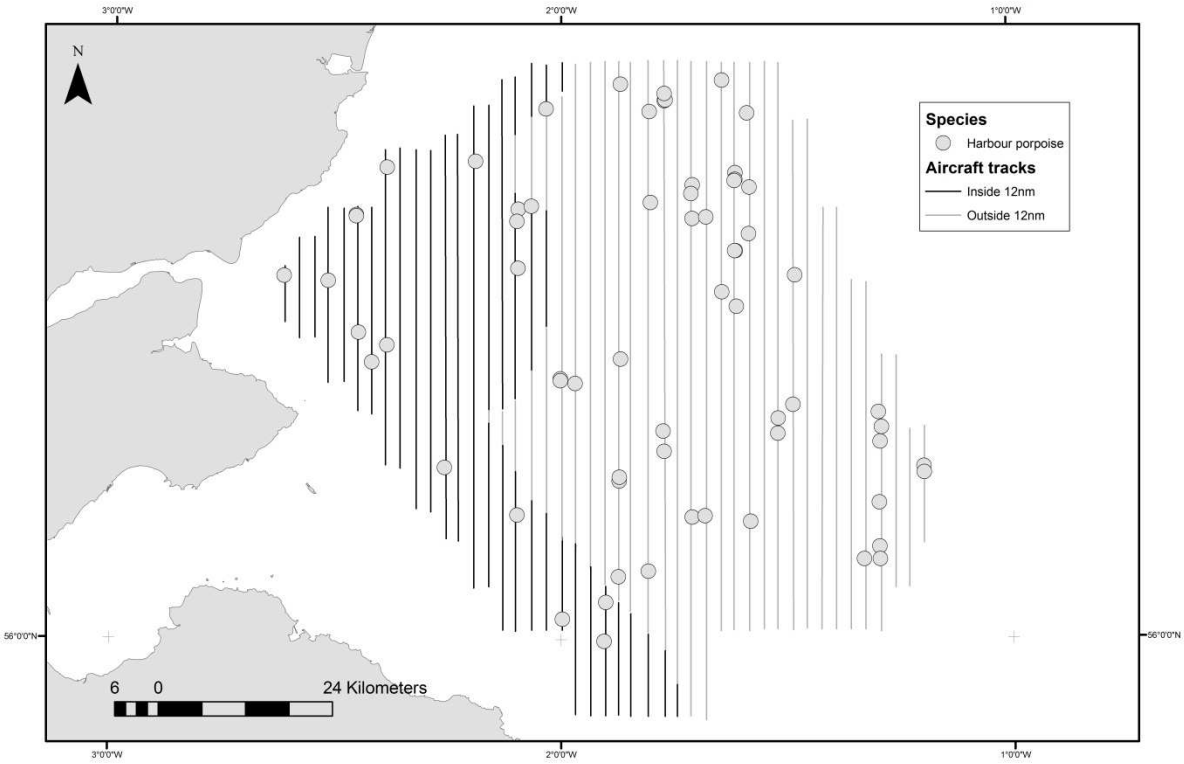


Figure 5. White-beaked dolphin – group size – all seasons

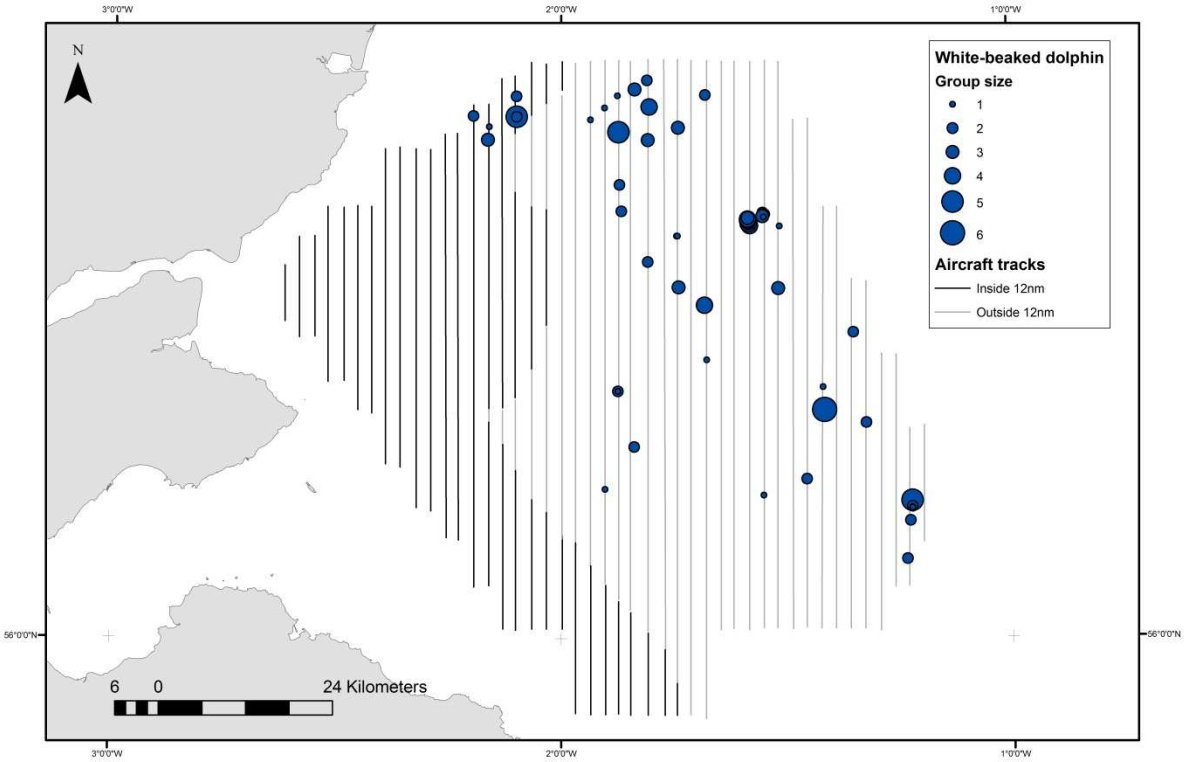


Figure 6. White-beaked dolphin – summer

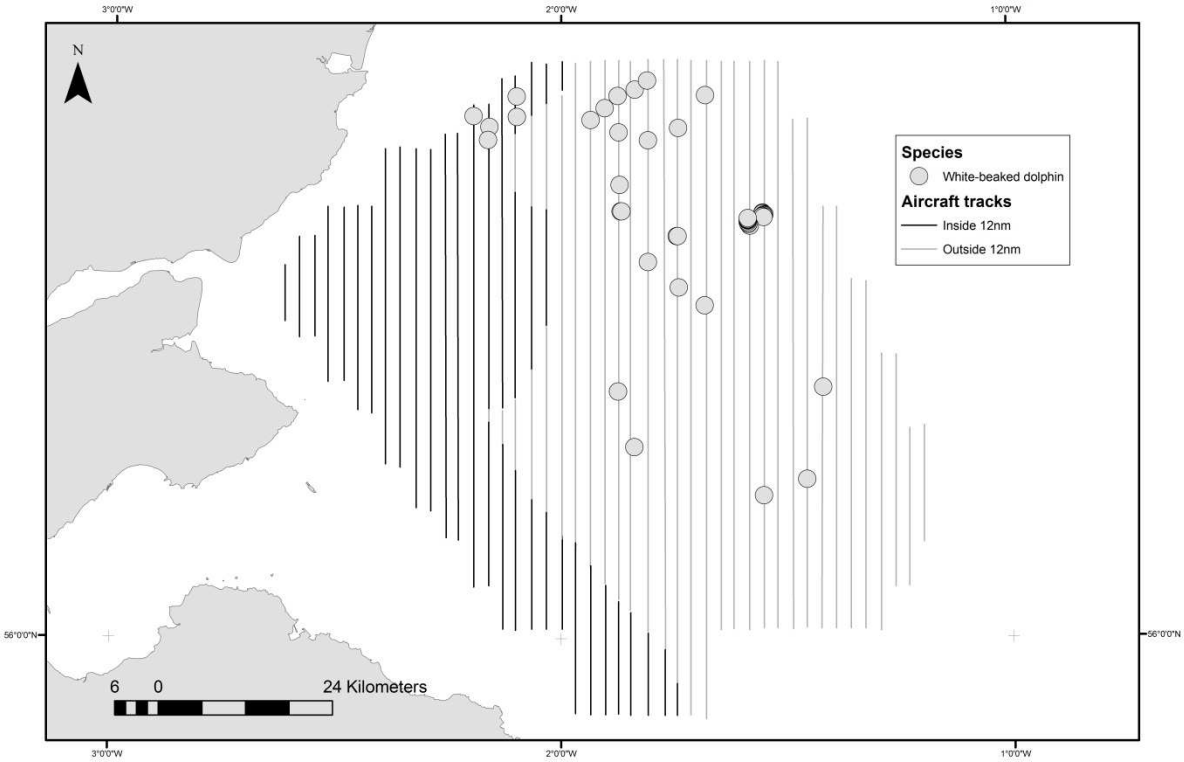


Figure 7. White-beaked dolphin – winter

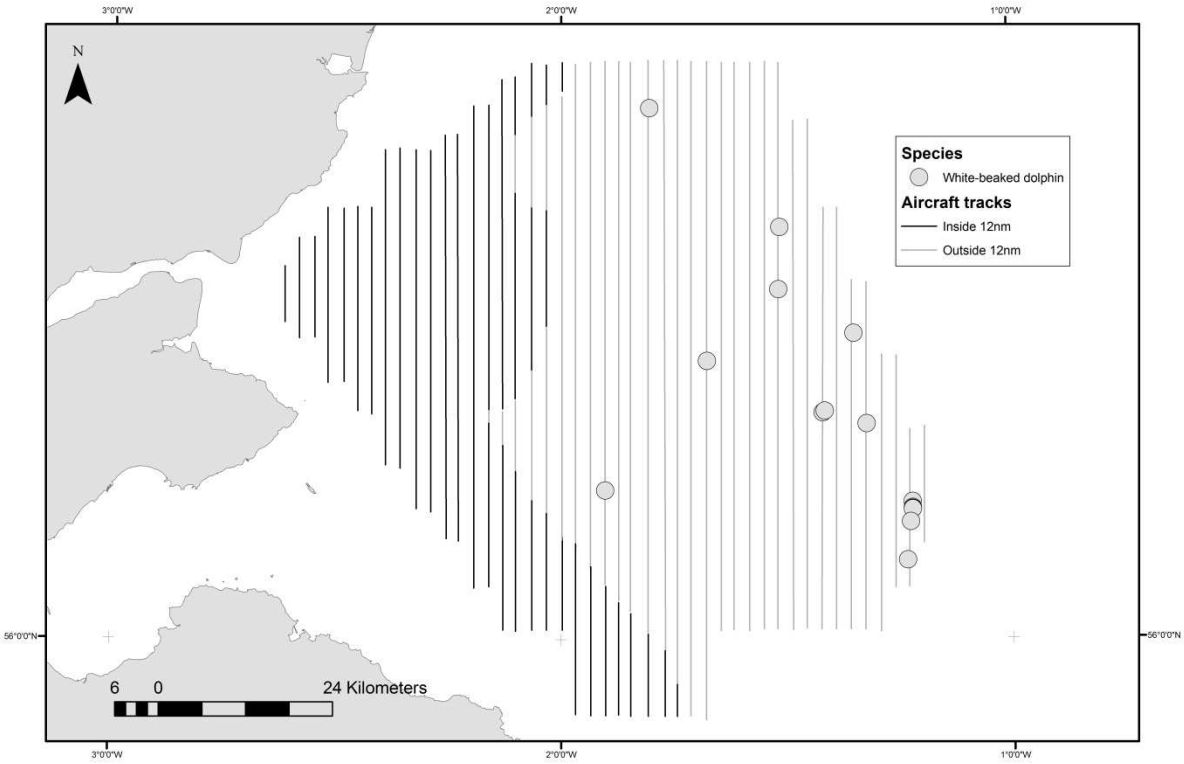


Figure 8. Seals – all seasons

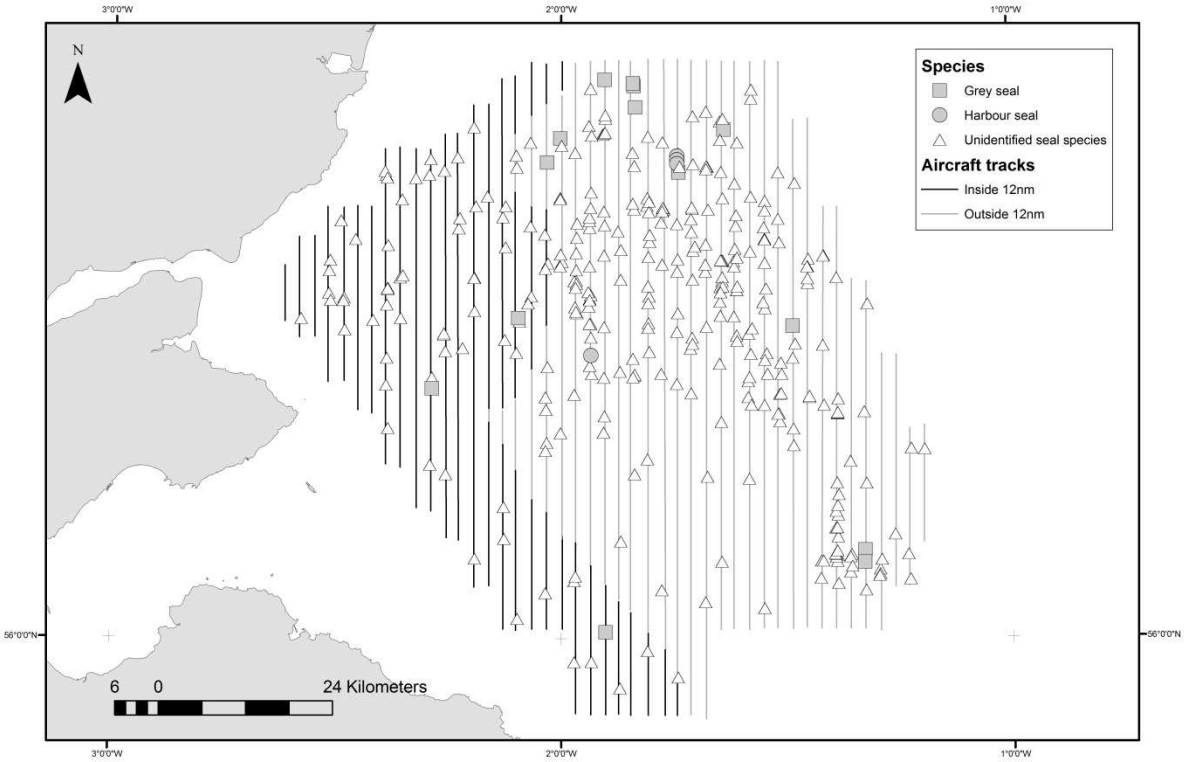


Figure 9. Seals – summer

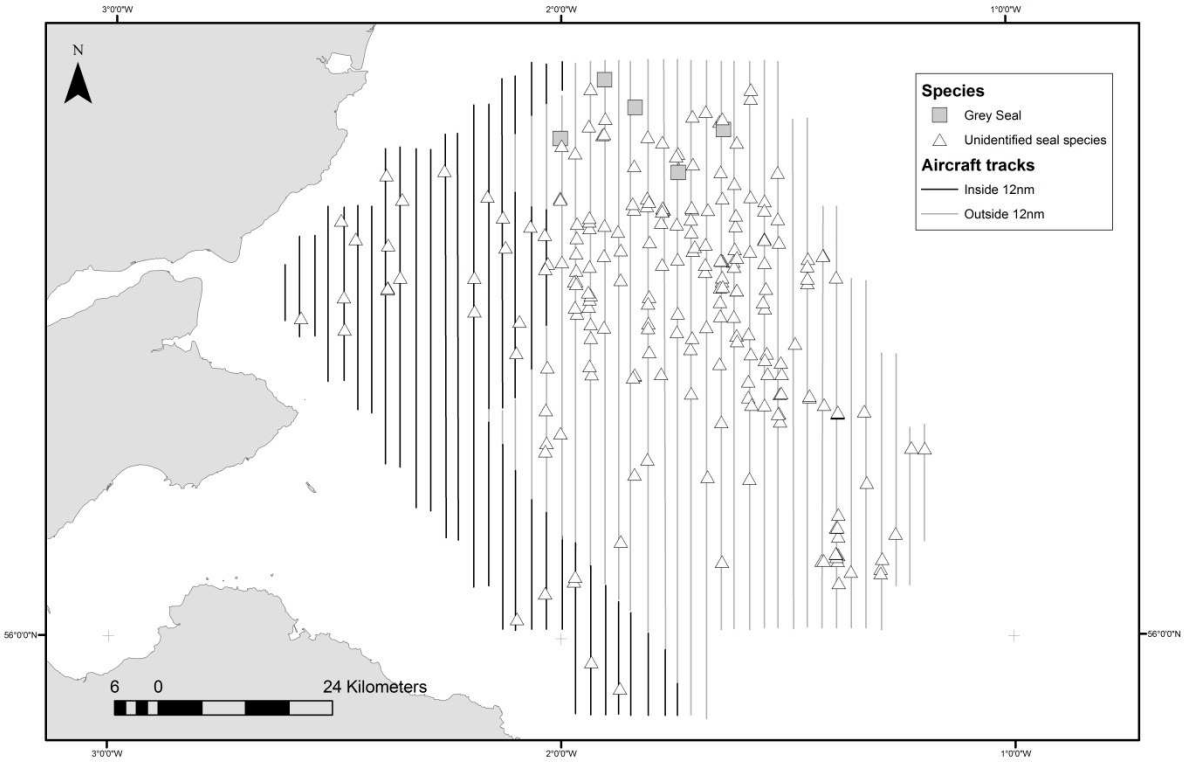


Figure 10. Seals – winter

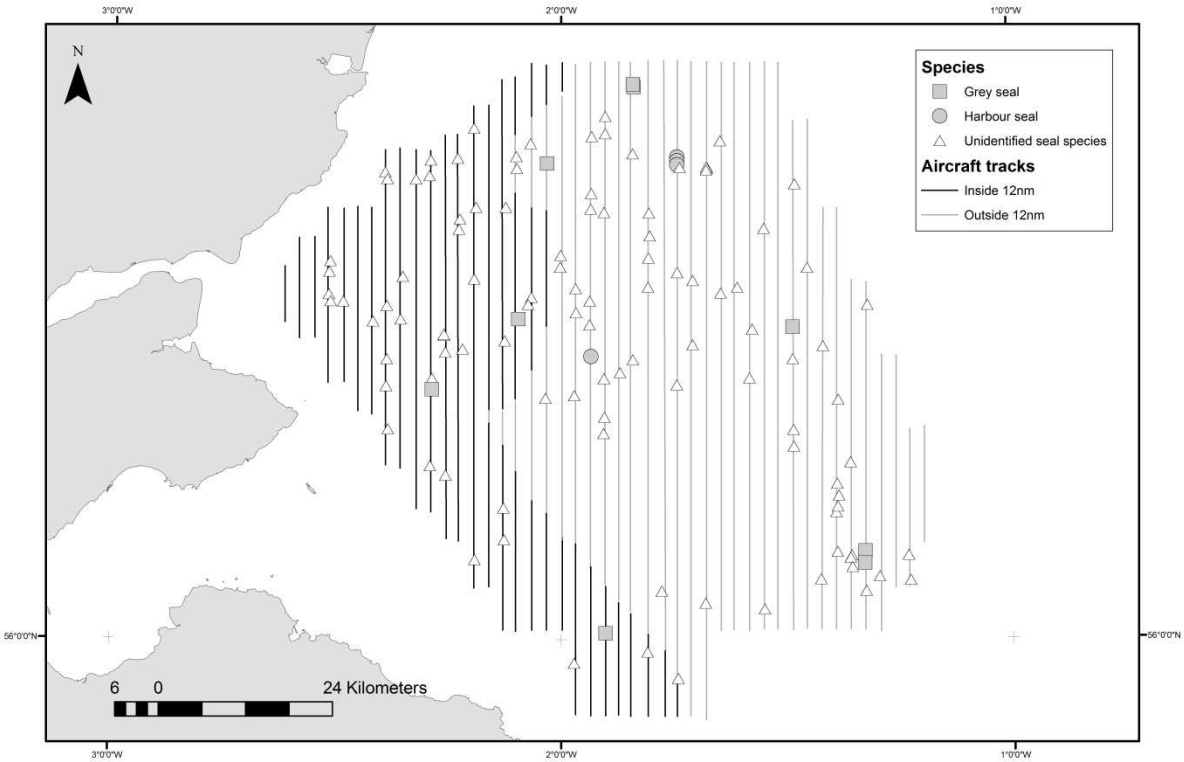


Figure 11. Dolphin species – all seasons

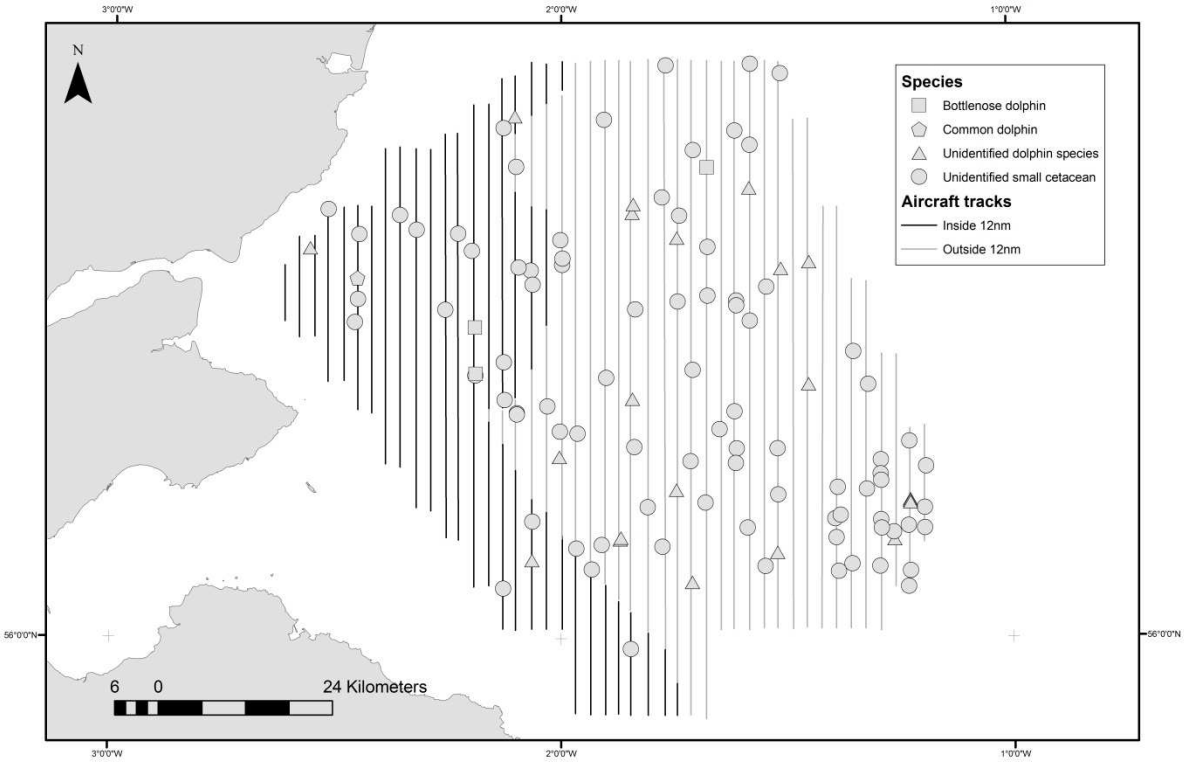


Figure 12. Dolphin species – summer

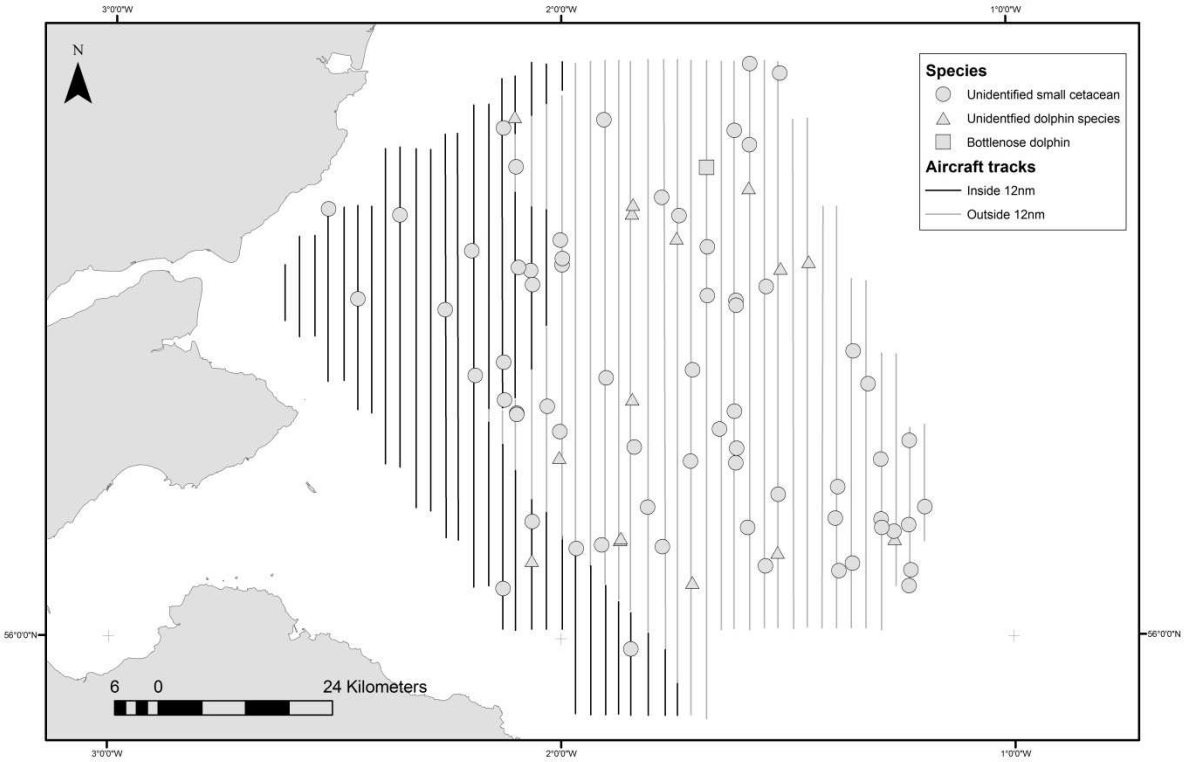


Figure 13. Dolphin species – winter

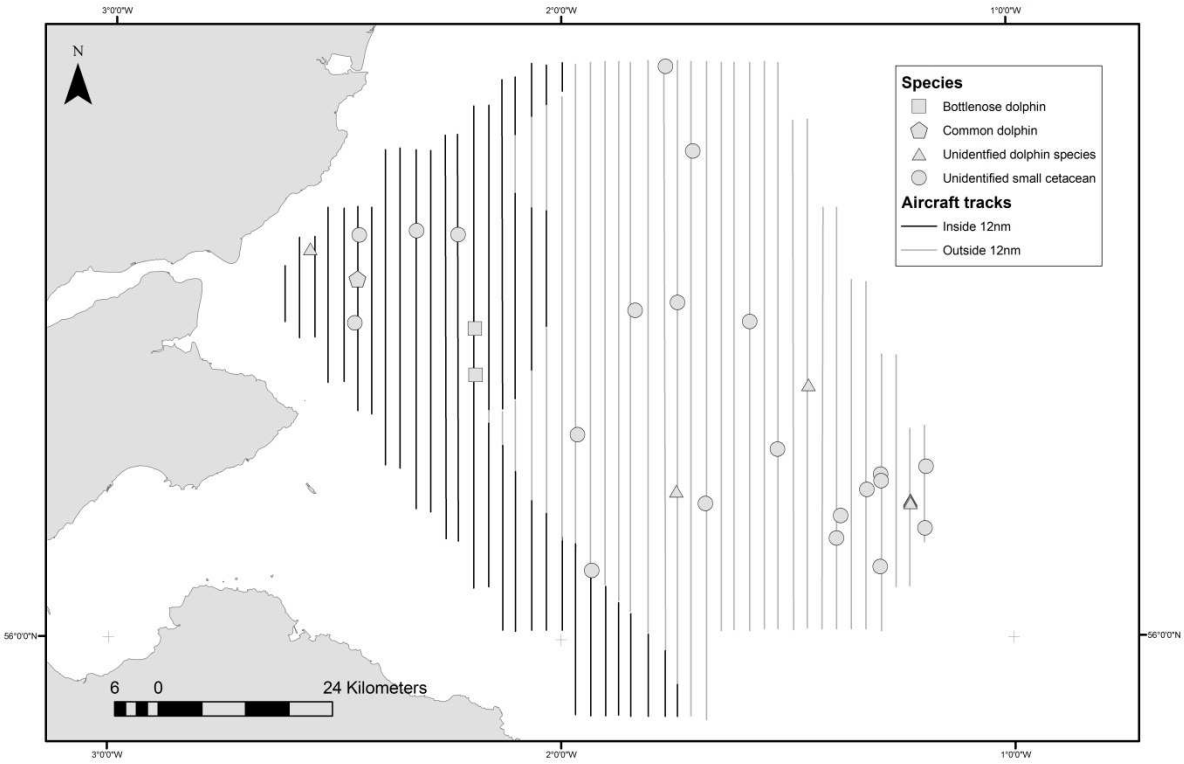


Figure 14. Large cetaceans – all seasons

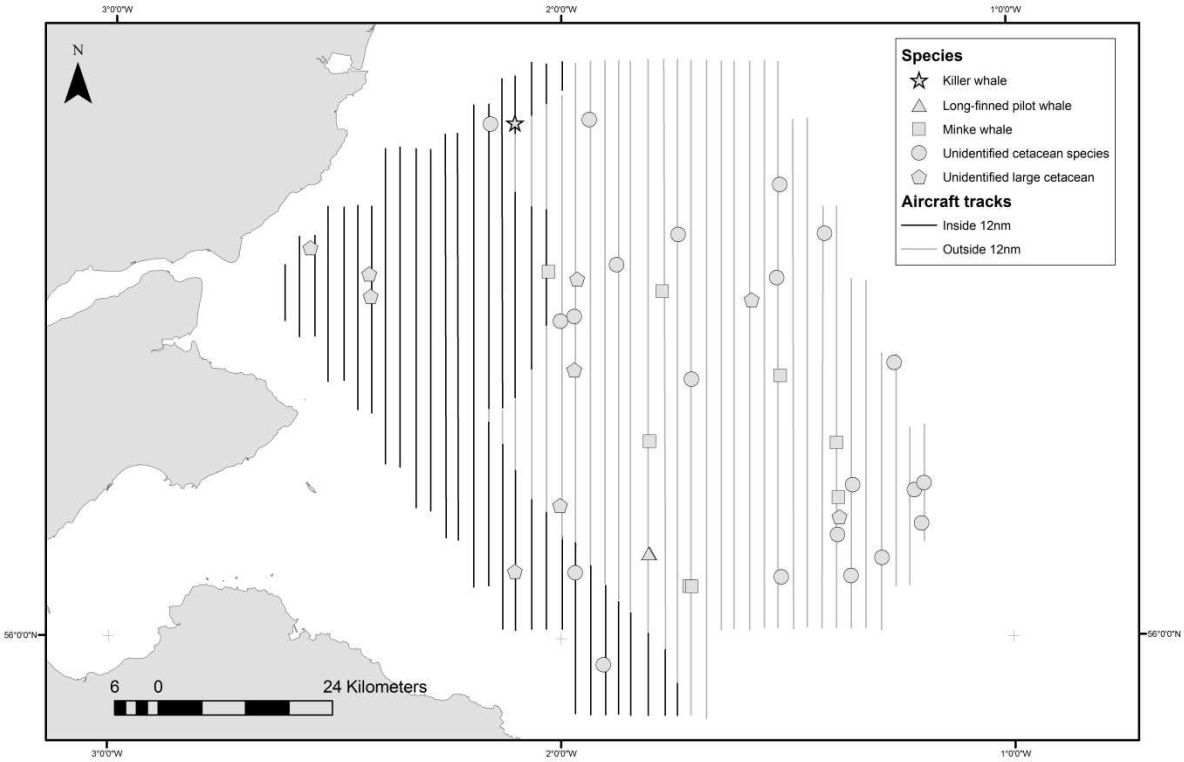


Figure 15. Large cetaceans – summer

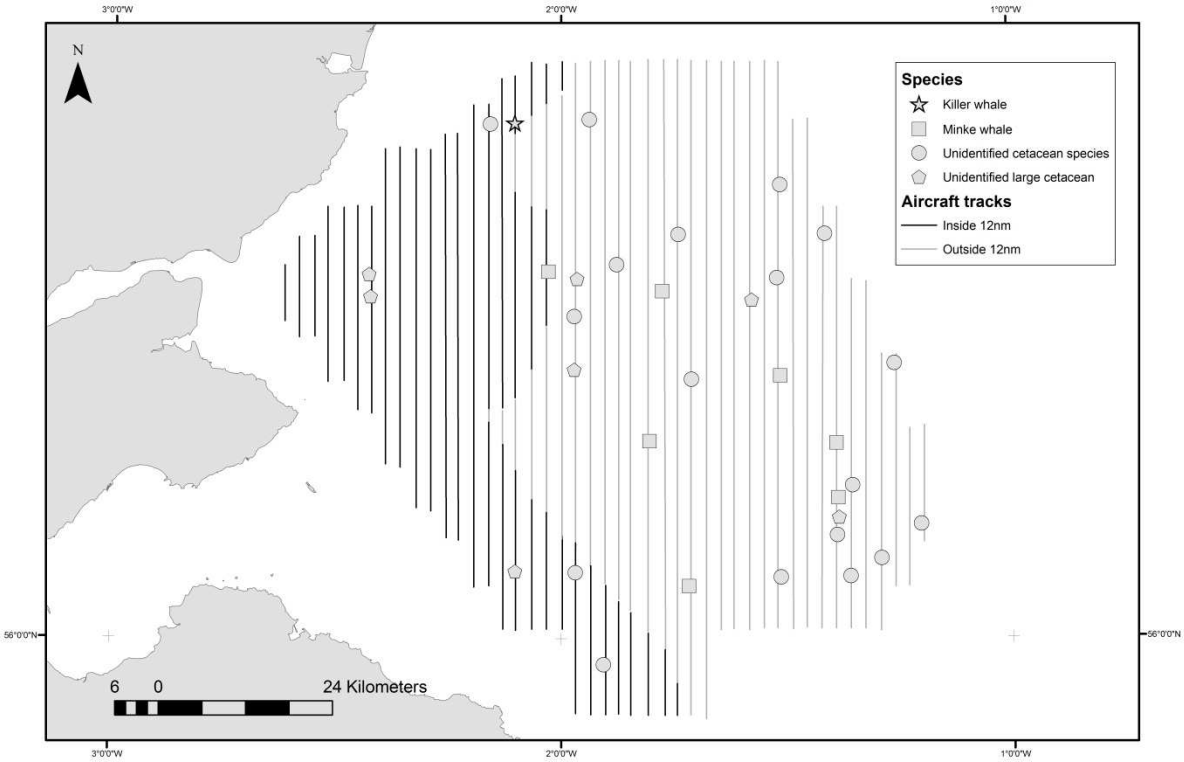
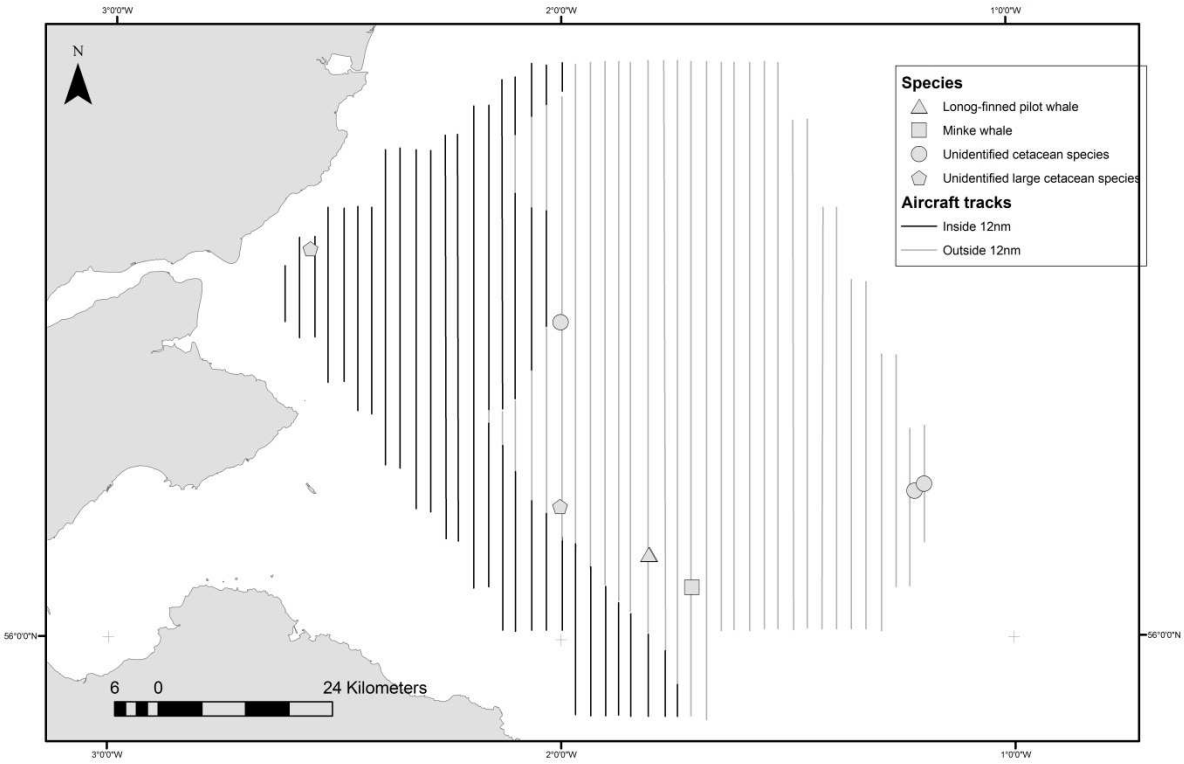


Figure 16. Large cetaceans – winter



Encounter rates

Encounter rates can be used as a basic index to make comparisons between 'relative abundance' of different species within an area or between areas and/or time periods. They are not a measure of density and are simply calculated by dividing the number of observations by the amount of survey effort (length of transect observed). It should be noted that encounter rates do not take into account the factors that affect the detectability of different species on different survey occasions.

Encounter rates were calculated for each species/species group using either all the data or subsets of the data (summer/winter, inshore/offshore). Sighting was used as the unit of observation in one analysis (Table 4); individual was used as the unit of observation in the other (Table 5). Both are valid; differences occur because individuals of some species are generally sighted alone (e.g. harbour porpoise) while individuals of other species are generally sighted in groups (e.g. white-beaked dolphin). If all sightings of a species were of single animals then the encounter rate (sightings per 100km) would equal the encounter rate (individuals per 100km). Encounter rates have been presented as individuals or sightings per 100km because the numbers per km are small.

The encounter rates (sightings per 100km and individuals per 100km) not only confirm the patterns of occurrence for each species shown by the distribution maps, they also allow comparison between species.

The species/species group with the greatest overall encounter rate was 'all seals' (1.95 sightings per 100km) followed by harbour porpoise (1.29 sightings per 100km) and white-beaked dolphin (0.36 sightings per 100km; Table 4 and Table 5). The species with the lowest encounter rates (all ≤ 0.05 sightings/individuals per 100km) were killer whale, common dolphin, long-finned pilot whale, bottlenose dolphin and minke whale.

'All seals' were encountered more than twice as often in summer (2.85 sightings per 100km) compared to winter (1.22 sightings per 100km). In summer, sightings were made three times more often in offshore waters (3.72 sightings per 100km) compared to inshore waters (1.09 sightings per 100km). Encounter rates (individuals per 100km) were greater than encounter rates (sightings per 100km) indicating that seals are sighted in groups as well as singly.

Harbour porpoises were encountered nearly three times as often in summer (2.01 sightings per 100km) compared to winter (0.70 sightings per 100km). They were encountered more often offshore than inshore in both seasons. Encounter rates (individuals per 100km) were greater than encounter rates (sightings per 100km) indicating that porpoises are not always sighted singly.

White-beaked dolphins were encountered four times more often in summer (0.61 sightings per 100km) compared to winter (0.15 sightings per 100km). They were encountered more often offshore than inshore in both seasons. Encounter rates (individuals per 100km) were greater than encounter rates (sightings per 100km) indicating that white-beaked dolphins were almost always sighted in groups.

Table 4. Encounter rate (sightings per 100km).

Species	All data	Summer			Winter		
		Inside 12nm	Outside 12nm	All data	Inside 12nm	Outside 12nm	All data
Bottle-nosed Dolphin	0.02	0	0.02	0.01	0.06	0	0.02
cetacean sp.	0.12	0.11	0.28	0.23	0	0.05	0.03
Common Dolphin	0.01	0	0	0	0.03	0	0.01
dolphin sp.	0.12	0.08	0.24	0.19	0.03	0.08	0.06
Grey Seal	0.08	0	0.09	0.06	0.09	0.09	0.09
Harbour Porpoise	1.29	1.17	2.43	2.01	0.57	0.76	0.70
Harbour Seal	0.02	0	0	0	0	0.06	0.04
Killer Whale	0.01	0.04	0	0.01	0	0	0
large cetacean sp.	0.05	0.11	0.07	0.09	0.03	0.02	0.02
Long-finned Pilot Whale	0.01	0	0	0	0	0.03	0.02
Minke Whale	0.04	0.04	0.11	0.09	0	0.02	0.01
seal sp.	1.85	1.09	3.63	2.79	1.18	1.04	1.08
small cetacean sp.	0.51	0.68	0.99	0.89	0.12	0.26	0.21
White-beaked Dolphin	0.36	0.30	0.77	0.61	0	0.23	0.15
All seals	1.95	1.09	3.72	2.85	1.27	1.19	1.22

Table 5. Encounter rate (individuals per 100km).

Species	All data	Summer			Winter		
		Inside 12nm	Outside 12nm	All data	Inside 12nm	Outside 12nm	All data
Bottle-nosed Dolphin	0.02	0	0.02	0.01	0.09	0	0.03
cetacean sp.	0.19	0.26	0.45	0.39	0	0.05	0.03
Common Dolphin	0.01	0	0	0	0.03	0	0.01
dolphin sp.	0.31	0.23	0.45	0.38	0.03	0.38	0.26
Grey Seal	0.08	0	0.09	0.06	0.09	0.09	0.09
Harbour Porpoise	1.65	1.36	3.01	2.46	0.76	1.10	0.98
Harbour Seal	0.02	0	0	0	0	0.06	0.04
Killer Whale	0.01	0.04	0	0.01	0	0	0
large cetacean sp.	0.05	0.11	0.07	0.09	0.03	0.02	0.02
Long-finned Pilot Whale	0.04	0	0	0	0	0.12	0.08
Minke Whale	0.05	0.04	0.13	0.10	0	0.02	0.01
seal sp.	2.08	2.26	3.81	3.30	1.18	1.04	1.08
small cetacean sp.	0.67	0.83	1.27	1.13	0.18	0.37	0.30
White-beaked Dolphin	0.83	0.75	1.76	1.43	0	0.53	0.35
All seals	2.18	2.26	3.91	3.36	1.27	1.19	1.22

Fine-scale spatial variation in encounter rate

In order to examine finer-scale spatial variation (between transects rather than inside/outside the 12nm zone) for the three most common species, encounter rate was calculated for each species for each transect on each date it was surveyed. These encounter rates were then combined to produce mean encounter rates per transect. The standard errors around these means reflect temporal variation in encounter rate. For reference when looking at the following three Figures, transects 13-26 were completely inside the 12nm zone, transects 27-41 crossed the 12nm line, and transects 42-57 were completely outside the 12nm zone.

Harbour porpoise encounter rate increased with distance from shore (from less than one to between four and five sightings per 100km; Figure 17). Although the error bars were quite tight for the middle section of transects (22-42), variability was greater for transects 43-57 (meaning that there was greater temporal variation in encounter rate further offshore).

In contrast to harbour porpoise, white-beaked dolphin encounter rates did not consistently increase with distance from shore (Figure 18). However, encounter rate was zero for transects 13-25, and roughly equal to one sighting per 100km thereafter out to the easternmost extent of the survey area. White-beaked dolphin encounter rate was greatest on transects 45, 46 and 56 (between 2.5 and 4 sightings per 100km) although variability was too great to be able to draw any conclusions.

Seal encounter rate was generally less than 2 sightings per 100km out to transect 30 (Figure 19). Encounter rate then increased consistently with distance from shore, peaking at more than 5 seals per 100km on transect 43. Encounter rate then decreased and by transects 52-57, was back at 1-2 sightings per 100km. Variability was greatest for the most inshore (14, 16 and 17) and sections of the offshore (e.g. 43-47) transects (meaning that there was greater temporal variation in encounter rate close inshore and in patches further offshore).

Figure 17. Encounter rate (sightings per 100km) ± standard error per transect for harbour porpoise. Transect 13 is the western-most transect, transect 57 is the eastern-most transect.

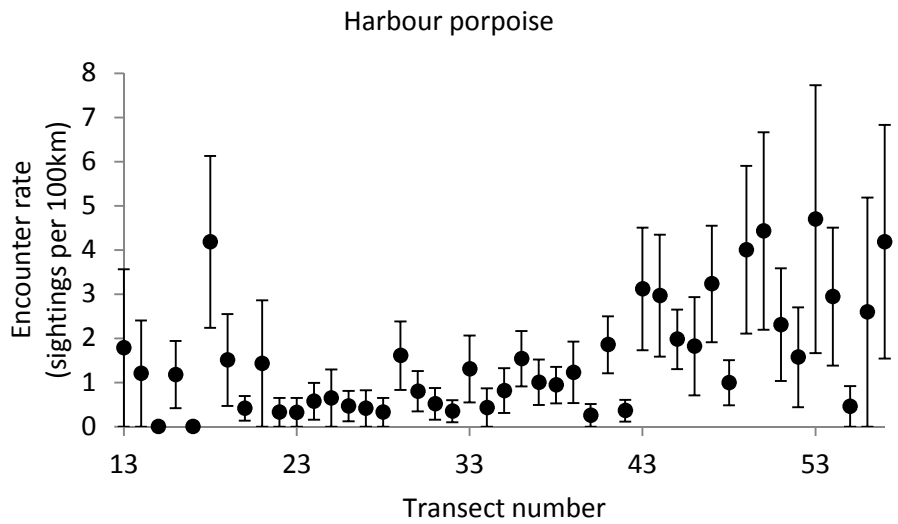


Figure 18. Encounter rate (sightings per 100km) ± standard error per transect for white-beaked dolphin. Transect 13 is the western-most transect, transect 57 is the eastern-most transect.

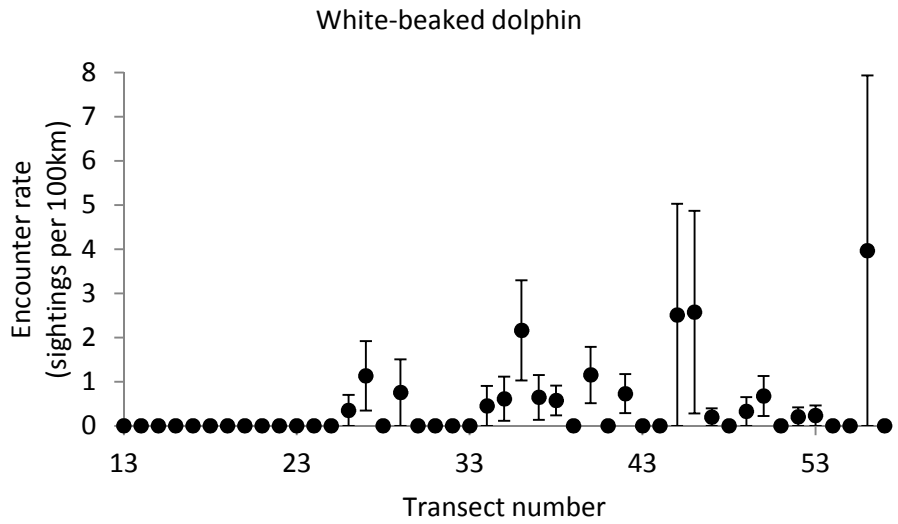
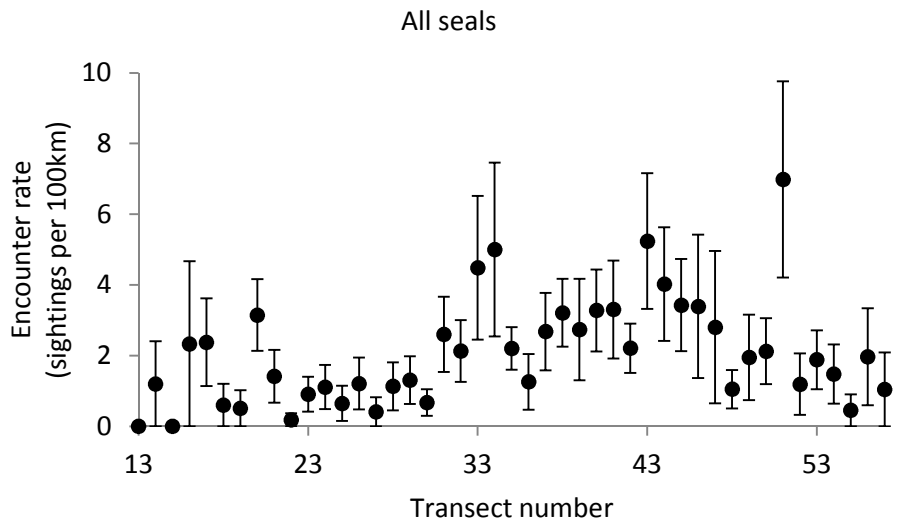


Figure 19. Encounter rate (sightings per 100km) ± standard error per transect for all seals. Transect 13 is the western-most transect, transect 57 is the eastern-most transect.



Fine-scale temporal variation in encounter rate

In order to examine finer-scale temporal variation (between months rather than summer/winter) for the three most common species, encounter rate was calculated for each species on each date a survey was carried out. These encounter rates were then combined to produce mean encounter rates per month. The standard errors around these means reflect temporal variation in encounter rate within that month.

Harbour porpoise and white-beaked dolphin encounter rates were generally greater between May and August 2009 than between November 2009 and March 2010. Because no environmental data were contained within the observation or effort files, there is currently no means of assessing the effect of varying sighting conditions on encounter rates. For example a consistently higher sea state in winter than summer could result in this pattern as could greater numbers of animals being present in summer. In the absence of environmental data it is not possible to assess whether these patterns are real or are artifacts of different sighting conditions. Notwithstanding this, white-beaked dolphins are known occur seasonally in other areas e.g. in June to August off Aberdeen-shire (Weir at al. 2007).

Encounter rates were generally greater between May and August 2009 than between November 2009 and March 2010 for 'all seals' (Figure 22). In the first period, mean encounter rate greatest in May (~4 sightings per 100km), lower in June and July (~2.5 sightings per 100km), and lower still in August (< 2 sightings per 100km). These lower encounter rates coincide with harbour seals coming ashore to give birth to their pups (in June and July), and to moult (in August; when the greatest and most consistent numbers of seals are found ashore; Duck et al. 2010). In the second period, mean encounter rate varied from 0.35 in November 2009 to 1.9 sightings per 100km in December. These months coincide with months when grey seals are breeding (November and December) and moulting (January-March). There are likely to be more grey seals in the 'all seals' category than harbour seals due to the difference in local population size – a total of 124 harbour seals counted in the Firth of Tay and Eden Estuary SAC during the August 2010 moult compared to an estimated pup production of 4047 for the Firth of Forth (Isle of May, Firth of Forth Islands, Fast Castle) in 2009. Therefore we would expect encounter rates to be lowest when grey seals are ashore breeding and moulting.

Figure 20. Encounter rate (sightings per 100km) ± standard error by month for harbour porpoise. No surveys were carried out in September or October.

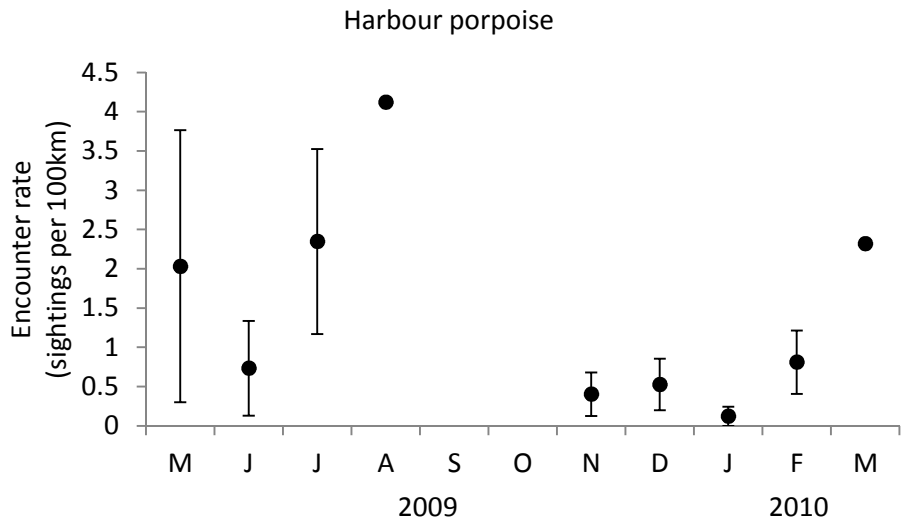


Figure 21. Encounter rate (sightings per 100km) ± standard error by month for white-beaked dolphin. No surveys were carried out in September or October.

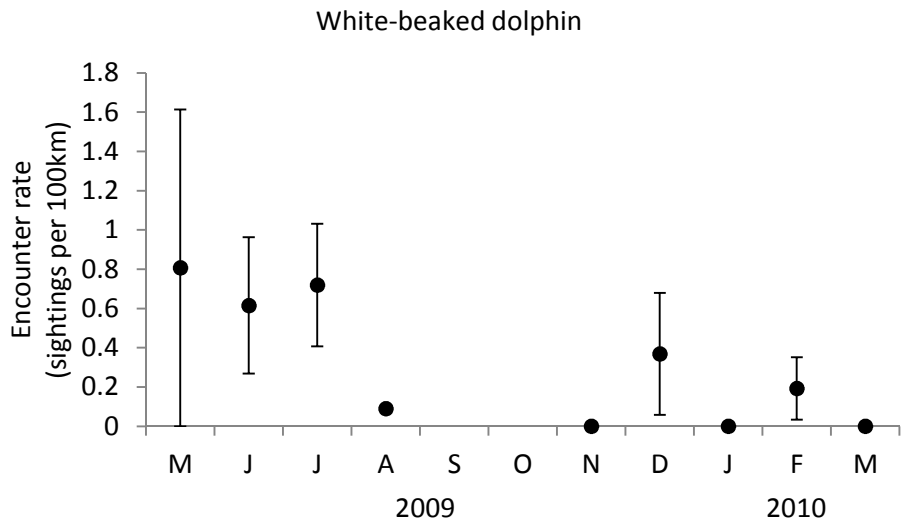
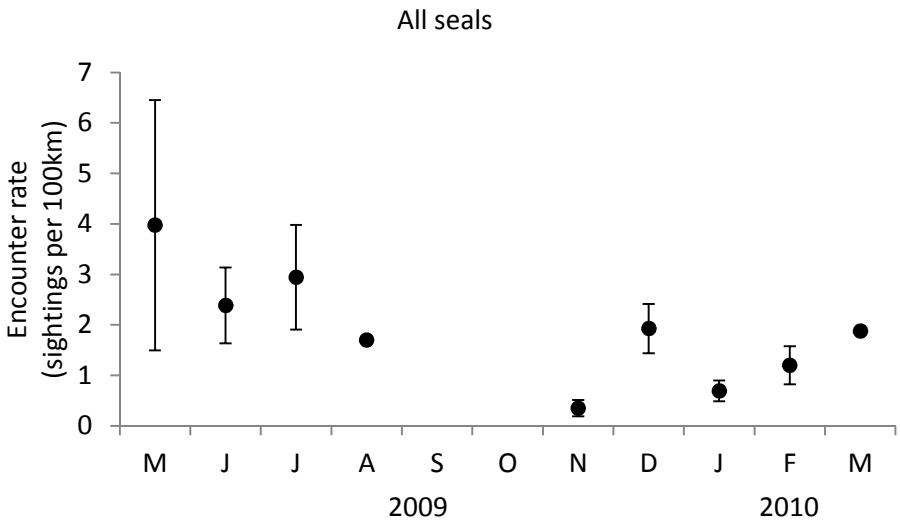


Figure 22. Encounter rate (sightings per 100km) ± standard error by month for all seals. No surveys were carried out in September or October.



Density estimates

The most common method used to estimate density of marine mammals is the 'line transect' approach, where exact measurements of distances to sightings are recorded in the field. All marine mammals from the transect line out to the edge of the observer's field of view are recorded (the fundamental assumption is that all animals on the transect line will be recorded). The probability of missing animals increases with increasing distance from the transect line; this relationship can be modeled by fitting a 'detection function' to the perpendicular distances to the observations recorded in the field. The recommended sample size to fit a detection function is 60-80 observations, although it is often possible to fit an adequate detection function with fewer (Buckland et al. 2001).

In contrast, the method employed during these aerial surveys is optimized for recording bird data (which were collected at the same time). It is essentially a modified 'strip transect' approach, where a detection function is fitted to observations allocated to four distance bands (A: 44-163m, B: 163-282m, C: 282-426m, and D: 426-1000m). As highlighted by Macleod and Sparling (2011), the search protocol and corresponding behaviour of observers has seriously affected the ability to fit a detection function to the marine mammal data. As a result, the data have been treated as a strip transect of width 44-163m (Band A). It should be noted that the strip transect approach assumes that all animals present within the strip are observed. This assumption will be seriously violated because marine mammals spend a proportion of their time underwater and can easily be missed by observers. The consequence of this is that density will be considerably underestimated. The density estimates presented should be considered as minimum estimates due to this inherent negative bias.

Density estimates for the species for which there were enough sightings (harbour porpoise, white-beaked dolphin, all seals) were calculated as the number of individuals observed in Band A on either side of the aircraft (port and starboard) on each date the transect was surveyed divided by the total area of the observed strip (0.119 x the observed transect length by the P observer measured in km x 2; Figure 23). Mean density was then calculated for all three species using the whole data set, and separately for summer and winter for harbour porpoises and all seals (Table 6). All seals had the highest density (0.106 individuals per km^2), followed by harbour porpoise (0.080 individuals per km^2) and white-beaked dolphin (0.042 individuals per km^2).

For comparison, density estimates from the SCANS surveys are shown in Table 7. Seals were not recorded during these surveys. Density estimates from both SCANS surveys were an order of magnitude greater than the minimum density estimate from this study for harbour porpoise; estimates for white-beaked dolphins from the three surveys were more similar.

Figure 23. Representation of the path taken by the survey aircraft along the transect line (centre arrow) and the size of the strips observed by the port observer (P) and the starboard observer (S).

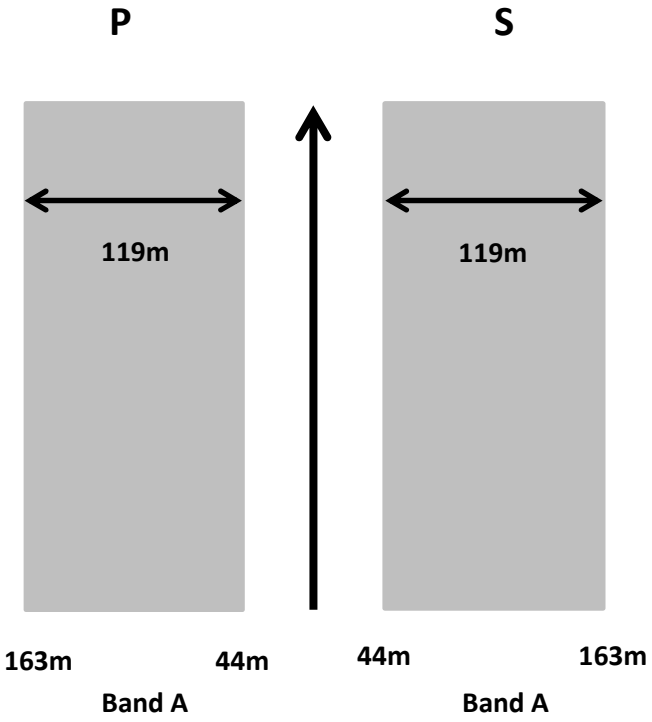


Table 6. Strip transect density estimates (individuals per km^2) for Band A. These density estimates should be considered as minimum estimates due to the inherent negative bias.

Species	All data		Summer		Winter	
	Density	CV	Density	CV	Density	CV
All seals	0.106	0.12	0.137	0.15	0.051	0.14
Harbour Porpoise	0.080	0.11	0.099	0.12	0.048	0.24
White-beaked Dolphin	0.042	0.31	0.052	0.35	0.024	0.66

Table 7. SCANS and SCANS II density estimates (animals per km^2) for the Blocks which included the area covered by TCE surveys.

Survey	Block	Size of Block (km^2)	Species	Density	CV
SCANS (July 1994)	C	43,744	Harbour porpoise	0.387	0.18
			White-beaked dolphin	0.0538	0.52
SCANS II (July 2005)	V	160,517	Harbour porpoise	0.294	0.37
			White-beaked dolphin	0.049	0.37

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