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USD 4:

Report

Examining the distribution of observed carcasses to identify biological and oceanographic patterns and distribution of potential causes to assess the patterns of risk associated with these unexplained seal deaths

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1 Executive Summary

This investigation sought to establish a monitoring protocol for analysing the potential of shipping interactions as the cause of spiral lesions in grey (*Halichoerus grypus*) and harbour (*Phoca vitulina*) seals. Two major projects aimed to: (a) assess fine scale shipping behaviour on an individual stranding, case by case basis and (b) establish the nationwide overlap between vessel traffic and seal usage. Automated Identification Systems (AIS) and radar were the primary sources of data in both cases. In addition telemetry data were used to generate seal usage maps.

A total of 26 strandings between January 2013 and January 2015 were assessed for possible, related fine-scale shipping behaviour. Candidate vessels were identified in all cases when wind-direction and estimated time-of-death were taken into account. Sixteen cases contained at least one identified candidate vessel which had also appeared in another case.

Shipping traffic around the UK was primarily within 100km of the coast, and the heaviest consistent densities were on the south coast of England, in the English Channel and the mouth of the Thames. For both UK species of seal areas of highest occurrence between seals and shipping are within 50km of the coast and coincide with areas of high seal usage. However, there does not appear to be a relationship between stranding locations and areas of high occurrence between seals and shipping.

It was concluded that, although candidate vessels could be identified in all cases, shipping densities illustrate that strandings are not occurring where expected if seal-shipping interactions were the primary cause of spiral lesions. However, this could be due to lack of reporting or identification in areas of high interaction rates. As yet, with the evidence presented here, there is no further reason to assume seal-shipping interactions are causing spiral seal lacerations.

2 Introduction

2.1 Background and Aims

Unexplained seal deaths (USD) around the UK are being investigated by the Sea Mammal Research Unit (SMRU). As part of this ongoing investigation into the causes of the spiral seal lesions interactions with ducted propellers were identified as the likely cause (Thompson *et al*., 2015; Onoufriou & Thompson, 2014; Bexton *et al.*, 2012). Fatally wounded animals bearing these lacerations have been found washed up along the UK coastline since 2007 (and two were reported in 1985) and it is likely they were killed close to where the bodies were found, commonly referred to as the "stranding" locations (Wilson *et al*., 2007). Attempts were therefore made to investigate potential links between shipping activity and seals at both a local/individual event scale and at a broader population/nationwide scale. In both cases reliance has been placed on the data available through automated identification systems (AIS). The objective of task USD4 was to identify candidate vessels on a case by case basis and to determine the spatial extent of the problem, primarily:

- Are seals usually killed close to shore where there is a high probability of interaction with shipping traffic (where seals are travelling to and from their haul-outs and ships in and out of harbours)?

and/or

- Could there be a more extensive problem with animals also being killed farther offshore?

At the fine scale/individual events level it was attempted to identify candidate vessels on the basis of AIS activity logs of vessels in the vicinity of the individual stranding locations during the period prior to and around estimated time of death.

At the broader population/nationwide scale, the analysis estimates relative encounter probabilities between grey and harbour seals and shipping traffic around the UK, to inform where potential future monitoring and experimental resources will be most effective. Due to the high-resolution, broad-scale approach of the software, smaller areas of interest can also be identified and shown in detail. This is particularly relevant for areas such as those around proposed offshore marine renewable developments or existing Special Areas of Conservation (SAC), which offer habitat protection for grey and harbour seals under Annex II of the European Commission Habitats Directive (ECHD). A specific set of questions was answered:

1. Are seals likely being killed further offshore because of a high probability of interaction between seals and shipping traffic in some areas?
2. Do seals and shipping traffic have a high incidence of overlap in areas where strandings are reported?
3. Are there any areas where strandings have not been identified but where seals and shipping have a high incidence of overlap?
4. Do locations of incidences of high overlap vary by seal species?

Concern about interactions between vessel activities and marine mammals however, are not limited to corkscrew seal deaths. Ambient noise is becoming increasingly prevalent in the marine environment, with the main proponents being shipping traffic, seismic surveys, and pile driving (Merchant *et al*., 2013). The EU Marine Strategy Framework Directive 2008 (European Parliament, 2008) has classed ambient noise as a pollutant, and developers are now required to provide mitigation or limitation initiatives in EIAs. This is important for the UK, which already has heavy shipping traffic. There is also a rapidly expanding offshore marine renewables industry, primarily driven by a target for 20% of the EU's energy consumption to be from renewable sources by 2020 (European Parliament, 2012). With the requirement for a range of vessels for installation and maintenance of devices the incidence of seal-shipping interactions is likely to increase; offshore near marine renewable development sites, which may overlap with seal feeding grounds, and inshore where seal haul-outs and harbours are already located in close proximity. Mapping existing shipping traffic will provide insight into the potential extent of the problem, assuming the candidate mechanisms highlighted in USD2 are correct.

2.2 Automated Identification Systems (AIS)

Primarily used in industry as a tool for identification and navigational safety, automated identification systems (AIS) provide a unique opportunity to observe vessel traffic in detail on a local, national and international scale. Data are routinely gathered on the distribution and activity patterns of all vessels over 300T and a substantial, but unknown proportion of smaller work boats, fishing vessels and pleasure craft.

AIS information is transmitted via either VHF radio or satellite depending on the location, speed and heading of the vessel (Roberts *et al*., 2004). Transmission via VHF is reliant on line-of-sight between the ship-board transmitter and a base station which is usually land-based. Therefore transmission success is largely dependent on the number of base stations and their coverage along coastlines. When VHF is not available, data are sent via satellite which allows voyages across large bodies of water to be tracked. The development of the technology has been applied to International Maritime Organisation operational regulations resulting in the ability to observe the real-time movements of all vessels which fit into a certain criteria. By 2005 all vessels exceeding 300 gross tonnage on international voyages, cargo vessels exceeding 500 gross tonnage on local voyages and all passenger vessels irrespective of size, are required to have on board AIS in operation. All others can voluntarily carry AIS but due to the uncertainty of the proportion of vessels without a system in operation such voluntarily marked vessels are mostly disregarded in research projects. The data which are provided by AIS is required to contain identity, vessel type, speed, heading, destination and position, however, in some instances further information such as propulsion system and operational status is provided. Due to the suspected ships involved in seal-propeller interactions which cause spiral lacerations it can be assumed that a large proportion of responsible vessels are observable using AIS assuming International Maritime Organisation regulations are adhered to in all cases.

Port authorities' primary use of AIS is for collision prevention but it is often used in conjunction with radar tracking systems to increase the accuracy of location information. The major advantage of radar information is that it is available for all vessels of all sizes, whereas AIS data depends upon the vessel being fitted with and operating an AIS transmitter. The disadvantages of radar systems are the limited range, which is a function of radar power and is in any case restricted to line of sight and the presence of radar-shadows caused by radio-dense bodies. Nevertheless, in small areas such as local ports, estuaries and small coastal regions, radar provides an extremely effective tracking method which, when combined with AIS data, allows precise, real-time tracking of vessels providing information on speed, heading and destination.

3 Investigating ship seal interactions for individual spiral seal events

This report details the method by which vessel traffic was monitored with regards to individual spiral seal stranding events. The primary aim of the investigation was to identify candidate vessels for each reported event as well as to analyse the large scale co-occurrence of shipping and seal distribution throughout the UK.

3.1 Method

3.1.1 Monitoring protocol of individual vessels relating to specific events

All spiral seal reports were examined and, where time of death could be assessed, attempts were made to identify any vessel that was potentially involved. In most areas the search effort was limited and many of the carcasses were of indeterminate age. However, in south-east Scotland the majority of the coast is frequently visited and strandings are often reported soon after they occur, therefore special attention was paid to this part of the coast. The coastal waters of south-east Scotland also have good, extensive AIS coverage available through publicly maintained and accessible databases. AIS data from multiple sources were used for the identification of individual vessels suspected of involvement in seal-propeller interactions. The publicly available databases are variable in terms of coverage and reliability. Where necessary multiple AIS resources were used for a single event; historical accuracy and data maintenance is often sacrificed for real-time tracking capabilities and therefore various sources could be used in conjunction to provide location history and vessel monitoring. During the winter and again during the late spring and summer AIS traffic was inspected on a daily basis for the main area of interest in the Firth of Forth and Tay region and a more sporadic inspection regime was maintained throughout the year.

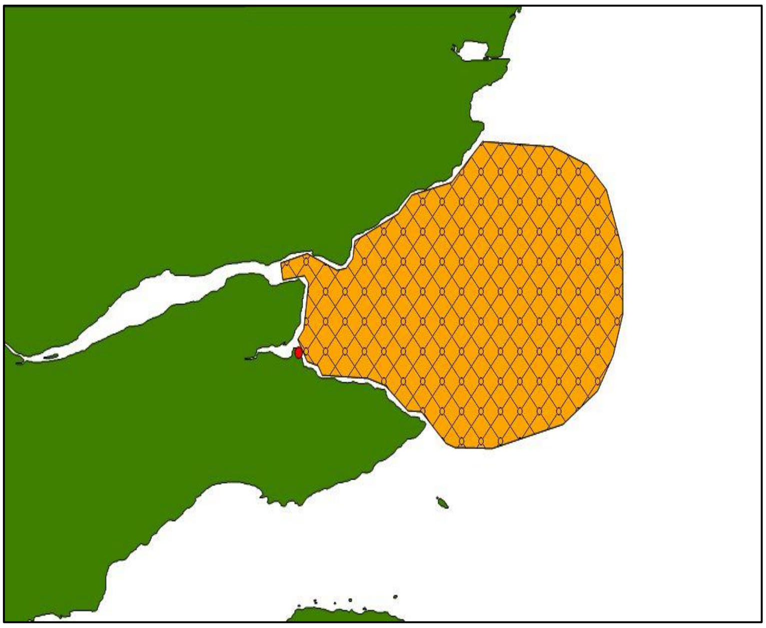
There were no resources available within the project to carry out regular searches of any sections of the coast; therefore reliance had to be placed on reports from the public supplemented by occasional beach surveys by SMRU staff. Any seal stranding reported between Montrose and the Firth of Forth was inspected either by SMRU or the Scottish Marine Animal Stranding Scheme (SMASS) staff, identified as a spiral-trauma injury on the basis of visual inspection and then an estimate of time of death was obtained. Whenever a seal with spiral-trauma injuries was reported a detailed examination of the activity records of any vessels identified as being within the area of interest during the period of interest were accessed and inspected.

The time-window that was analysed changed on a case by case basis and was determined by the inferred time of death and therefore time of interaction. Time of death was estimated as far as possible using post-mortem data and visual assessment of the levels of autolysis and scavenger damage. Determining time of death is extremely difficult even after thorough post-mortem analysis. Unfortunately, the pathological techniques used to determine time of death are limited in their effectiveness such that at more than 72 hours post mortem only very rough estimates of time of death can be made. A conservative approach was therefore employed to ensure all possible vessels were included and minimum time of one week prior to the discovery of the seal was used as the potential time window for all relatively fresh carcasses.

The extent of the monitoring area for each specific case was determined by location of the stranding site. Where possible tidal flow and coastal current information was used to determine a reasonable search area. POLPRED (a proprietary surface current flow prediction package created by the National Oceanography Centre, Southampton) was used to hindcast possible movement patterns of carcasses prior to stranding. The lack of accurate estimates of timing of stranding and the uncertainty in the time of death means that in all cases this could only provide an approximate search area. However, by running the software for a range of putative collision times it was possible to generate a conservatively wide search area. Where plausible, wind speed and direction were also taken into account when identifying vessels. Again, the lack of precise times for the start and end of drifts means that wind information could either narrow down or in some cases expanded the potential search area depending on the patterns of prevailing winds during the estimated time window. An example for a seal discovered on West Sands, St Andrews, is shown in Figure 1; the monitoring area encompassed the entire bay of St Andrews, and the Eden and Tay estuaries.

As AIS reporting is only mandatory for vessels over 300t and reporting for smaller vessels is voluntary, the coverage for smaller vessels is more sporadic and an unknown proportion of their activity is missed by AIS. Fortunately, the approaches to both Edinburgh and Dundee ports are covered by continuous radar monitoring. Forth and Tay Navigational Services (FTNS) provided access to radar archives whenever a corkscrew seal stranding was reported within their jurisdiction (Figure 2). While specific vessels could not be attributed to individual cases, AIS and radar monitoring was used to provide a list of candidates for each event. The vessel lists were then compared with previous candidate vessels and those with regular or repeated presence during stranding events were flagged. The data presented throughout this report have been anonymised and individual vessels and/or operating companies are not specifically identified in any instance.

The final criterion with which vessels were judged to be candidates was their propulsion systems. From the results of scale model trials presented in Onoufriou & Thompson (2014), certain vessels were discounted from the analysis as they did not have the ducted or cowled propellers thought to be the likely cause of spiral lesions. All candidate vessels were investigated to identify their propulsion system. In all cases tested, this information was readily available through various AIS and shipping web sites. As a result of this filtering exercise most cargo and passenger vessels and small pleasure craft were discounted from the analysis. Fishing vessels do not routinely use AIS transmitters, however, few large fishing vessels operate in the area of interest therefore fishing boats were also



discounted from the analysis.

Figure 1. Minimum AIS monitoring area for a theoretical ‘spiral-trauma seal case’ discovered on West Sands, St Andrews, Fife. Theoretical case location indicated in red with the search area delineated in yellow.

Figure 2. Radar coverage of the Firth of Forth and the Firth of Tay provided by FTNS. Radar stations can be seen in red with coverage areas delineated in yellow.

3.2 Results

3.2.1 Cases reported in 2013 and 2014

Thirty-one stranded seals have been identified as having ‘typical spiral trauma injuries’, which were the primary cause of death, in Scotland, between January 2013 and January 2015. Of these, 13 were juvenile grey seals, 15 were adult harbour seals, 1 was a juvenile hooded seal (*Cystophora cristata*) and 2 were unidentifiable to a species level (Figure 3). Each case from April 2013 onwards was individually analysed to determine the candidate vessels potentially involved in the seal-propeller interactions and examples of associated vessel tracks from various sources are displayed below (e.g. Figure 4). At least one candidate vessel was identified for each case and a catalogue of vessels was kept in order to track future voyages (Table 1).

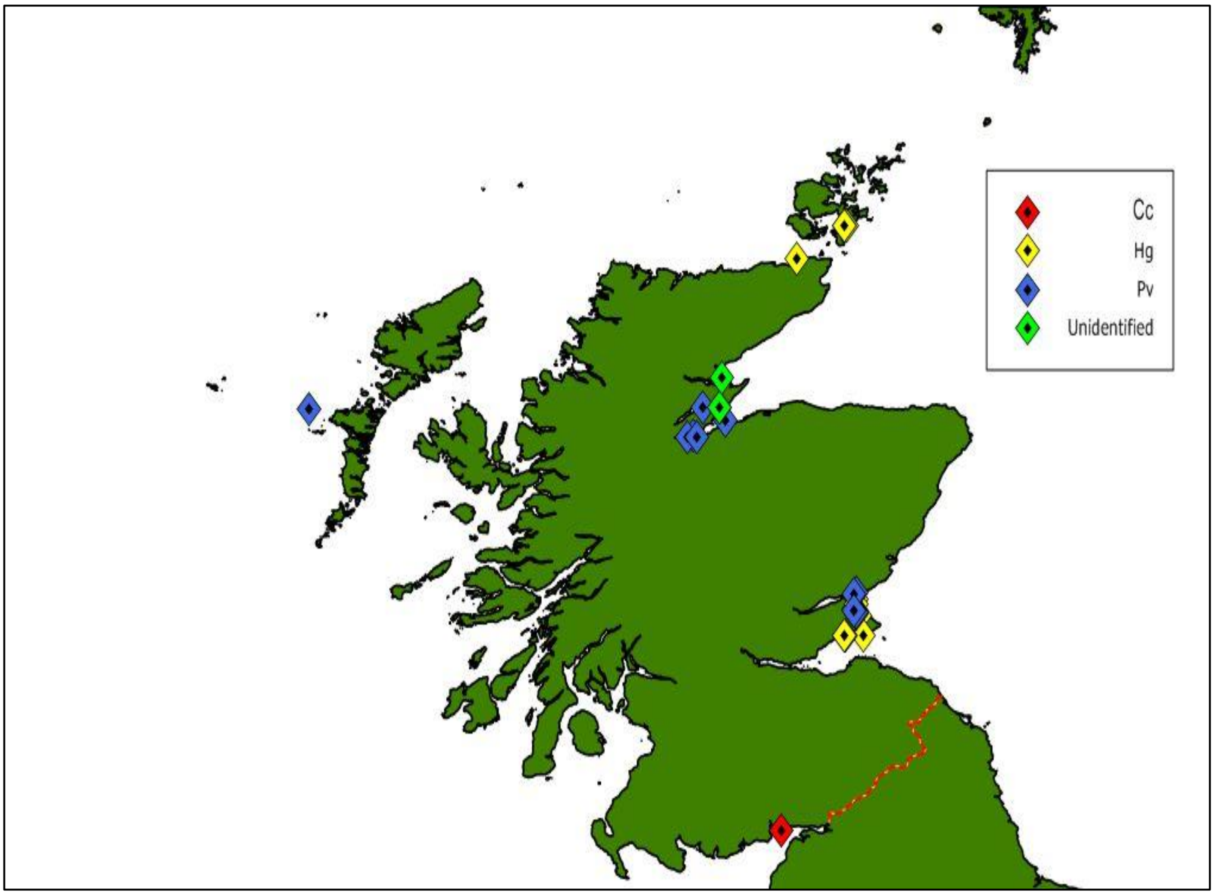


Figure 3. Locations, by species, of all seal strandings exhibiting spiral lesions since January 2013.

3.2.1.1 Example 1: Case M19/14b

Case M19/14b was a female juvenile grey seal discovered on 22/01/2014 in Pittenweem, Fife, with typical spiral wounds. While only the caudal section of the carcass remained in-tact, a single, curvilinear smooth edged wound was evident along with an avulsed left scapula. The relatively high level of autolysis of this case led to an expansive, more wide-spread search of vessel history over the 3 weeks prior to the discovery. The activity patterns of the vessels in the area and the prevailing south-westerly winds over the search period led to a list of five possible vessels. The example tracks below were from vessels that were identified as candidates due to their twin ducted Azimuth propulsion systems and tunnelled bow thrusters, coupled with their continued movement throughout the survey period.

Table 1. Number of identified candidate vessels for each individual case. Rows highlighted with an asterisk indicate instances where at least one candidate vessel was identified in a different case.

Case Number	Species	Date Reported	Location	Latitude	Longitude	Candidate Vessels
M104/13	*Halichoerus grypus*	12/04/2013	Eden Estuary, Fife	56.368816	-2.8213674	3*
M145/13	*Halichoerus grypus*	20/04/2013	Tentsmuir, Fife	56.441952	-2.80323	7*
M182/13	*Phoca vitulina*	30/05/2013	West sands, Fife	56.37083333	-2.8125	7*
M184/13	*Phoca vitulina*	02/06/2013	Eden Estuary, Fife	56.36763	-2.8213593	11*
M200/13	*Halichoerus grypus*	13/06/2013	Tentsmuir, Fife	56.379389	-2.824766	14*
M230/13	*Phoca vitulina*	14/07/2013	Easthaven beach ,Angus	56.47951	-2.8021574	3
M239/13	*Phoca vitulina*	22/07/2013	West sands, Fife	56.346407	-2.8054243	6*
M247/13	*Halichoerus grypus*	25/07/2013	East sands, Fife	56.333293	-2.7783883	6*
M314/13	*Phoca vitulina*	25/09/2013	West sands, Fife	56.35981	-2.8112982	3*
M358/13	*Halichoerus grypus*	03/12/2013	Brough Caithness	58.647544	-3.3450518	2
M388/13	*Phoca vitulina*	19/12/2013	Charlestown, North Kessock	57.504384	-4.2730612	4
M19/14b	*Halichoerus grypus*	22/01/2014	Pittemween, Fife	56.209992	-2.744241	5*
M23/14	*Halichoerus grypus*	24/01/2014	Lower Largo, Fife	56.209546	-2.9065266	5*
M3/14	*Phoca vitulina*	04/01/2014	Whiteness Head, Arderseir	57.599024	-3.9894393	2
M128/14	*Halichoerus grypus*	27/05/2014	Tentsmuir, Fife	56.410085	-2.8102612	1
M148/14	*Phoca vitulina*	17/06/2014	Invergordon	57.683823	-4.1930989	5
M153/14	*Phoca vitulina*	20/06/2014	Beauly Firth	57.495047	-4.3234315	5*
M182/14	*Phoca vitulina*	27/06/2014	Beauly Firth	57.81906	-4.937144	5*
M185/14	*Phoca vitulina*	13/07/2014	South Kessock	57.49443	-4.2463751	4
M180/14	*Halichoerus grypus*	08/07/2014	Lower Largo, Fife	56.209546	-2.9065266	8*
M186/14	*Phoca vitulina*	15/07/2014	Monifieth Beach	56.477408	-2.8248293	8*
M187/14	*Halichoerus grypus*	12/07/2014	Lower Largo, Fife	56.210475	-2.9098052	8*
M249/14	*Phoca vitulina*	05/09/2014	Cromarty	57.679328	-4.0402469	5
M310/14	*Phoca vitulina*	21/10/2014	West sands, Fife	56.363807	-2.8237334	6*
M252/14	Pinniped (indeterminate)	08/09/2014	Cromarty	57.68219	-4.0382441	3
M382/14	*Halichoerus grypus*	01/12/2014	Burray	58.857644	-2.8910345	4

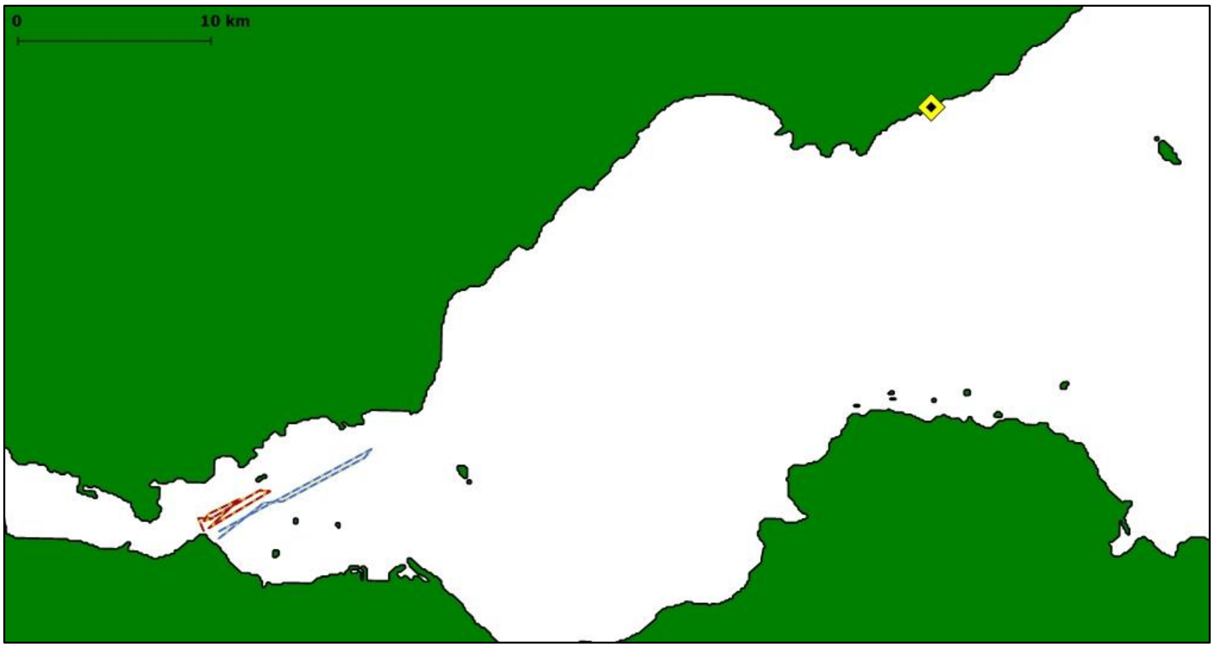


Figure 4. Stranding location of case M19/14b (yellow diamond) and position history of 2 buoy tug vessels (red and blue tracks) on 17/01/2014. Vessel data generated by Marine Traffic.

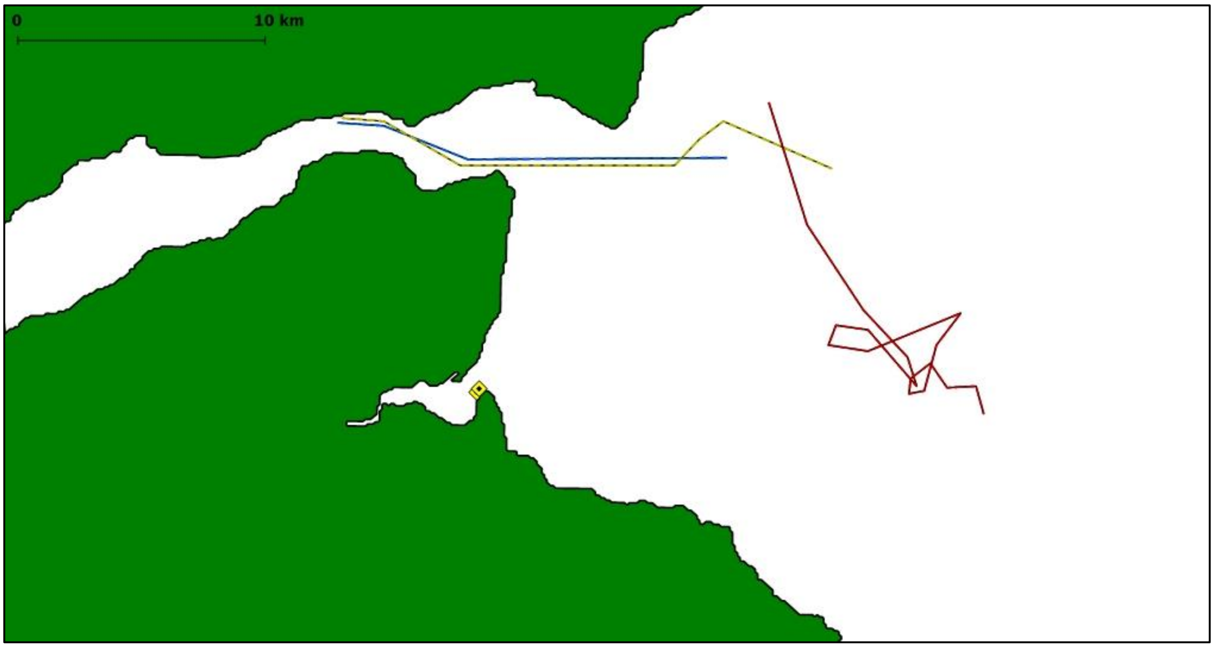


Figure 5. Locations of cases M182/13 and M184/13 (yellow diamonds) and position history for three vessels identified as candidates for cases M182/13 and 184/13 on 29/05/2013. The vessels can be seen to exit the mouth of the River Tay. The yellow track refers to the near identical tracks of five vessels, all of which were supporting the movement of an oil rig into the Tay Estuary. The vessel data was generated by Marine Traffic.

3.2.1.2 Example 2: Cases M182/13 and M184/13

Case M182/13 was a pregnant, adult female harbour seal reported dead stranded on 30/05/2013. The carcass displayed a single, curvilinear laceration rotating once around the body, avulsed scapula and a severed trachea. Case M184/13 was an adult male harbour seal found dead stranded on 06/05/2013 with a single, smooth edged wound which was restricted to the region above the pectoral flippers. Although the lesion was not a full spiral laceration the wound demonstrated sufficient similarities to a typical corkscrew injury that it was included in the analysis. These cases were coupled in this example due to their similarity in both location (at the mouth of the Eden Estuary) and time of death estimate (Figure 5).

Seven vessels were identified as candidates due to their various ducted propulsion systems and activity around the Tay and Eden estuaries within the survey period (Figure 5). The tracks were taken from archival data from 29/05/2013 on Marine Traffic and detailed vessel movements one Day and seven days prior to the discovery of cases M182/13 and M184/13 respectively.

3.2.1.3 Example 3: Case M128/14

Case M128/14 was a female, juvenile grey seal reported dead stranded with spiral lacerations on 27/05/2014. This case was of particular interest due to the unusual time of year for a grey seal stranding report (grey seals with spiral lesions are typically reported during the winter months) and the fact that time of death was known to a more accurate degree than usual; the individual was a study animal at the SMRU captive facility and had been released 3 days prior to stranding. The survey period for this case was consequently 3 days and results were more concise and localised than other cases. Only one vessel was identified as a candidate with no other vessels demonstrating behaviour which could lead to an interaction under the assumptions used (Figure 6).

Figure 6. Tracks from a single, candidate workboat on 24/05/2014. The blue tracks indicate data retrieved from ShipAIS©. The red track indicates the data gathered from radar and AIS data from FTNS Grangemouth. The stranding location is indicated with a yellow diamond.

3.3 Conclusions

The ability to identify candidate vessels for each individual stranding event, while not evidence that shipping interactions are the cause of spiral lacerations, at least indicates that a seal-boat interaction could have occurred at a time and place such that it was a possible cause for a particular spiral laceration. In all but one case, multiple candidate vessels were identified and usually close association of groups of vessels could be seen. The outlying case, in which a single vessel was identified, occurred with a more specific estimation of time of death than all other cases. This result highlights the importance of discovering cases soon after they strand especially for recently killed seals. AIS history becomes increasingly diluted with time and a more precise idea of relevant vessel activity can be obtained in the event of early discovery. An important conclusion of this ongoing observational project is therefore the need to continually improve strandings reporting and response.

The identification of smaller vessels with intermittent AIS transmission as candidates in some cases relied entirely on local observers being aware of arrival and departure times.

The existing current/tide models provide inaccurate results when attempting to predict water movements in close proximity to the shore and this makes it difficult to back trace movement in coastal areas. Consequently the search areas demonstrated above are expansive as a conservative approach was required. Further work would need to be conducted to assess the oceanographic systems and topographical nature of various stranding locations to more accurately determine likely locations of seal-boat interactions to produce a more definitive list of candidate vessels. Identification of specific vessels in even a small number of cases would provide a greater understanding of the means by which seals are potentially attracted to and interact with any mechanism which causes spiral lacerations.

While it is not yet confirmed that shipping interactions are the cause of spiral lacerations in seals, a larger sample size of recently dead individuals with these lesions would be beneficial in determining the extent and cause of the phenomenon and highlights the value of continued monitoring.

The results do not as yet allow the identification of any specific vessels as the source of individual spiral wounds in any specific cases. However, the repeated occurrence of particular vessels may make it possible to target any potential future vessel based observer programmes to maximise the likelihood of witnessing and recording such events.

4 Investigating ship seal interactions on a broad, nationwide scale

4.1 Methods

To estimate relative encounter probability rates between seals and shipping traffic, two modelled data sources were used: seal usage maps and ship density maps, and overlaid these with the locations of strandings.

4.1.1 Seal usage maps

Seal usage maps have been produced for both grey and harbour seals around the UK at a $5x5km^2$ resolution. Telemetry data from 259 grey seals and 277 harbour GPS-tagged seals deployed between 1991 and 2013 were synthesised with terrestrial counts between 1996 and 2013. Telemetry data were regularised to reduce sampling bias. Haul-out locations provided a link between telemetry data on individuals and regional terrestrial counts allowing the maps to be scaled to current (2013) population levels (Jones et al. In review). Tracks were kernel-smoothed and weighted for each animal. Plausible null-usage maps were derived for each haul-out site where population data were available and incorporated into the telemetry maps (Jones *et al*., in review). Figure 8shows data processing steps undertaken to produce each species map.

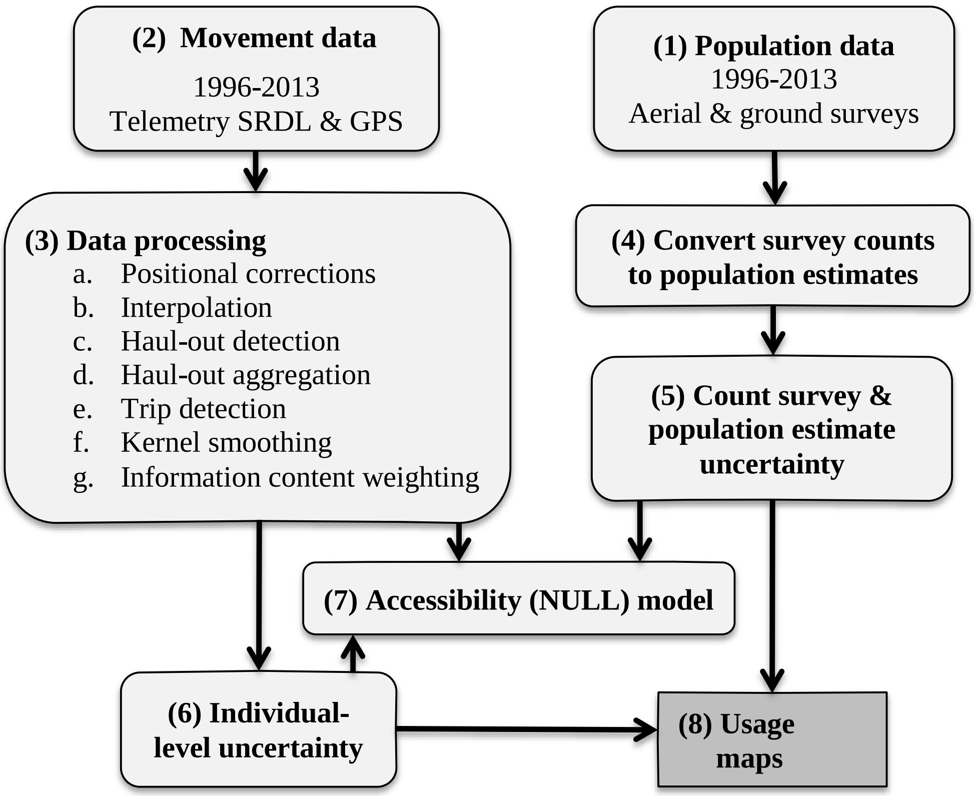


Figure 8. Flowchart representing high-level analytical methodology of seal usage maps (taken from Jones *et al*., in review).

4.1.2 Ship density maps

The Marine Management Organisation (MMO) contracted ABP Marine Environmental Research Ltd (ABPMer) to produce density maps from Automatic Identification System (AIS) ship tracking data for 2011 and 2012 (MMO 2014a, b, 2013a, b; Marine Scotland, 2014). Positional data were supplied by the Maritime and Coastguard Agency (MCA), collected by their network of UK receiving stations (Figure 9). The likely range of the land-based receiving stations for AIS is 40 nautical miles (ranging from 20 to 350 nautical miles), meaning there will be increasing under-estimation of shipping density further away from land, beginning at 20 nautical miles out to sea. AIS data were used over a timeframe of 12 UK-wide, 7-day periods. The data sets were sampled from the first 7 days of each month, commencing in January, at 2-month intervals during 2011 and 2012. Track lines were summarised as a scaled density grid of $2x2km^2$ to represent 'weekly density'. AIS-A data were defined as being "carried by international voyaging ships with gross tonnage (GT) of 300 or more tonnes, and all passenger ships regardless of size" (MMO, 2014b). AIS-A data were verified again using the Port of Southampton VTS database, which showed that approximately 16% of the vessels shown in the VTS database were not identified in the dataset. An overall confidence assessment concluded there was a 2% AIS misclassification rate (recorded vessels were not the ship type identified in their transmission). Stationary vessel positions were not included in the analysis. Data processing to translate the raw AIS locations into a $2x2km^2$ density surface is summarised in Table 2. The spatial extent of 2011 data did not extend to northern Scotland, and neither 2011 nor 2012 data extended to western Ireland.

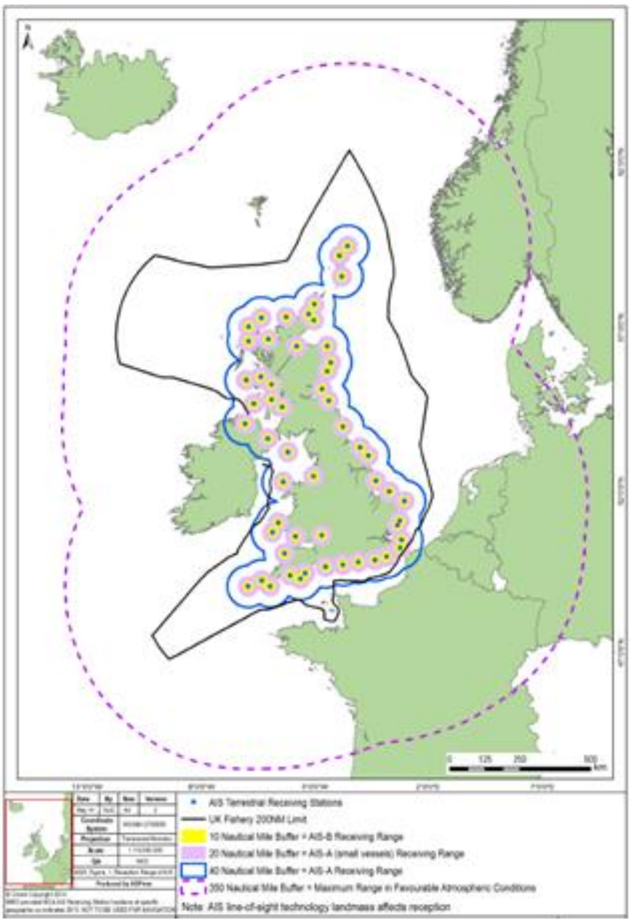


Figure 9. Receiving stations around the UK, covering 47% of UK waters to the boundaries of the UK continental shelf (taken from MMO 2014b).

Table 2. Summary of AIS shipping data processing.

Stage 1	• Decoding and sorting of AIS signal (positional reports and voyage information). • Associating ship static and voyage information with positional reports for each vessel.
Stage 2	• Identification of vessel transits. • Quality assurance of vessel transit lines. • Transit simplification. • Identification and reporting of vessel AIS processing statistics.
Stage 3	• Plotting of vessel transits in GIS. • Spatial QA of transit lines to remove overland transit segments. • Identification of vessel transit start/finish points within regional zones. • Validation and correction of vessel information against a third party vessel statistics database.
Stage 4	• Calculation of Vessel Transit Classification (VTC). • Creating density grids. • Calculating temporal differences. • Calculation of regional shipping statistics.

Density grids for 2011 and 2012 were produced by vessel type (Table 3). Only density grids of the following vessels were selected: Non-Port service craft (1), Port service craft (2), Vessels engaged in dredging or underwater operations (3), Military or law enforcement vessels (5), Cargo vessels (7), and Tankers (8). These layers were then aggregated and the resulting weekly density was multiplied by 52 to give an annual shipping density.

Table 3. AIS data vessel groupings (taken from MMO, 2013b).

Group	Type	Description
0	Unknown	
1	Non-port service craft	Search and rescue vessels Towing and Towing where length of tow exceeds 200m or breadth exceeds 25m Medical transports (as defined in the 1949 Geneva Conventions and Additional Protocols) Ships according to resolution No. 18 (Mob-83) Other special craft (56 & 57 reserved for local use)
2	Port service craft	Pilot vessels Tugs Port genders and vessels with anti-pollution facilities or equipment
3	Vessels engaged in dredging or underwater operations	Vessels engaged in dredging or underwater operations Vessels engaged in diving operations (see note)
4	High speed craft	
5	Military or low enforcement vessels	
7	Cargo vessels	
8	Tankers	
9	Fishing	Fishing vessels
10	Sailing and pleasure craft	Pleasure craft Sailing vessels

Note ‘Vessels engaged in diving operations’ are predominantly commercial diving operations, for example, related to underwater maintenance

Ship density and seal usage maps were assessed to ensure that: (1) They could be overlaid accurately, (2) they represented analogous information, and (3) any limiting factors could be determined (Table 4). To calculate relative encounter probabilities, all data layers needed to be at the same resolution. Ship density maps were scaled from 2x2km^2 resolution to the same 5x5 km^2 resolution as the seal usage maps. Both data layers were originally projected in Universal Transverse Mercator 30° North, datum World Geodetic System 1984 (UTM30N WGS84) and this projection was used for the analysis. Although uncertainty was quantified for seal usage, this was not the case for ship densities, so uncertainty could not be used in this analysis. The spatial extent of the analysis was limited to the likely range of the ship density maps (40 nautical miles from the coast, varying from 20 to 350 nautical miles). Finally, ship density maps were produced for shipping traffic in 2011 and 2012, whereas the seal usage maps show the 2013 estimated population of grey and harbour seals (Jones et al. In review). Although this is not a direct temporal overlap, it is assumed that they represent synoptic usage.

Table 4. Summary of the assessment between AIS ship density maps and seal usage maps.

Metric	Ship density maps	Seal usage map	Consolidate/mitigation measure
Grid cell resolution	2km^2	5km^2	Ship density maps were rescaled to match seal usage maps.
Uncertainty	No uncertainty quantified	Uncertainty maps	Encounter probability and comparison analysis did not use uncertainty.
Analyses metrics	Weekly density	Yearly density	Shipping data were rescaled to reflect yearly densities.
Spatial extent	~40 nautical miles from the coast	~162 nautical miles from the coast	Comparison will only have spatial extent of ship density maps.
Track regularisation	Data are thinned (not regularised) and processed accounting implicitly for locational error	Tracks regularised to 2-hourly intervals	Although these analyses are not produced in a similar manner, the end product were 2 yearly densities of shipping and seals, so were comparable.
Projection	UTM30N WGS1984	UTM30N WGS1984	Same projection
Timescale	2011 (England and Wales only) and 2012	Reflects current (2013) usage	Cannot consolidate this any further.

4.1.3 Strandings

Stranding data were collected opportunistically and a database is maintained by SMASS and SMRU. These data were overlaid onto the maps of relative encounter rates to produce a qualitative assessment of overlap. Sampling effort was variable around the coast and unquantified. Well sampled areas were around St Andrews Bay, east Scotland and the coast of Norfolk. However, each identification is by its nature an opportunistic sighting in areas either accessed by members of the public (e.g. dog walkers) or as part of other scientific studies (e.g. Moray Firth seal monitoring program). Therefore, remote sections of coastline were not be surveyed, producing variable and biased sampling effort. Locations of stranded grey (n=85) and harbour (n=71) seals whose deaths were attributed to "physical trauma with 'spiralled' lesions" through post-mortem, were collected from 2007-2014 (and 2 harbour seals in 1985).

4.1.4 Relative encounter probabilities

The expected fatalities occurring per day in a grid cell is S_iB_iQ, where S_i is the number of seals present in grid cell i; B_i is the number of boats present in grid cell i; and Q is the constant probability that the seal will be involved in a collision with a boat in one day. However, Q is unknown, so the relative encounter probability P_E was calculated as S_iB_i (see Appendix for details).

4.2 Results

The estimated at-sea usage for grey and harbour seals at 2013 population levels were used (Jones et al. In review) (Figure 10). Figure 11 shows the original weekly shipping densities for 2011 and 2012. Figure 12 shows average yearly shipping densities from selected vessel groupings at 5x5km^2 resolution. Shipping traffic around the UK was primarily within 100km of the coast, with the heaviest consistent densities on the south coast of England, in the English Channel and the mouth of the Thames. Although the AIS receiver stations have limited range, Figure 12 shows shipping density out to approximately 500km from the coast.

Figure 13 shows the relative encounter probabilities for grey and harbour seals in 2011 and 2012 overlaid with stranding data locations. Broadly, spatial patterns are similar between years for both species. Therefore, the text will concentrate on 2012 analysis as the relative encounter probabilities could be calculated for all of Scotland (Figure 13b and Figure 13d). For both species, areas of highest incidence between seals and shipping occur within 50km of the coast and coincide with areas of high seal usage. For grey seals (Figure 13b), high relative encounter probabilities and strandings (n=13 between 2007 and 2014) coincide in Orkney, and to a lesser extent in the Eden Estuary and Forth of Firth (n=46 between 2009 and 2014). For harbour seals (Figure 13d), stranding locations (n=20) and high encounter probabilities overlap in The Wash, East Anglia. With the exception of these areas, there does not appear to be a relationship between stranding locations and areas of high incidence of seals and shipping.

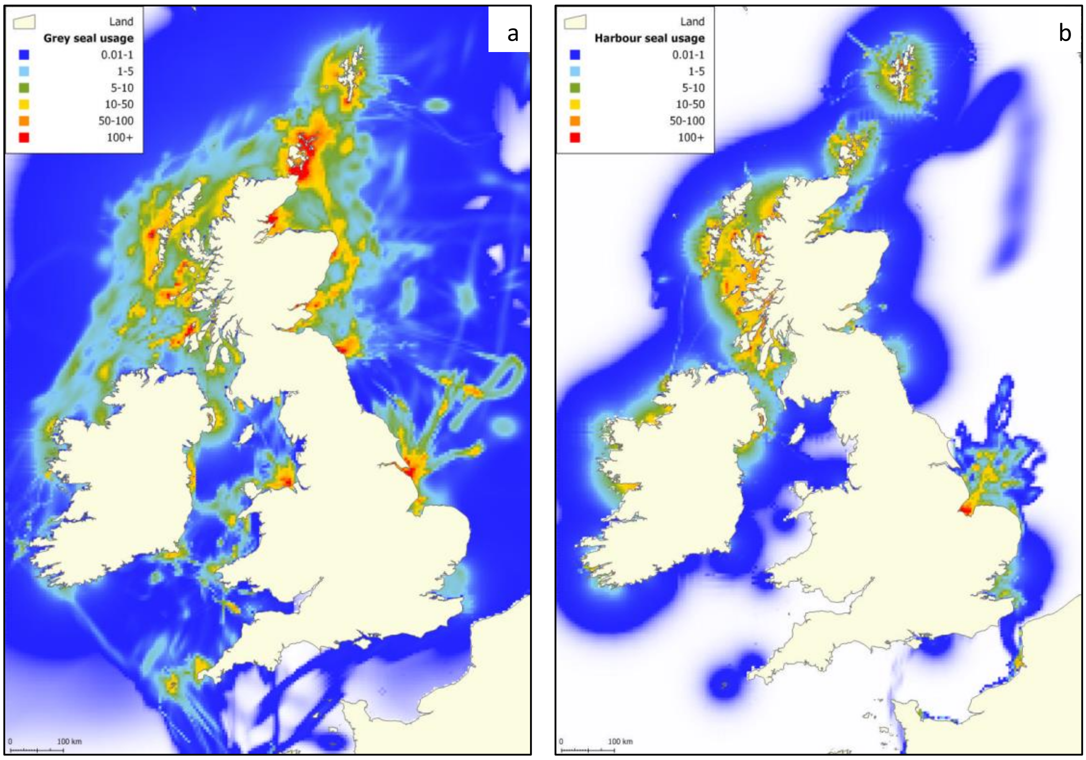


Figure 10. At-sea seal usage maps. (a) grey seals; (b) harbour seals; showing the predicted number of seals in each 5x5km^2 grid square using the most current count data available (e.g. a yellow square denotes between 10 and 50 seals are within that grid square).

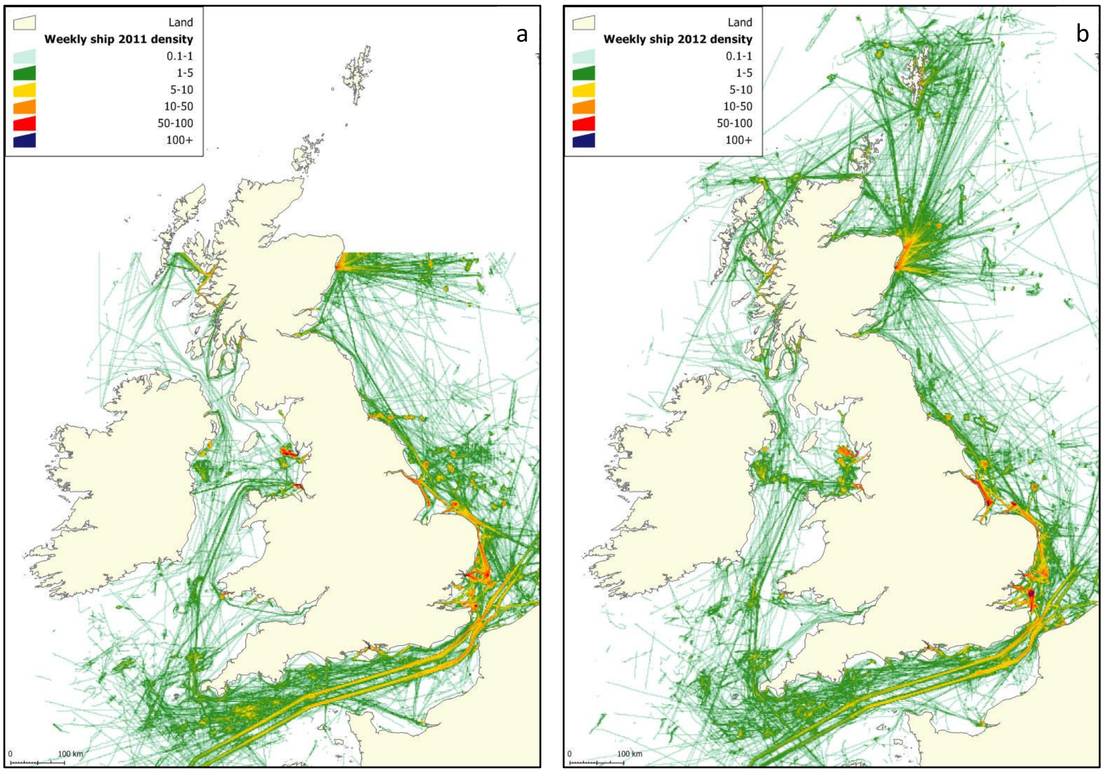


Figure 11. Weekly ship density maps using AIS data. (a) 2011; (b) 2012; showing the estimated number of vessels in each 2x2km2 grid cell (e.g. a yellow square denotes between 5 and 10 vessels will be found within that grid square at any given week).

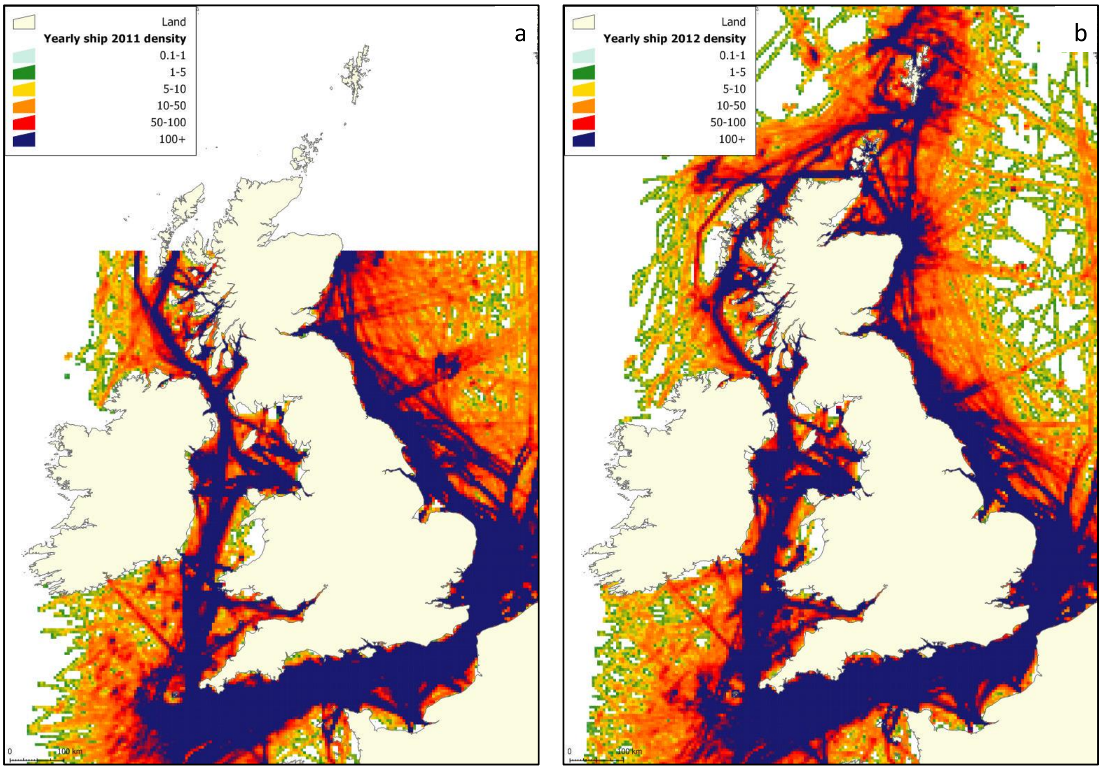
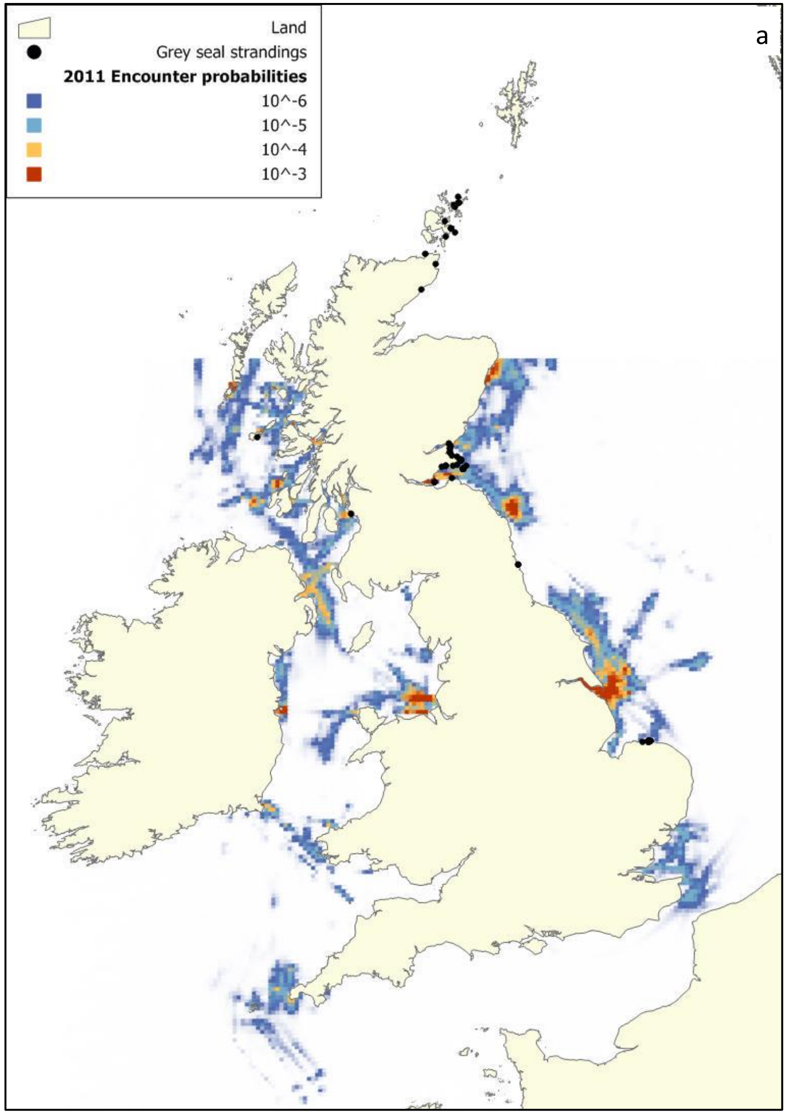
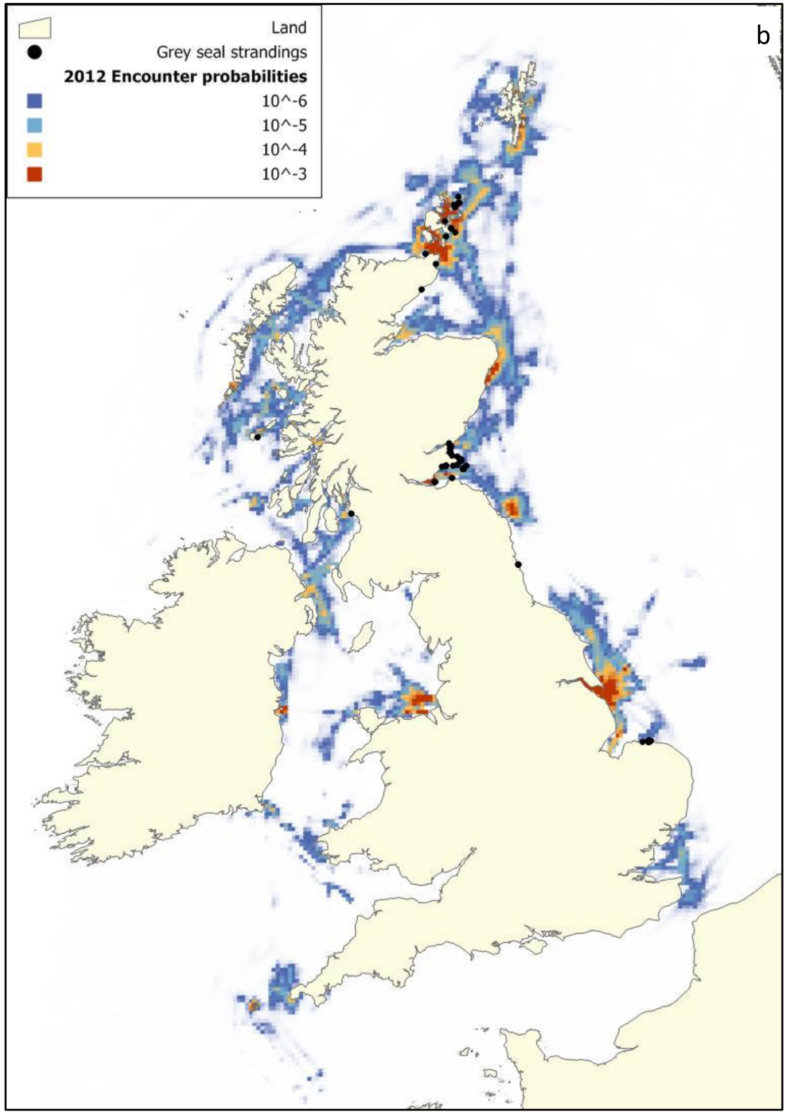


Figure12. Average yearly ship density for (a) 2011; (b) 2012; showing the estimated number of vessels in each 5x5km2 grid cell for each year (e.g. a red square denotes between 50 and 100 vessels will be found within that grid square).


Land
Grey seal strandings
2011 Encounter probabilities
10^-6
10^-5
10^-4
10^-3
a


Land
Grey seal strandings
2012 Encounter probabilities
10^-6
10^-5
10^-4
10^-3
b

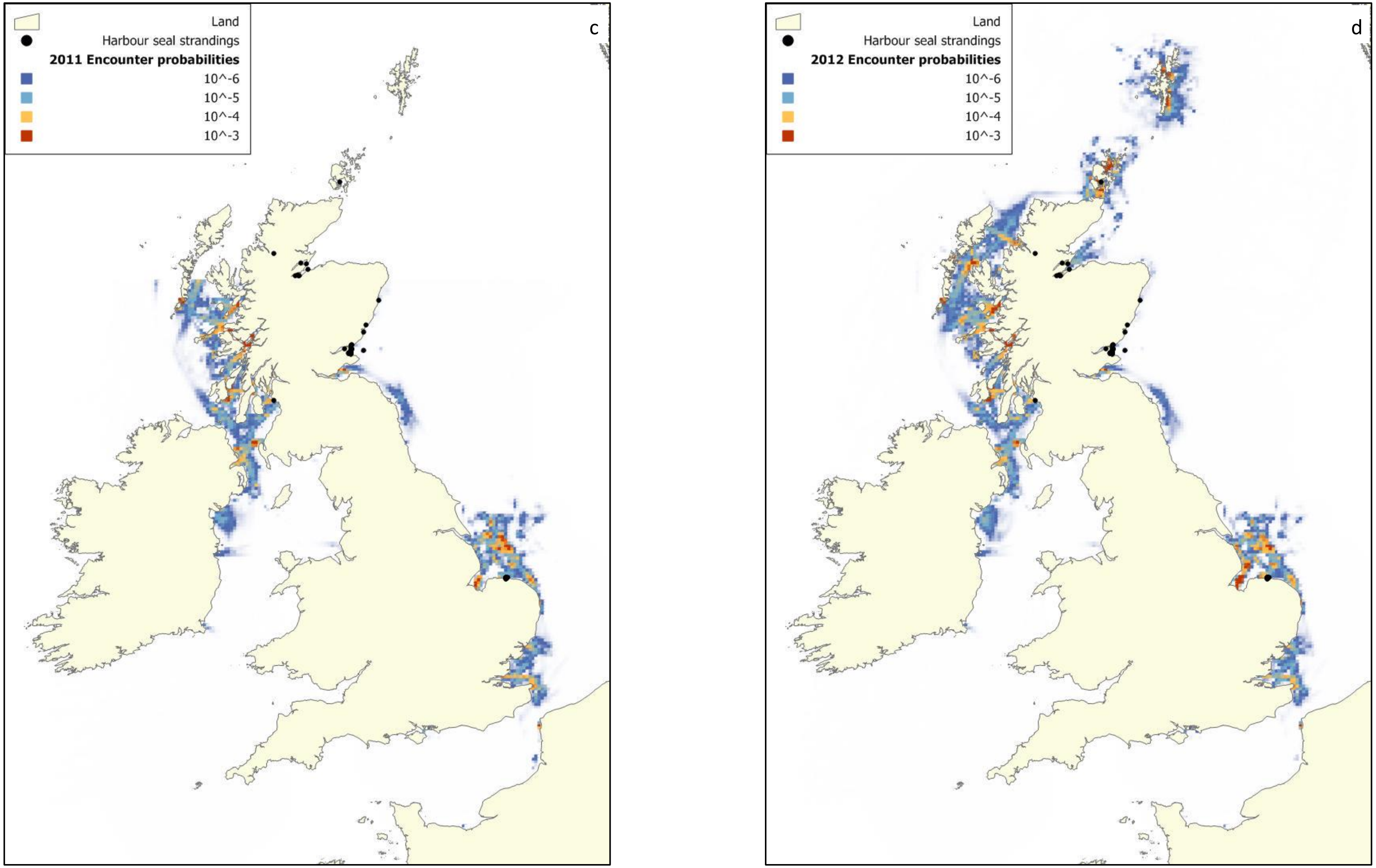


Figure 13. Relative encounter probabilities between grey seals (2013) and shipping traffic in (a) 2011 and (b) 2012; and between harbour seals (2013) and shipping traffic in (c) 2011 and (d) 2012; at 5x5km2 resolution. Red indicates areas of high incidence.

4.3 Conclusions and recommendations

Areas with high relative encounter probabilities are within 50km of the coast. This means that if seal-shipping interactions cause fatal corkscrew injuries to seals, these will most likely occur relatively close to the coast. A recommendation is to continue to develop a land-based observer network.

However, there appears to be little or no correlation between high relative encounter probabilities between seals and ships, and the locations of stranded animals.

Areas of high relative encounter probability are, by definition, where there are also large aggregations of seals. However, due to sporadic sampling, strandings in some of these areas may not have been recorded.

Possible post-mortem carcass movement due to environmental factors such as tides and currents is currently not accounted for. This means that it is not possible to assess whether stranded animals are found close to where they were killed or whether they have drifted. In some cases it may be possible to model possible carcass drift movement to more accurately locate the source of these fatal injuries (e.g. vessel simulator software, BMT Argoss software) although this is limited by the absence of accurate time of death and time of stranding information.

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6 Appendix

Collision Risk through spatial overlap

If a seal is in a grid square and one boat is present, the probability that the seal will be involved in a collision with that boat in a unit time interval (say 1 day) is Q. Q is assumed to be small.

The probability that a seal will NOT be involved in a collision is then 1-Q

If there are B boats in the area, the probability of a seal avoiding collisions is $(1\text{-}Q)^B$

If there are S seals in the area, the expected number of seals avoiding collisions is $S(1\text{-}Q)^B$

Q is small and a Taylor expansion is done around Q=0 for the number of surviving seals:

$f(q) \sim f(0)+(q-0)f'(0)+\ldots$ { terms involving higher powers of q are ignored}

$= S(1-0)^B - SB(1-0)^{B-1}(Q-0)+ \ldots$

$= S – SBQ$

So an expression for expected seals surviving 1 day is obtained, which is S(surviving)=S-SBQ

And expected fatalities per day would be S-S(surviving) = SBQ

Therefore, where collision risk is low, the quantity SB can be used as an indicator of the **relative** level of collision risk in one area compared with another. *However, only relative levels can be indicated as Q is currently not known.*