A CONTRIBUTION TO pMPA DISCUSSIONS

Identifying zones where basking sharks occur more frequently within a possible MPA to aid management discussions

For further information on this report please contact:

Dr Suzanne Henderson
Scottish Natural Heritage
Great Glen House
INVERNESS
IV3 8NW
Telephone: 01463 725238
E-mail: suzanne.henderson@nature.scot

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Identifying zones where basking sharks occur more frequently within a possible MPA to aid management discussions

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Summary

Scottish Natural Heritage (SNH) has provided advice on four Marine Protected Areas (SNH 2014) to Scottish Government, and a public consultation on these possible MPAs (pMPA) is planned in 2019. One of these pMPAs is the Sea of the Hebrides, which includes the protected feature, basking sharks as well as minke whale, oceanographical fronts and the geomorphological feature Inner Hebrides Carbonate Production Area.

To help inform potential advice given by SNH on management of the Sea of the Hebrides pMPA, and to assist in discussions with stakeholders, existing data sources were collated and analysed for basking sharks in the pMPA. Two options of *basking shark awareness zones* were identified based on these data. These are zones where sharks are expected to occur most frequently in relatively high numbers and are therefore most vulnerable to certain human activities. The basking shark awareness zones options presented provide a starting point for discussing potential management with stakeholders through the public consultation process.

For further information on this project contact:
Name of Project Manager – Dr Suzanne Henderson
Tel: 01463 725238
For further information on the SNH Research & Technical Support Programme contact:
Knowledge & Information Unit, Scottish Natural Heritage, Great Glen House, Inverness, IV3 8NW.
Tel: 01463 725000 or research@snh.gov.uk

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1. INTRODUCTION

This report collates and interprets datasets on basking shark distribution within the Sea of the Hebrides possible Marine Protected Area (pMPA) to delineate areas where the species is most likely to be present, both at the surface and at depth, and thus potentially vulnerable to:

i. Vessel collisions - hull and propeller strike
ii. Accidental fisheries catch - entanglement in static and mobile fishing gear
iii. Disturbance from vessels

We have analysed multiple, independently collected, datasets that describe basking shark presence across the entire Sea of the Hebrides over 20 years. All ecological datasets have inherent biases and limitations, but by using diverse datasets with a broad spatial and temporal range, we have provided an enhanced understanding of basking shark distribution. By mapping basking shark presence in surface waters, the location of potential 'basking shark awareness zones' has been proposed, which identify where the species is most vulnerable to the pressures identified above. This work and the awareness zones produced can facilitate pMPA management discussions with the intention that possible management measures may then be considered within the basking shark awareness zones. Interrogation of depth-use data was also undertaken to determine whether zones of higher use could be identified in the water column in addition to surface waters.

2. METHODOLOGY

2.1 Rationale for approach

The development of evidence-based awareness zones requires datasets that contain basking shark locations that overlap with the pMPA between May and October (reflecting our current understanding of basking shark occupancy within the Sea of the Hebrides based on public sightings and satellite tracking data; Annex 2&3). There are currently no comprehensive, repeated inter- and intra-annual aerial or sub-surface surveys for basking sharks in the Sea of the Hebrides. This would be the ideal method to locate areas of high relative density, but such surveys are expensive and time consuming to collect and hence have not been undertaken. Instead, there are a range of datasets, collected by different organisations, at different periods, with differing biases, that can be used to determine relative basking shark abundance and distribution. The spatially explicit high relative abundance zones from each dataset can be overlaid to investigate consistency in basking shark presence between years and parts of the Sea of the Hebrides pMPA. High relative abundance zones that are consistently indicated in multiple datasets are most likely to represent areas where sharks are predictably and repeatedly present. Thus, if we wish to reduce risks, such as from vessel collision and accidental capture/entanglement by fisheries, these are potential candidate areas for conservation action. In addition, sharks aggregating in high densities at such sites may be doing so for courtship and mating, such that disturbance may have considerable effect on life history processes. The multi-dataset approach presented here is conservative, but provides a complete picture of basking sharks in the pMPA.

2.2 Data sources used

A survey of known spatial datasets describing basking shark occurrence around Scotland was undertaken (Table 1); such datasets were subsequently prepared and mapped. The datasets vary in how they were collected and subsequently treated for follow-on analysis.

First, the effort spent to observe sharks during standard surveys for marine life can be quantified, meaning that the data can be expressed as relative abundance (i.e. a sighting of a single shark alone during a standardised survey suggests that there was only one shark present at the surface / low density of sharks at that same time and place). The effort spent to observe sharks by the public (e.g. Table 1F), or using satellite tracking, where basking sharks may spend long periods underwater without sending location data (e.g. Table 1G) cannot be quantified, and these data are typically treated as presence only data with no accompanying estimate of abundance (i.e. a sighting or location from one shark does *not* necessarily suggest that more sharks may have been present at the same time and place). Secondly, the spatial coverage of data can vary enormously. Public sightings data have a huge spatial coverage at fractional expense, while standardised surveys may be very focused on specific target sea areas, but at considerable expense.

For the purposes of the present report, we considered that standardised surface surveys for basking sharks could be used where they covered much of the spatial extent of Sea of the Hebrides pMPA. These data provide synoptic coverage for the site and suffer from only minor limitations in survey coverage. Hence any differences in sightings density between regions should reflect the true distribution of animals and should not be an artefact of survey effort. Data collected by the Hebridean Whale & Dolphin Trust and Wave Action (Table 1A & B) have been used in a previous SNH report (Paxton *et al*. 2014) to generate an index of predicted basking shark surface persistence certainty (i.e. the chances that a basking shark would be present at the surface), and thus to avoid duplicating data, we have used the modelled Paxton product, rather than the original survey data in analyses. We have not directly used sightings data from a boat-based survey by Scottish Power Renewables for the proposed Argyll Array in 2012 because of its limited spatial extent to the west of the island of Tiree (Booth et al. 2013), although these are important contextual data. We considered that data with unquantifiable survey effort (e.g. public sightings) could be used, if they also covered the majority of the Sea of the Hebrides. These encompassed public sightings data gathered by the Marine Conservation Society UK (https://www.mcsuk.org/sightings) as well as locations of basking sharks from satellite tracking (Doherty *et al*. 2017a, b; Witt *et al*. SNH report 752 & 908). Finally, data describing basking shark breaching behaviour from accelerometry tags deployed in 2017 (Table 1H) and aggregation behaviour from towed video tags deployed in 2018 (Table 1I) were not used in the formal spatial analyses because of their limited spatial extent west of Tiree. While behavioural data like these cannot be easily integrated in to spatial distribution analyses, they can provide important contextual data on: (i) why basking sharks might occupy regions within the pMPA (e.g. for breeding, mate finding and feeding), (ii) information on specific habitat preference (e.g. habitat type) and (iii) likely types of behaviour that may be susceptible to disturbance.

Table 1. Sources of data describing basking shark presence in the Sea of the Hebrides. Table shows the data name and details, the time period over which the data were collected, the spatial scale and notes about its inclusion for spatial analysis.

Data name	Period	Spatial extent	Used in spatial analysis to produce awareness zone(s)
A. Hebridean Whale & Dolphin Trust (HWDT) boat-based survey for Minke whales and basking sharks	2003 to 2011	West Scottish seas	Not directly used as incorporated in Paxton *et al*. persistence index
B. Wave Action boat-based survey for basking sharks (Colin Speedie and Louise Johnson)	2002 to 2006	Sea of the Hebrides	Not directly used as incorporated in Paxton et al. persistence index
C. Index of predicted basking shark surface persistence certainty based on HWDT and Wave Action basking shark data, with environmental data, created using Generalised Estimating Equations (Paxton et al. 2014. CR594)	2001 to 2012	National to 12 nm	Data used in spatial analysis
D. Hi-Definition aerial camera survey for basking sharks of the proposed MPA in the Sea of Hebrides by a Cesna 406 aircraft flying at 610 m above sea surface at 220 km/hr (3 surveys flown)	2016	Sea of the Hebrides	Data used in spatial analysis
E. Scottish Power Renewables boat survey for basking sharks	2012	West of Tiree	Data not used due to limited spatial extent, but used as contextual layer
F. Public sightings of basking sharks, collated by the Marine Conservation Society	1998 to 2013	National to 12 nm	Data used in spatial analysis
G. Satellite tracking of basking sharks using Smart Position Only Tags (SPOT, n=34 sharks, funded by Scottish Natural Heritage 33 tags, and the Marine Conservation Society 1 tag)	2012 to 2015	National to 12 nm	Data used in spatial analysis
H. Archival pop-off tracking of three basking sharks using Daily Diary accelerometer tags, providing data on where breaching behaviours take place	2017	West of Tiree	Data not used due to limited spatial extent, but used as contextual layer
I. Archival pop-off towed cameras attached to three basking sharks, providing details of where basking sharks aggregate	2018	West of Tiree	Data not used due to limited spatial extent, but used as contextual layer

2.3 Spatial analysis

In order to delineate possible basking shark awareness zones within the pMPA, we combined the modelled persistence, aerial survey, public sightings and satellite tracking data. First, we created a raster of 1x1 km grid cells across the entire pMPA region (see methodology schematic; Fig. 1). Then, for aerial survey, public sightings and satellite tracking data (Fig. 2-4) we created kernel density estimates from basking shark locations using a quartic kernelling approach. We optimised the smoothing parameter and grid cell size and extents across all three datasets to a bandwidth of 10 km on a 2.5x2.5 km grid. We then extracted the 50% kernel density estimate from the three datasets, which indicate that at least 50% of the most densely aggregated location data for each dataset occur within that defined area (Fig. 2-4), and re-mapped these final kernel density estimates using the initially established template raster (1x1 km grid cell size). A 50% kernel density estimate was selected as this is common practice in ecological studies seeking to determine core animal distribution. For modelled persistence, we calculated the median value of all grid cells (equivalent to 593 in scaled units) within the Sea of the Hebrides pMPA, and retained all cells of this value and higher (Fig. 5). These cells have persistence values greater than the median persistence value within the region, and this is analogous to identifying regions using a threshold approach such as the 50% kernel density estimate used above. The resulting modelled persistence regions were then expressed on a 1x1 km grid. The results of the first stage of analysis were four raster datasets with the same spatial resolution and extent. Once converted to binary form, these datasets (0 for all cells outside the 50% region and 1 for cells within the 50% region) could be spatially summed (Fig. 6). The maximum possible value for any grid cell within the final spatial product was four (i.e. where all four datasets had spatially co-occurring regions greater than the 50% threshold). No dataset-specific weightings were applied prior to summing the binary surface maps. All analyses were conducted in MATLAB (The MathWorks), R (R Foundation) and ArcGIS (ESRI).

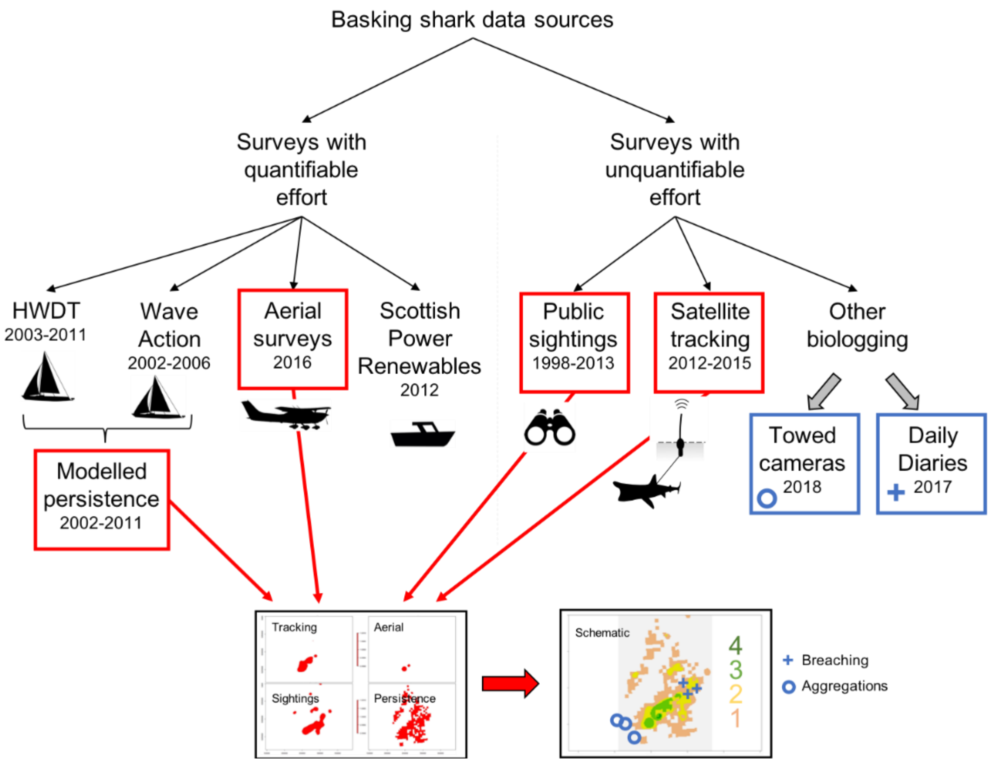


Figure 1. Schematic showing source data used to create a putative basking shark awareness zone. Source data selected for analyses are highlighted in red (resultant schematic maps of their 50% kernel density estimates shown). The four source datasets are combined to create a final raster (bottom right) where colours indicate the number of datasets that were present for each grid cell.

2.4 Alternative options around thresholds and dataset overlaps

A variety of thresholds could be used to determine regions of high relative abundance within each basking shark distribution dataset. The adopted threshold (50% kernel density for public sightings, satellite tracking and boat-based survey datasets), and 50^{th} percentile (median) value for modelled persistence, represents a conservative approach and reflects generally accepted methods of identifying core regions in animal distribution datasets. It would also be possible to repeat the process using the 75% kernel density estimates from each survey type, which would delineate a larger area where more basking sharks may be present at the sea surface - a more precautionary approach. Conversely, using the 25% kernel density estimate would provide a smaller estimate and offer a less precautionary approach. The suggested 50% threshold represents an initial option. The threshold eventually selected could be influenced by the types, efficacy and extent of management measures that are required. Pragmatic and layered trade-offs may be needed, for example, more restrictive management measures where disturbance to sharks is critical to minimise (e.g. no shark approaches) could be pursued in smaller areas that might be identified using a 25% threshold, whereas voluntary measures, with less demanding management requirements (e.g. speed restrictions) could operate over larger areas and these regions might be identified using a threshold of 75%.

In addition to changing threshold values, awareness zones could be determined from any number of spatially overlapping basking shark distribution datasets. The fewer the number of overlapping datasets required for an awareness zone the larger the resulting area, and conversely the greater the number of overlapping datasets required the smaller the subsequent awareness zone.

Weightings might also be applied to differing basking distribution datasets prior to spatial aggregation, this would allow certain datasets to have greater influence where they perhaps have greater confidence (e.g. more complete spatial coverage, high detection probability, repeated observations throughout the main season) might influence outputs more than those with greater uncertainty (cf. patchy data in space and time). However, in the current work, weightings have not been applied.

Two proposed basking shark awareness zones were prepared for stakeholder discussions, these zones were, in general, bounded by grid cells where at least two, and three, independent datasets overlapped respectively. We refer to these from hereon as *Option A* and *Option B* (Fig. 7 and 8). To facilitate the discussion of an awareness zone that maritime users could locate while at sea, it was necessary to simplify the boundaries of Option A and Option B and hence in places they deviate from the underlying principles of the number of datasets they circumscribe. The boundaries of Options A and B were considered with respect to the 50m bathymetric contour and coastal-land / rock features visible at sea. Vertices of the boundaries were reduced in number, and key vertices aligned with the 50m depth contour and/or positioned with respect to visible landmarks from sea. Sea-going vessels are commonly fitted with depth-finding equipment and hence should be able to locate themselves at least with respect to seabed depth and to notable landmarks. Additional manual adjustments were applied to the boundaries of these zones to further simplify them (see section: Options for basking shark awareness zones).

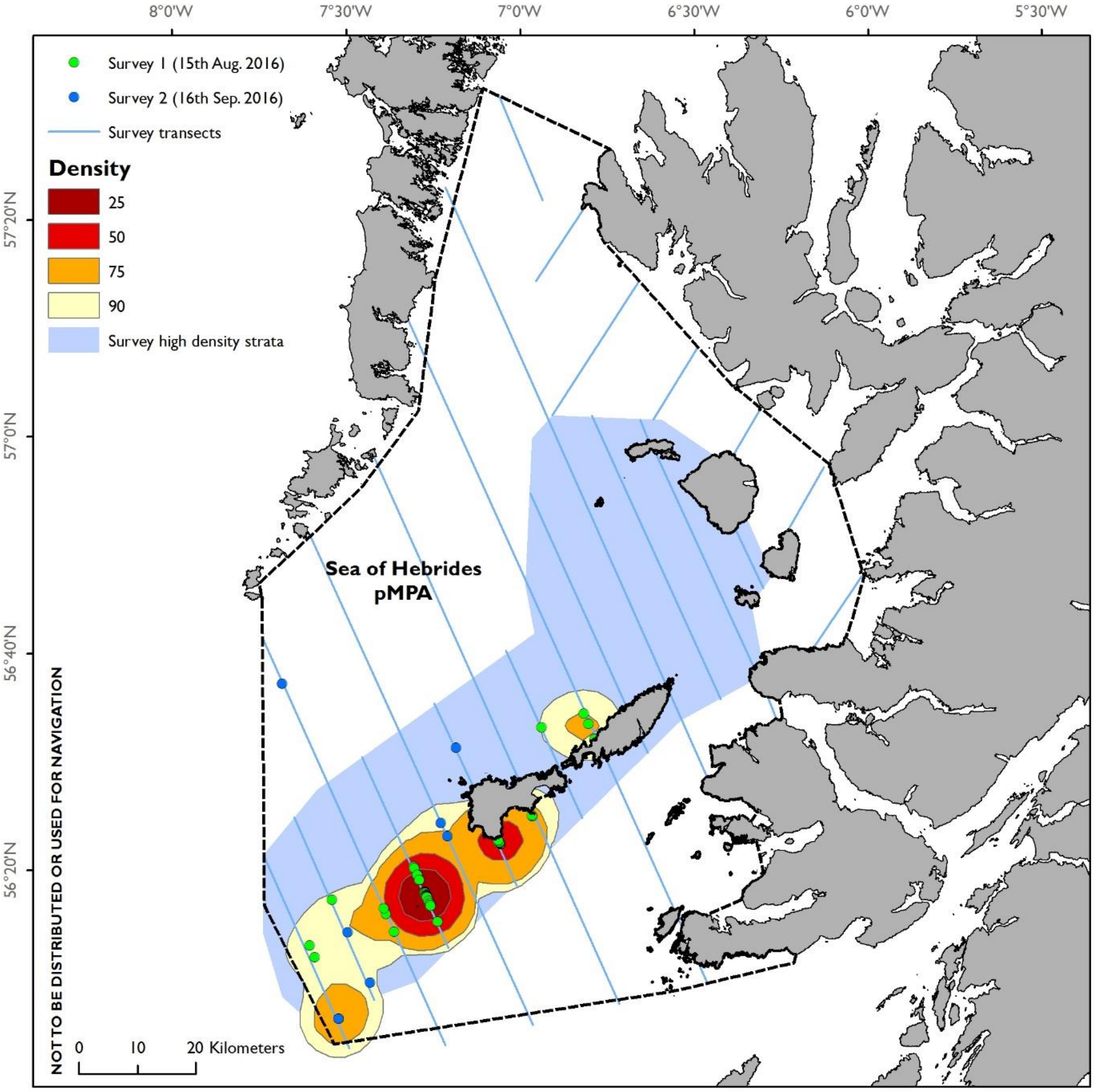


Figure 2. Map showing 25, 50, 75 and 90% kernel density estimates (in red to yellow shades) of basking shark presence from an aerial survey carried out in 2016 (Webb et al. 2018). Aerial survey track denoted in blue, locations of sharks sighted during survey 1 and survey shown as green and blue points. Sea of the Hebrides pMPA (black dashed polygon). Contains OS data © Crown copyright and database right (2019).

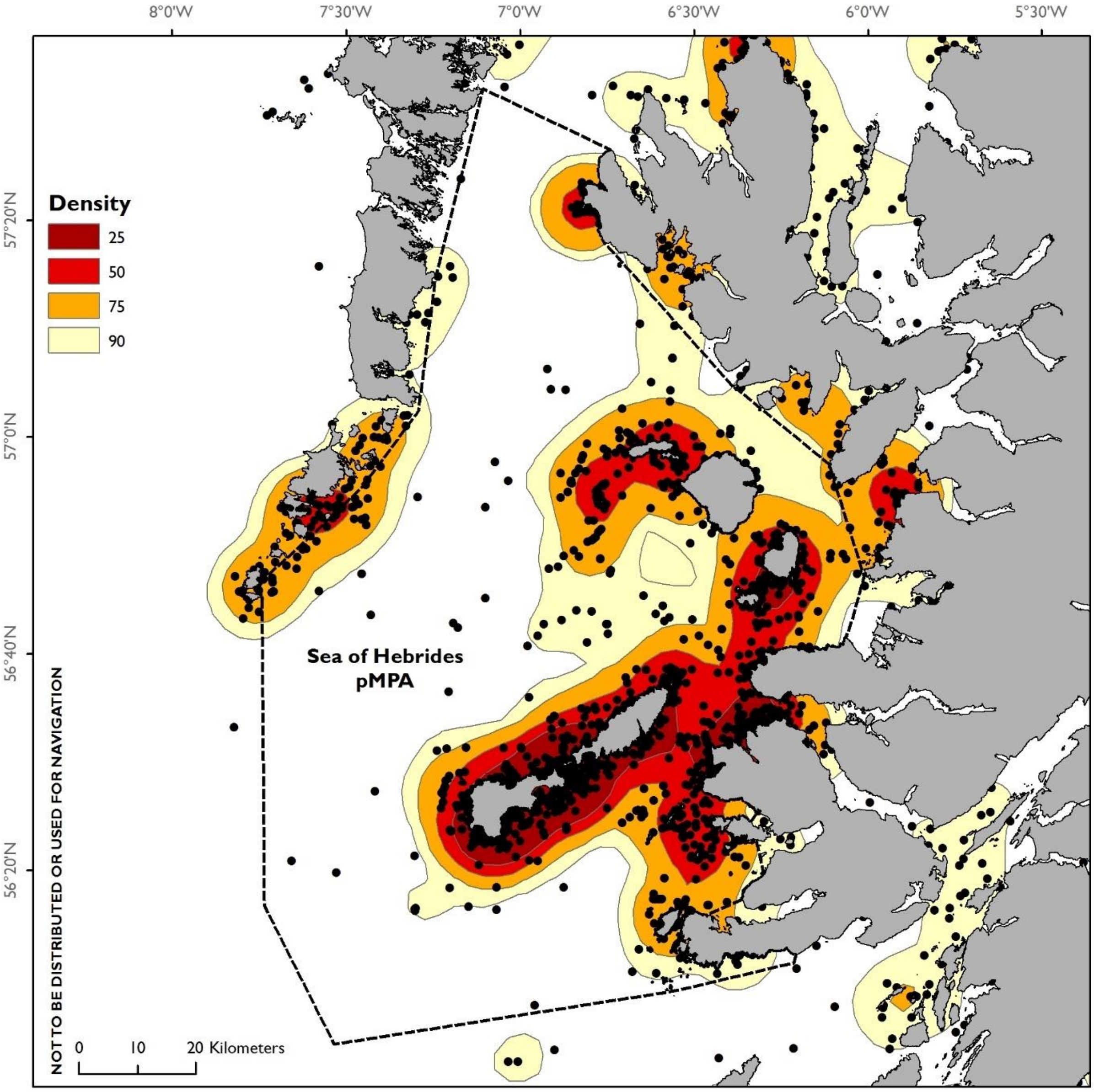


Figure 3. Map showing 25, 50, 75 and 90% kernel density estimates (in red to yellow shades) of basking shark presence from public sightings gathered by the Marine Conservation Society UK between 1998 and 2013. Sightings shown as black points. Sea of the Hebrides pMPA (black dashed polygon). Contains OS data © Crown copyright and database right (2019).

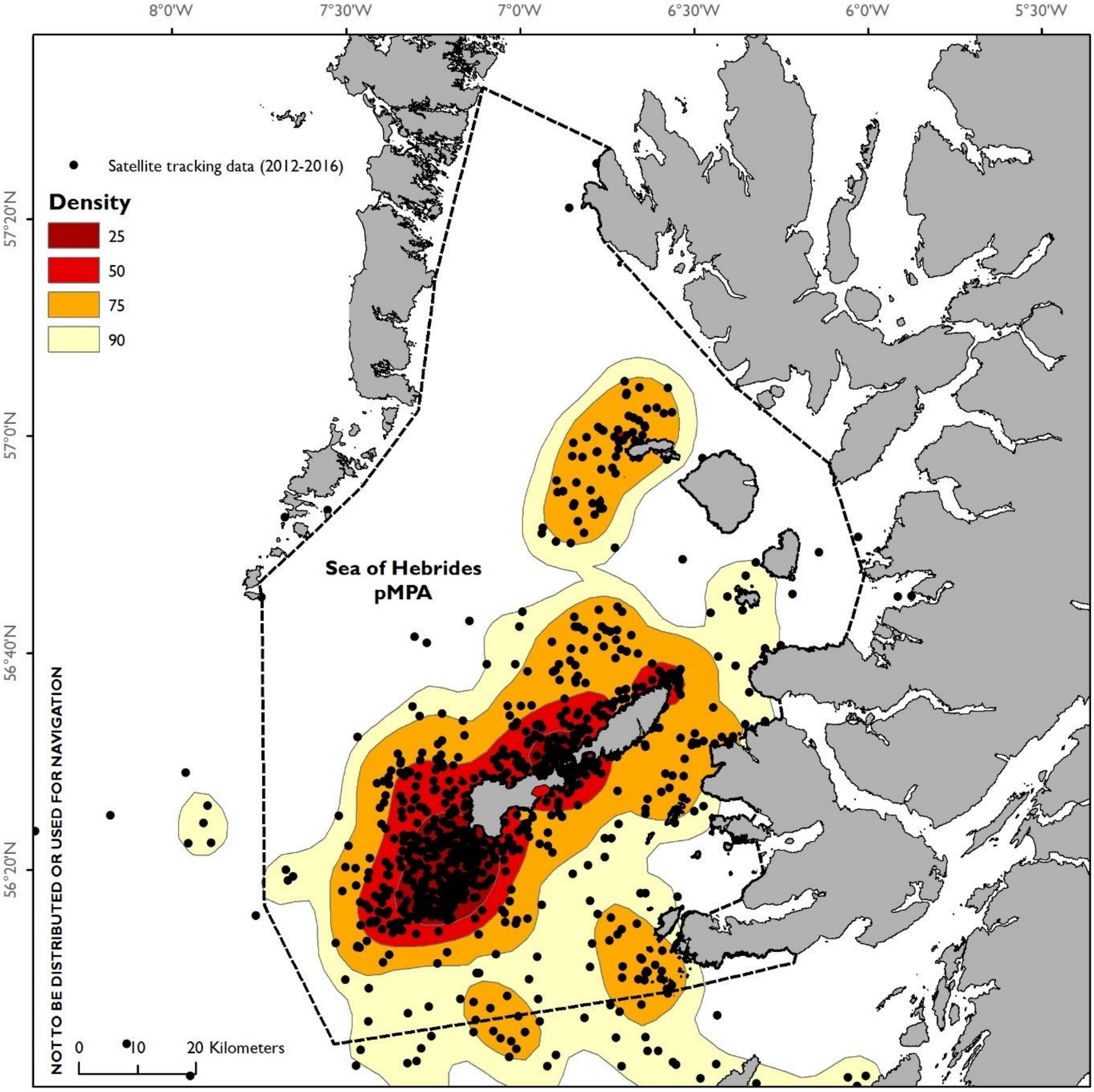


Figure 4. Map showing 25, 50, 75 and 90% kernel density estimates (in red to yellow shades) of basking shark presence from satellite tracking between 2012 and 2015. Individual filtered location points (see Doherty et al. 2017a, b, Witt et al. 2014, 2017 for more details) shown as black points. Sea of the Hebrides pMPA (black dashed polygon). Contains OS data © Crown copyright and database right (2019).

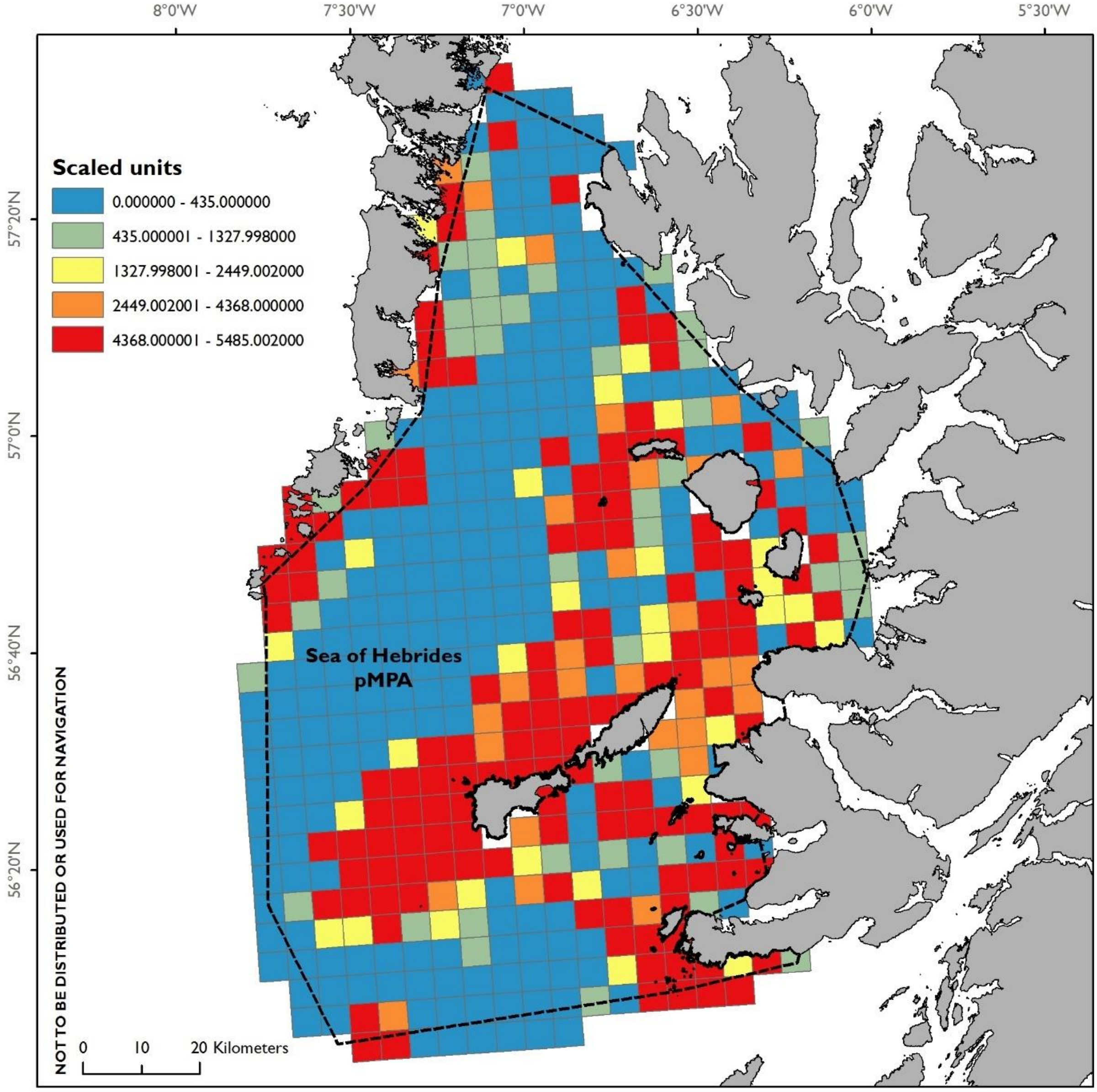


Figure 5. Map showing modelled persistence of basking sharks expressed as an index of predicted surface persistence certainty on a 5x5 km grid (see Paxton et al. 2014 for more details) where warmer colours indicate greater persistence, or greater certainty of persistence of basking sharks. Sea of the Hebrides pMPA (black dashed polygon). Contains OS data © Crown copyright and database right (2019).

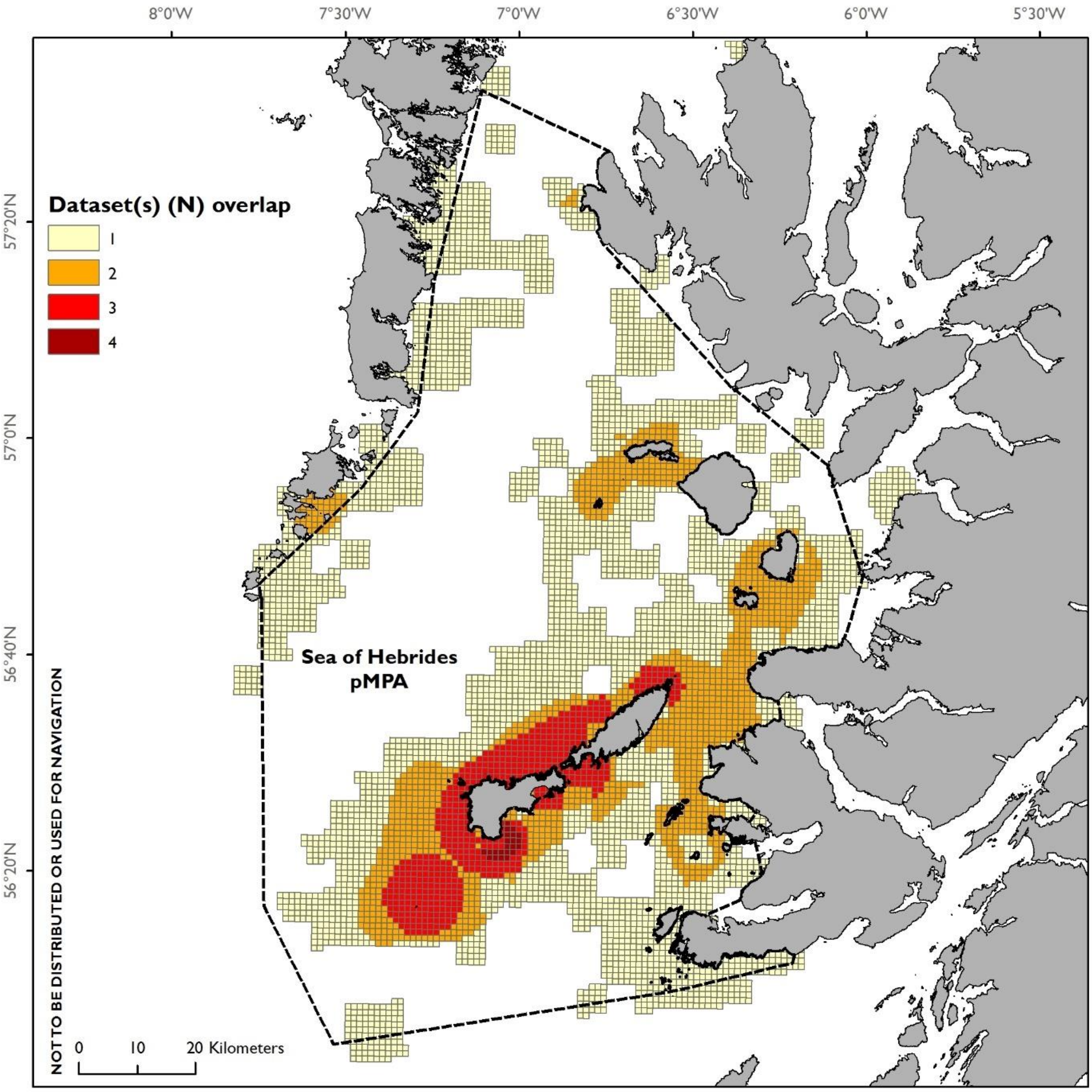


Figure 6. Map showing the location of key areas where basking sharks are likely to be present at the sea surface in the Sea of the Hebrides pMPA (black dashed polygon) based on four contributing datasets (modelled persistence, aerial survey, public sightings and satellite tracking data), shown in dark red (all four datasets indicate presence), red (three datasets indicate presence), orange (two datasets indicate presence) and yellow (one dataset indicates presence). Contains OS data © Crown copyright and database right (2019).

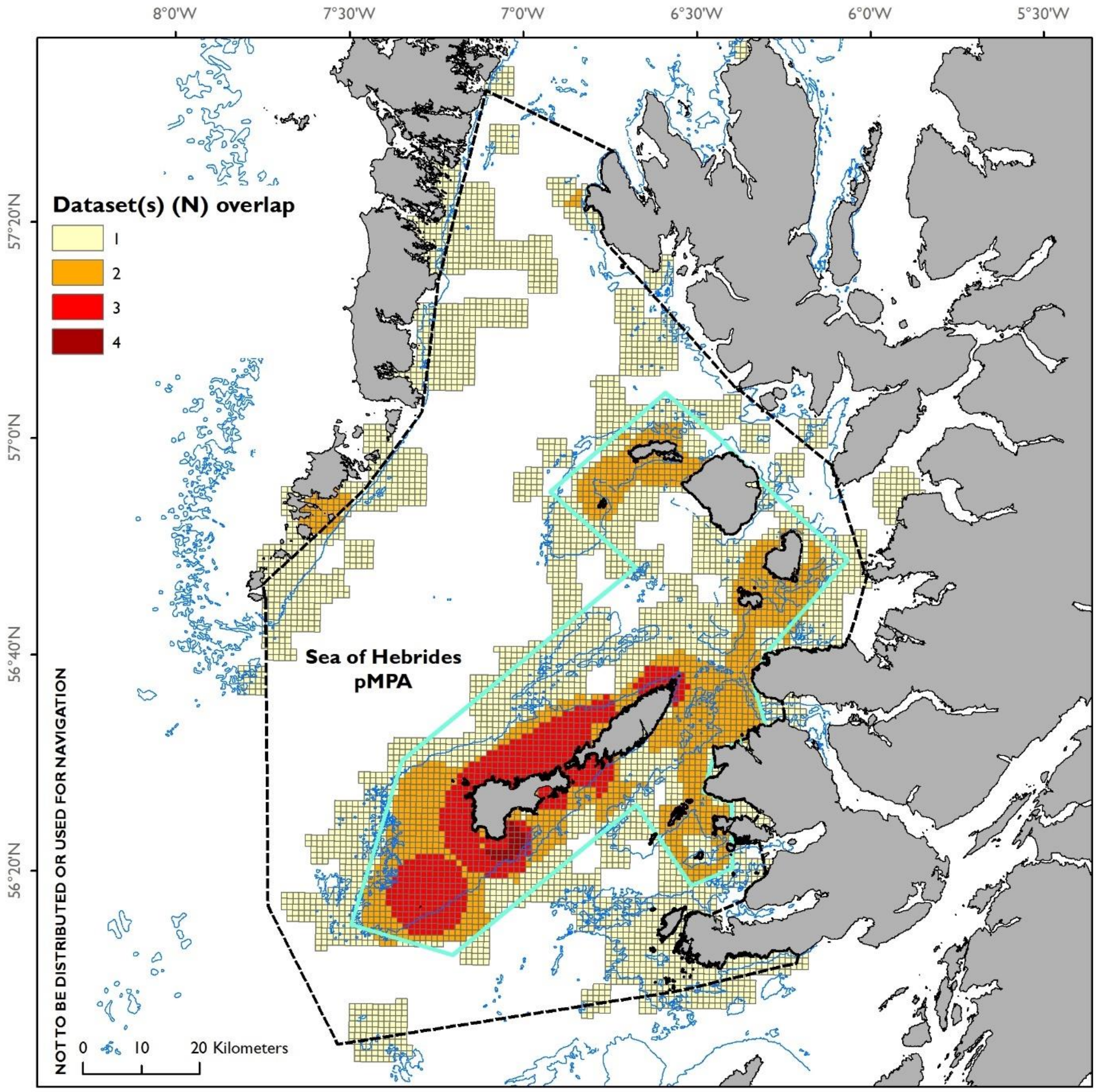


Figure 7. Map showing location of a proposed basking shark awareness zone (Option A; 3290 km^2) (turquoise polygon) within the Sea of the Hebrides pMPA (black dashed polygon) overlaid on basking shark overlap data (see Figure 6 for symbology). Thin blue solid line indicates 50m bathymetric contour. Contains OS data © Crown copyright and database right (2019).

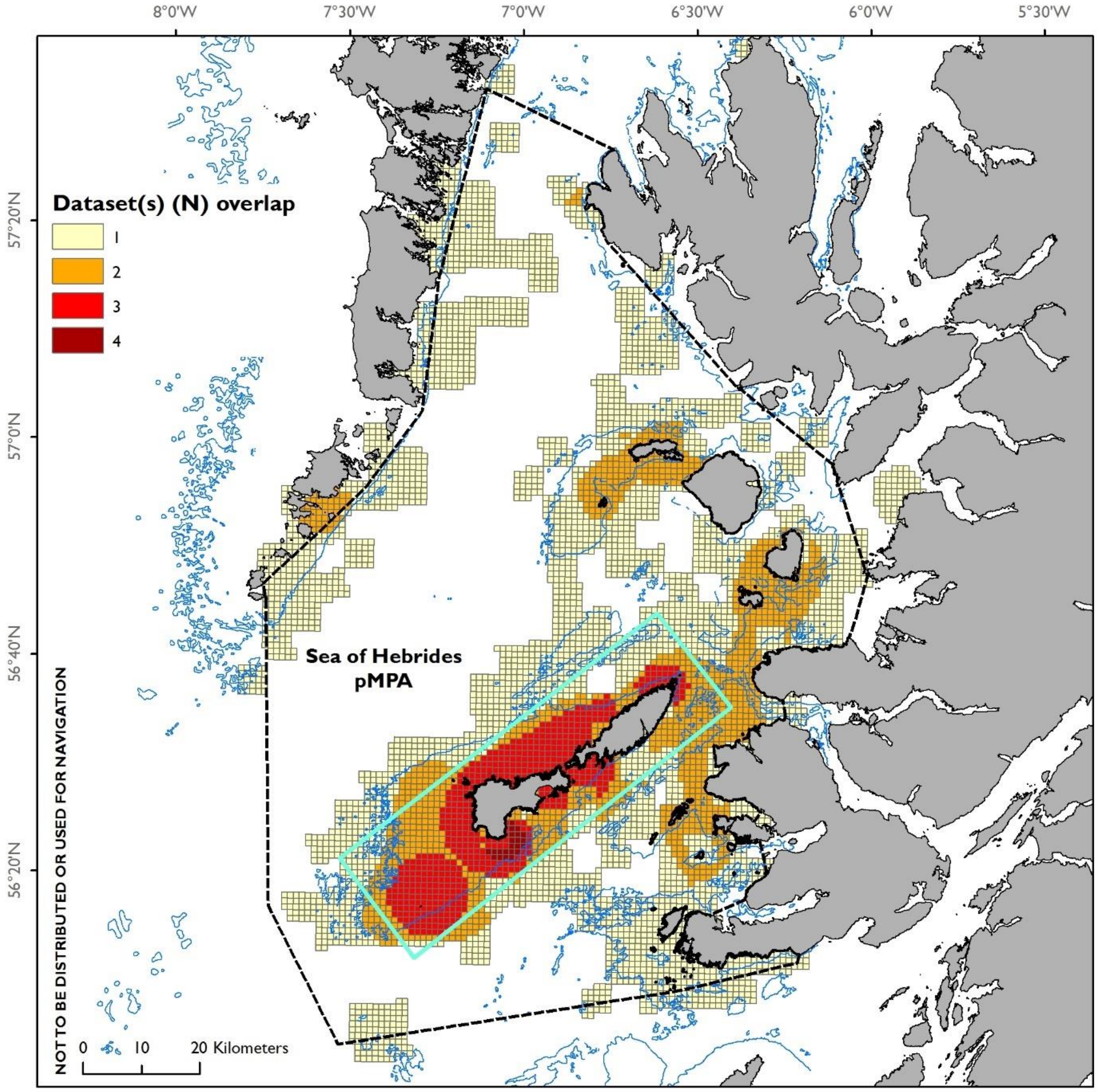


Figure 8. Map showing location of a proposed basking shark awareness zone (Option B; 1300 km^2) (turquoise polygon) within the Sea of the Hebrides pMPA (black dashed polygon) overlaid on basking shark overlap data (see Figure 6 for symbology). Thin blue solid line indicates 50m bathymetric contour. Contains OS data © Crown copyright and database right (2019).

2.5 Integrating depth data

Previous satellite tracking work (Doherty *et al*. 2017a, Doherty *et al.* 2017b, Witt *et al*. 2016) has shown that basking sharks in the wider Sea of the Hebrides spend much their time in the upper 200-metres of the water column (84% of tracking time). Within the pMPA region, basking sharks demonstrate both diel vertical migration (i.e. moving to the surface at night and returning to depth during the day) and reverse diel migration (i.e. moving to the surface during the day and returning to depth at night). This is likely to be a response to the physical (e.g. temperature and salinity) structure of the water column, which in turn influences the distribution of zooplankton, the major prey of basking sharks (Sims *et al*. 1997). We present the depth use preferences (recorded at 15-second intervals) of twelve sharks that carried dive recording transmitters (SPLASH and MiniPAT; Wildlife Computers) between July and August in 2012, 2013 and 2014. Tags on these sharks did not record location at a fine-scale, instead carrying light-geolocation satellite tracking tags that are accurate to within 50 km in open-water environments (and less so in coastal waters). However, higher spatial resolution SPOT tags, which do not record depth data, on 34 other sharks demonstrated consistent space use of the Sea of the Hebrides pMPA during the period July and August and we therefore assume that sharks carrying depth recording tags were also present in the Sea of the Hebrides at this time. From SPOT tags it is evident that as the summer progresses, the probability of sharks occurring outside the pMPA increases and so depth data gathered in July and August have high certainty of occurring within the pMPA.

The depth-use data (Fig. 9) highlight considerable variability between individuals with some sharks consistently occupying shallower waters than others. This level of variability within and among individuals suggests a precautionary principle should be adopted for integrating the depth data into producing awareness zones. In addition, regional weather patterns, seabed depth and tidal conditions can influence water-column structure and thus plankton presence, thus it is challenging to generate a simple spatially constrained understanding of basking shark distribution based on depth. We therefore propose that any awareness zone should capture the area from the sea surface to the seabed and be active over the complete 24-hour daily cycle at least for the main period when basking sharks are thought to occupy the region based on both public sightings data and satellite telemetry research (May to October; Annex 2&3).

2.6 Contextualising data

Within the proposed awareness zones additional basking shark data from a wildlife survey funded by Scottish Power Renewables exist (Fig. 10), which provide important information on basking shark abundance. Behavioural data from research into the breaching of basking sharks, which has been often linked to courtship, was conducted in 2017. Three archival accelerometry tag systems were deployed and revealed information on breaching within Gunna Sound and to the west of Tiree (Fig. 11). All tagged sharks were observed to breach, with the longest tracked shark (30 days) breaching on 57 occasions, often not as single events, but undertaking several breaching “episodes” with multiple breaches per event. In addition, towed video camera tags were deployed in 2018 to investigate individual sub-surface behaviour, and revealed that basking sharks aggregate near the bottom along the south-eastly edge of the reef plateau extending from Tiree and west to Skerryvore lighthouse (Fig. 11). It is not yet clear whether this happens regularly, or whether it happens elsewhere, but aggregation behaviour such as this is a strong indicator that the Sea of the Hebrides may be a key site for basking shark courtship. All these areas are encompassed in both Options A and B presented.

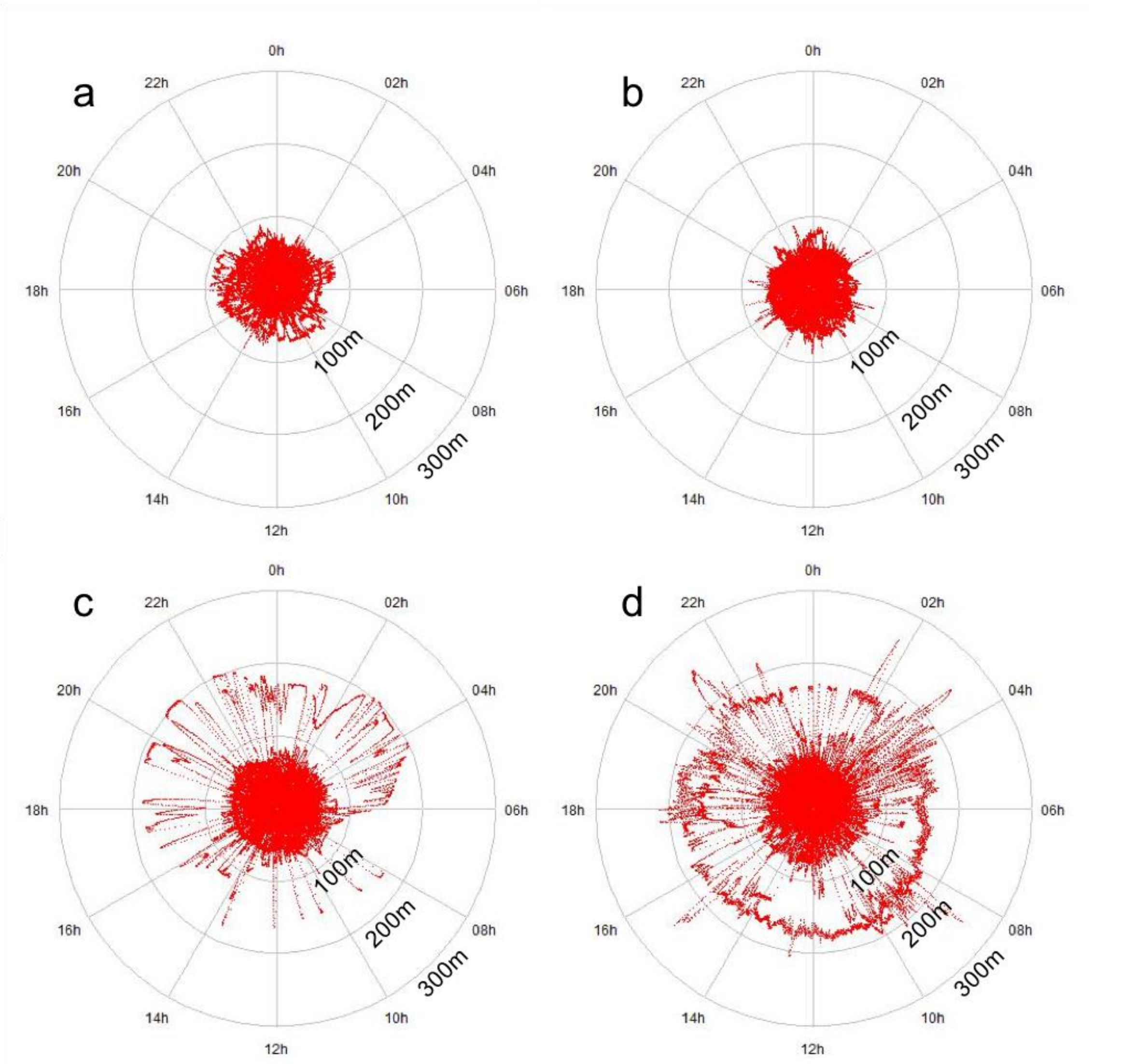


Figure 9. Circular plots showing the diurnal diving behaviour of 4 sharks (a to d) in August. Circular axis shows time of day from midnight (top of circle) through midday (bottom of circle) to midnight again (top of circle), distance from centre of circle indicates dive depth in 100m bins up to 300m (indicated in bottom right of each plot). All sharks predominantly remain within the upper 100m of the Sea of the Hebrides, and do not vary their depth use with the time of day, but shark c makes a series of additional dives to almost 200m, and shark d makes many more dives to almost 200m, with a few excursions deeper still. See also data for eight more sharks in Annex 1.

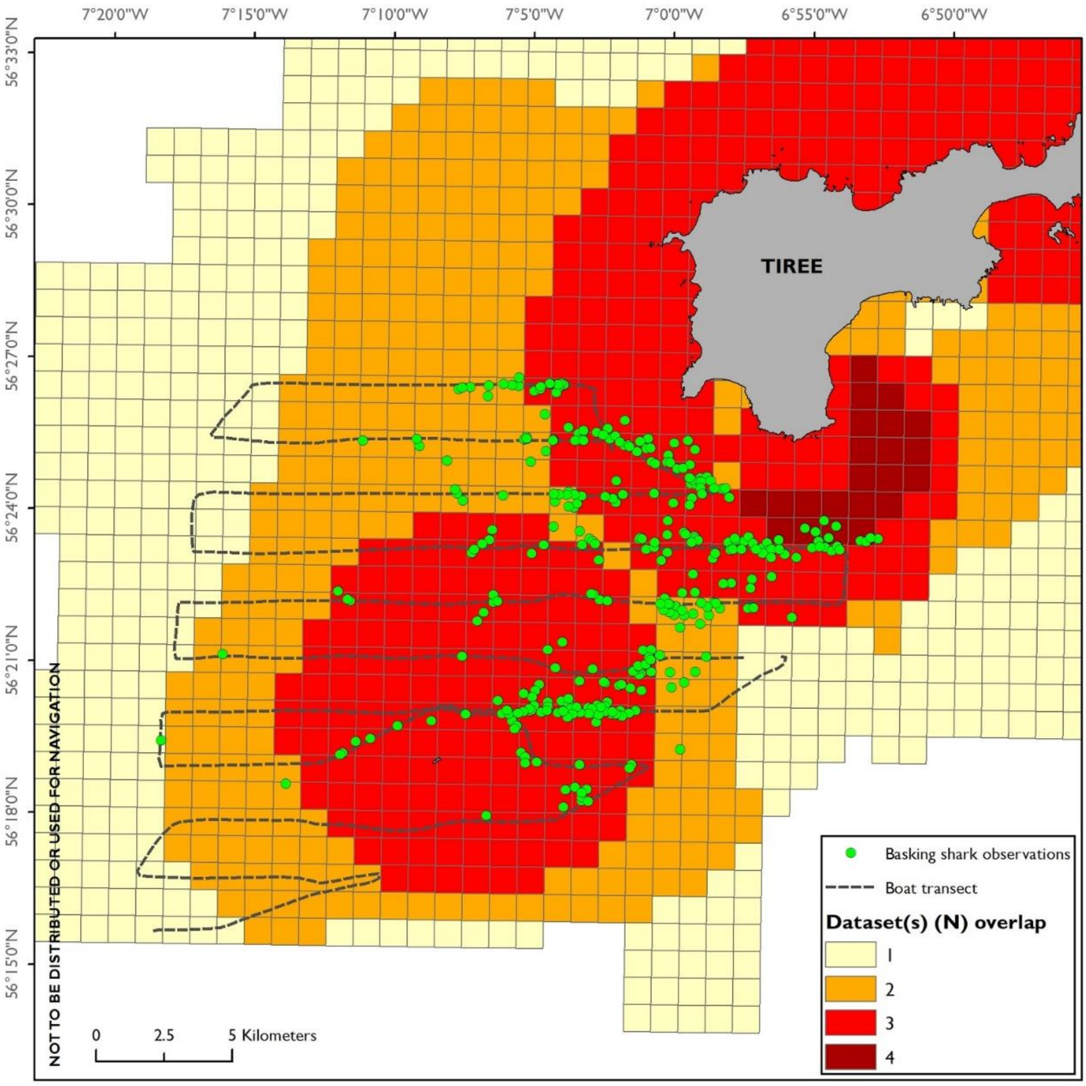


Figure 10. Map showing a portion of the southern end of a putative basking shark awareness zone within the Sea of the Hebrides pMPA where shading indicates the presence of the contributing variables (modelled persistence, aerial survey, public sightings and satellite tracking data) in relation to a boat-based survey for Scottish Power Renewables in 2012 (black dashed line shows survey track) for basking sharks (sightings shown as green points). Contains OS data © Crown copyright and database right (2019).

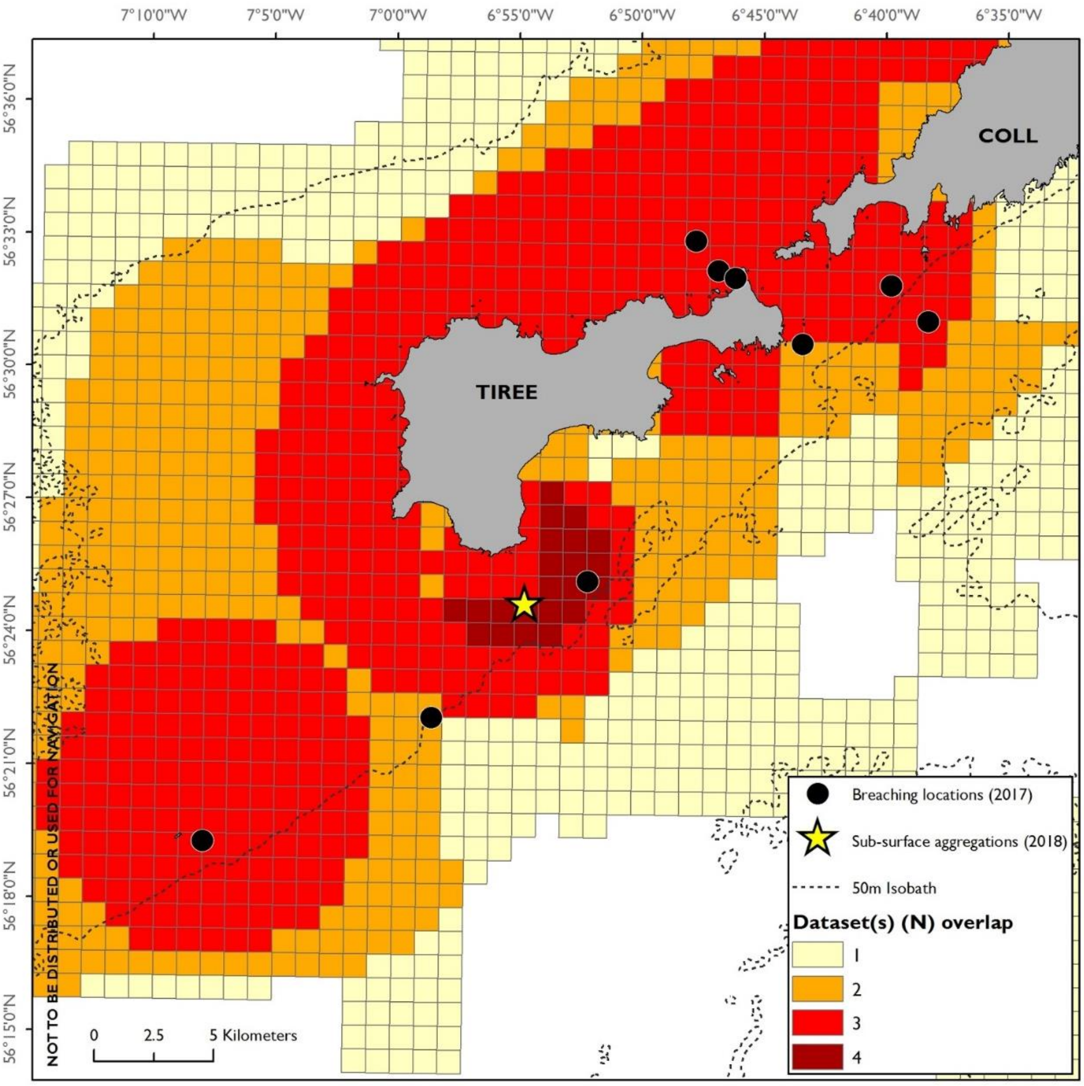


Figure 11. Map showing a portion of the southern end of a putative basking shark awareness zone within the Sea of the Hebrides pMPA where shading indicates the presence of the contributing variables (modelled persistence, aerial survey, public sightings and satellite tracking data) in relation to breaching behaviour (black points) detected using accelerometry tags (Witt et al. unpublished), and aggregation behaviour detected using towed camera systems attached to sharks (Witt et al. unpublished). Contains OS data © Crown copyright and database right (2019).

2.7 Options for basking shark awareness zones

As outlined above, two basking shark awareness zone options have been delineated, which are described below. These represent areas where basking sharks are considered to be more vulnerable to vessel collisions and disturbance.

Option A: This option seeks to encompass the marine regions of Canna, Rhum, Eigg and Muck, the waters around Hyskier and the Mill Stone into a single awareness zone that incorporates Coll and Tiree and the coastal waters to the west of the Isle of Mull. To the south of Coll and Tiree, geographic areas with two or more basking shark datasets, are less congruent with the 50m contour and so future development of awareness zones, should not simply be a function of depth (Fig. 7). The boundary is very similar to that of the aerial survey high density strata region (as shown in Fig. 4) in the eastern sector of the zone. The northern boundary of Option A to the north of Coll and Tiree deviates somewhat from the region circumscribing at least two basking shark datasets, this is an attempt to form simple parallel lines with the southern boundary of Option A.

Option B: A simple rectangular polygon encompassing three or more datasets and aligned with the dominant axis of the Isles of Coll and Tiree (Fig. 8). This option does not incorporate waters to the north of Canna or waters surrounding Eigg, Muck, Rhum or Hyskier and the Mill Stone.

Option A is much larger (3,290km^2) than Option B (1,300km^2) and is therefore more likely to encompass more basking sharks but may restrict a greater number of marine users from carrying out their activities depending on any measures developed. Option B encompasses the core area of basking shark presence, and because it is smaller, may affect the activities of fewer users, and be easier to manage, but may suffer from failing to protect basking sharks sufficiently. For example, satellite tracking data suggested that an individual basking shark may occupy a home range of between 2,600 and 3,300km^2 (Doherty et al. 2017b) over the course of the summer months, which is far larger than Option B and a similar size to Option A. Furthermore, Option B does not encompass regions such as Mill Stone, to the south west of Hyskeir, that anecdotally support considerable numbers of large sharks, but the region is not resolved particularly well in the extant basking shark distribution datasets. There may indeed be scope for multiple smaller awareness zones, and this approach might be useful avenue to approach with stakeholders.

2.8 Consideration of incidental fisheries catch

Basking sharks are occasionally accidentally caught or entangled in fishing gear (Lack & Sant 2009, Oliver et al. 2015, van der Molen 1998) and it is possible that they may also be disturbed or harmed by fisheries interactions that do not result in their capture. Interactions between basking sharks and fisheries are not well understand, in particular the spatial extent to which it occurs, the magnitude or factors concerning their survivability should they be released alive. Under-reporting of accidental capture/entanglement events is highly likely given the protected nature of the species. Data on benthic fisheries effort were sourced from the International Council for the Exploration of the Sea (http://www.ices.dk/sites/pub/Publication%20Reports/Data%20outputs/ICES.2018.OSPAR-spatial-data-fishing-intensity.zip). These data (cumulative hours fished) are expressed on a 0.05 by 0.05 °grid (for 2017; vessels ≥ 12m length). The most comprehensive and available spatial data on pelagic (mid-water) and static fisheries were obtained from the Scottish Government National Marine Plan Interactive (NMPi; http://marine.gov.scot/node/12882). This report makes use of data for the period 2009 to 2013 from vessels ≥ 15m length, specifically we use the spatial distribution of fisheries (relative density of vessel locations operating at speeds indicative of gear specific fishing) directed towards crab and Nephrops (static and mobile). Other fisheries data are available from the NMPi, including information on pelagic herring and mackerel, lobster, squid, although these do not occur to any appreciable level within the pMPA boundary and so were not considered. We extracted and overlaid fisheries data with the proposed awareness zones (Fig. 12). Data were also obtained from ScotMap (Kafkas et al. 2014), a spatial fisheries information data product focusing on the distribution and monetary value of inshore fisheries (within 12nm of land) conducted by vessels <15m in overall length. These map products, available by dominant fisheries type, including mobile and static Nephrops fisheries, crustacean fisheries for lobsters and crabs and demersal fishing for scallops where mapped and contextualised with the Option A and Option B basking shark awareness zones (Fig. 13). Hotspots of fisheries effort in the Sea of the Hebrides occurred to the northeast of both proposed awareness zones, with less fishing effort overlapping with both proposed zones. However, to the west of the core basking shark area, there is a hotspot of crab fishing. Basking sharks have been reported entangled in crab pot lines (OSPAR Commission 2009) and the Scottish creel fishing industry recognises this as a potential issue and is working in partnership with scientists, NGO's and government to understand the issue. The Scottish Entanglement Alliance (SEA) was formed with the support of the European Maritime Fisheries Fund to engage with the Scottish inshore creel fishing fleet to better understand the incidence of marine animal entanglements, and to develop sustainable and proportional mitigation strategies. SEA have developed, with industry, a best practice guide including methods to setting creels for reducing the risk of entanglement (https://www.scottishentanglement.org/downloads/best-practise-guide-for-fishermen). Taken together, this suggests that the potential threat of accidental capture or entanglement by fisheries in the awareness zones may not be significant, although the findings from the SEA project should influence the need for any future mitigation/management measures.

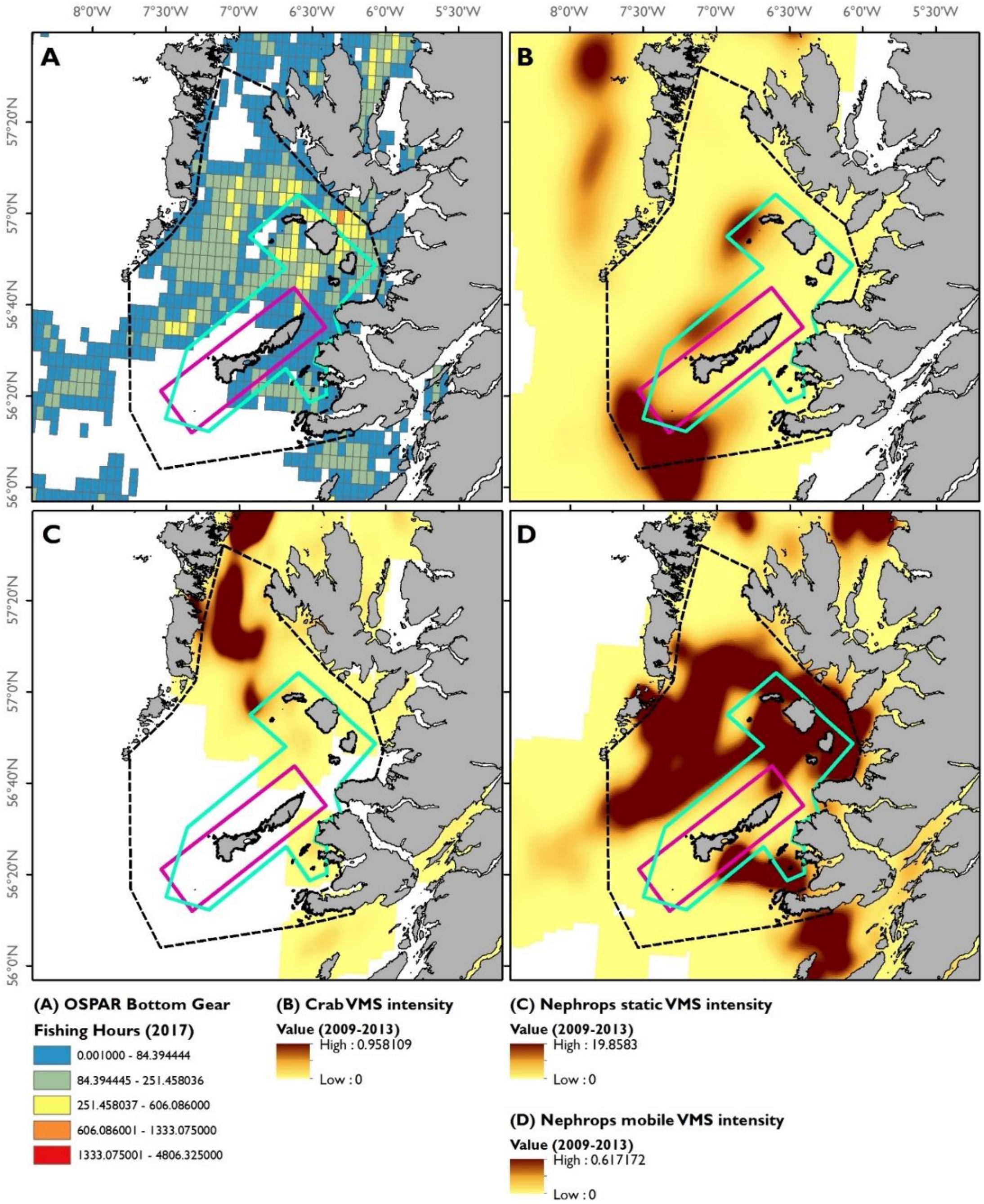


Figure 12. Distribution of fisheries effort within the Sea of Hebrides pMPA. (A) OSPAR bottom mobile gear effort for 2017 (cumulative hours), (B) Crab fisheries, (C) Nephrops static fisheries and (D) Nephrops mobile fisheries. Option A awareness zone (turquoise empty polygon), Option B awareness zone (purple empty polygon). Contains OS data © Crown copyright and database right (2019).

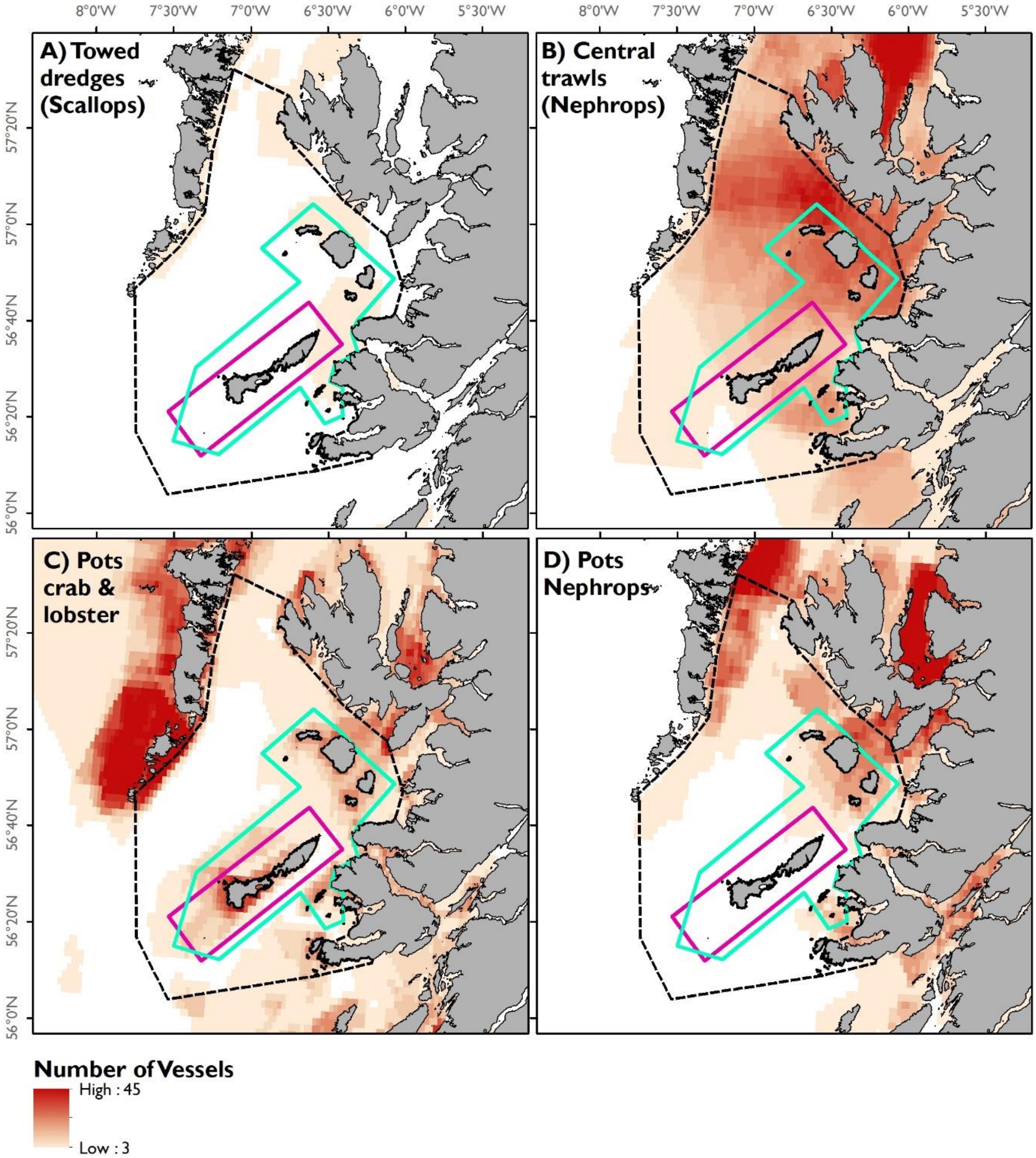
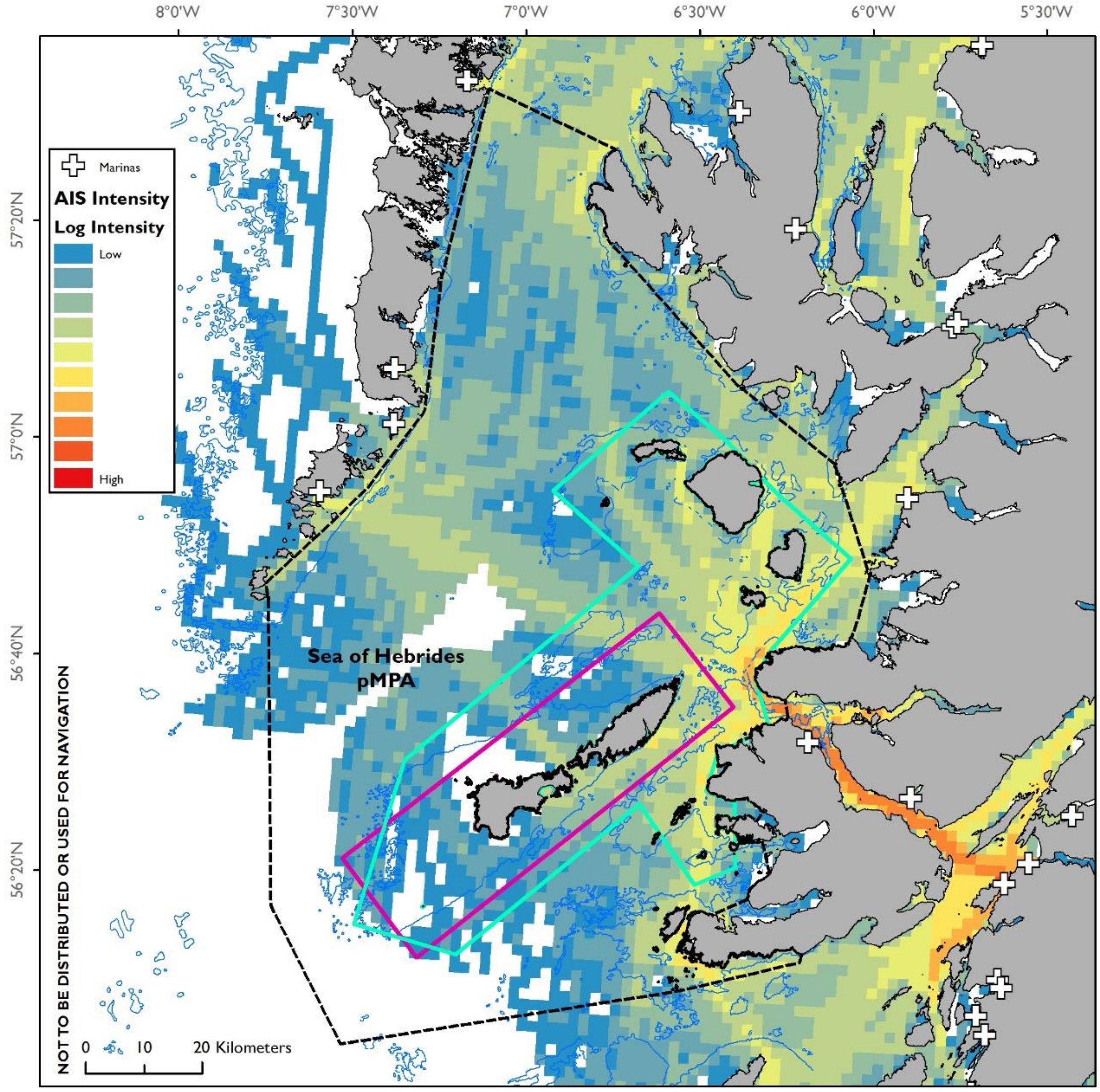


Figure 13. Distribution of the number of vessels (<15m length) engaged in fishing activities within the Sea of Hebrides pMPA. (A) Towed dredges primarily for scallops, (B) Trawlers targeting nephrops, (C) Potting vessels crab and lobsters, and (D) Potting vessels targeting nephrops. Option A awareness zone (turquoise empty polygon) Option B awareness zone (purple empty polygon). Contains OS data © Crown copyright and database right (2019).

2.9 Recreation yachting

Spatially explicit data on the movements of recreational craft within the Sea of Hebrides pMPA were obtained from the [1]Royal Yachting Association. Positional data from vessels carrying VHF equipment communicating with the Automated Identification System (AIS; class B messages) were mapped and expressed as log vessel density for 2016 (Fig. 14). Both options of basking shark awareness zones circumscribe recreational vessel activity, with a noteworthy corridor of activity extending northwest from Gunna Sound towards Barra. Slow moving recreational vessels including yachts and sailed powered craft likely represent minimal risk to basking sharks due to their slow relative speed and low noise characteristics (cf. powered vessels). This data layer likely under-represents vessel traffic from ecotourism activities operating within the pMPA which often aggregate within the Option B awareness



zone.

Figure 14. Distribution of recreational vessel activity in 2016. Option A awareness zone (turquoise empty polygon) Option B awareness zone (purple empty polygon). Contains OS data © Crown copyright and database right (2019).

[1] UK Coastal Atlas of Recreational Boating 2.0 (2016). Royal Yachting Association.

3. CONCLUSIONS

The analysis undertaken in this report to propose a basking shark awareness zone has highlighted that there are key areas in which basking sharks can be expected to occur and hence sharks will be at risk of at least vessel collision and disturbance in these areas. Two options have been drafted for consideration as basking shark awareness zones. The novel observations of basking shark breaching and aggregation behaviour, which occur in the core of the proposed awareness zones between Coll and Tiree, and immediately south of Tiree, provide important additional contextual information. These are considered potential courtship behaviours in other shark species (Jacoby et al. 2012) so we consider that these particular areas of the awareness zone may be amongst the most important to consider for protection from activities that have the potential to kill, injure or disturb basking sharks. Whilst it is considered that basking sharks may not be at great risk of accidental capture or entanglement in fishing gear within the awareness zones, initiatives such as the Scottish Entanglement Alliance will help inform future discussions. However, it is uncertain whether other surface or benthic activities are likely to affect basking sharks. Within both zone options there is potential for interaction between basking sharks and vessels via collision and disturbance but the risks associated with this are difficult to quantify. Additionally, basking sharks are likely to be distributed unpredictably throughout the water column to 200m depth in the pMPA. Therefore, this lends support to a precautionary approach for managing activities within the awareness zones.

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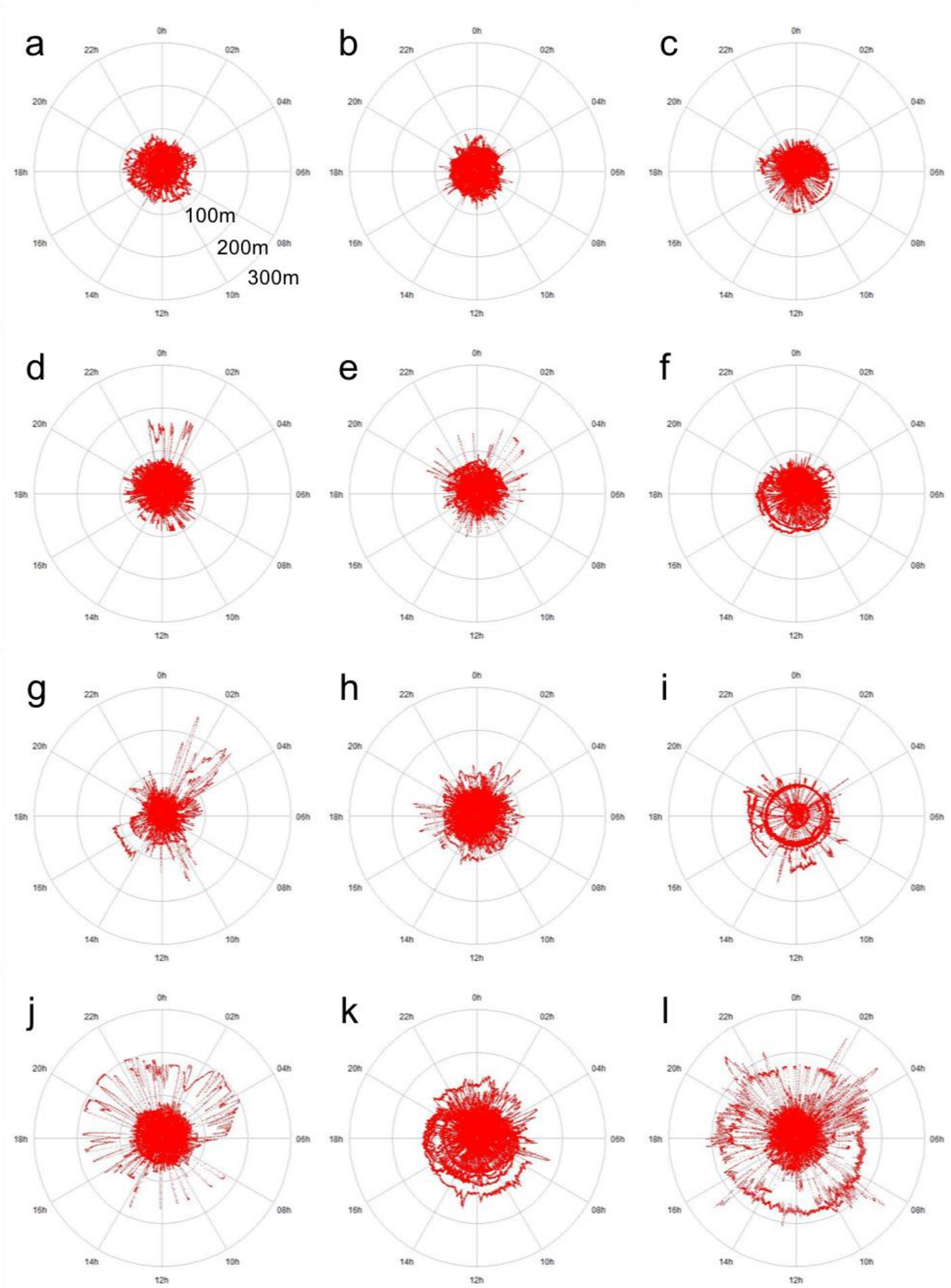
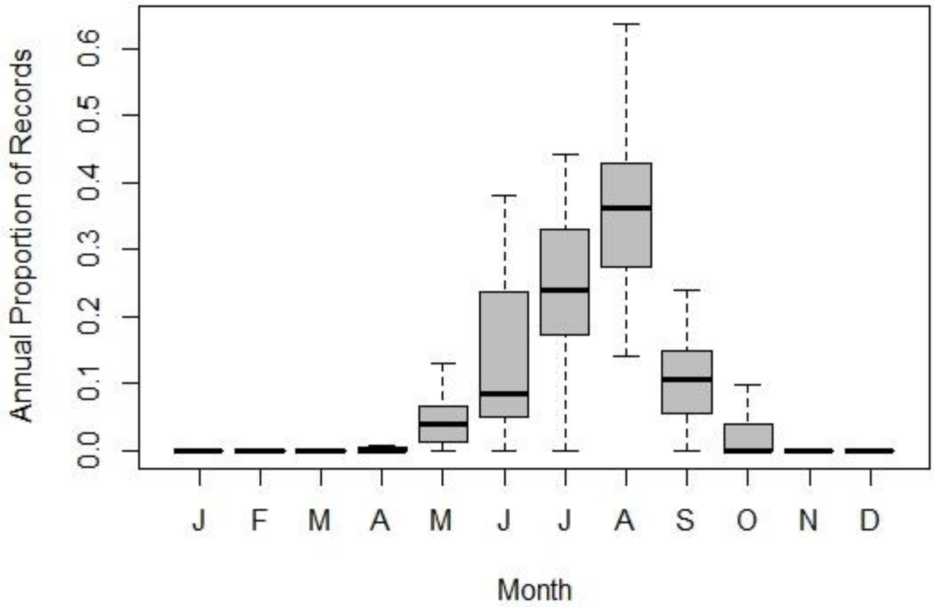
ANNEX 1: DEPTH UTILISATION BEHAVIOUR



Circular plots showing the diurnal diving behaviour of 12 sharks (a to l) in August. Circular axis shows time of day from midnight (top of circle) through midday (bottom of circle) to midnight again (top of circle), distance from centre of circle indicates dive depth in 100-metre bins up to 300 metres (indicated in bottom right of (a)). All sharks predominantly remain within the upper 100 metres of the Sea of the Hebrides, and do not vary depth use with the time of day, but several make deeper excursions, with the deepest depths used by individuals j, k and l.

ANNEX 2: SEASONALITY OF PUBLIC SIGHTINGS



Seasonality of public sightings data for basking sharks observed off the west coast of Scotland (1998-2013). Boxplot shows the distribution of the annual proportion of records occurring within respective months. Median for each distribution (month) highlighted by bold horizontal lines in each vertical boxplot. Boxplot highlights key sightings season for basking sharks, which ranges between May and October. August is the month receiving most records each year (median: 37% of records, although ranging between 15 and 65% of records within any one year), followed by July (24%) and September (11%).

ANNEX 3: SPATIO-TEMPORAL LOCATION OF TRACKED BASKING SHARKS

Monthly location of basking sharks with respect to pMPA. Matrix highlights month at location of tagged basking sharks with respect to Sea of the Hebrides pMPA (dark grey = within pMPA). Not all tags remained attached to reveal month of return to the region. Tag detached (D). Synthesis of data from Witt et al. SNH Commissioned Reports 752 & 908.

Tag ID	Tag model	Sex	Year	Tracking duration (months)	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
129431	SPLASH-F	F	2013	2		D													
129432	SPLASH-F	U	2013	2		D													
129433	SPLASH-F	M	2013	2		D													
129434	SPLASH-F	U	2013	2			D												
137646	SPLASH-F	M	2014	2		D													
137647	SPLASH-F	M	2014	2		D													
119855	SPOT	U	2012	2		D													
120497	SPOT	F	2012	2		D													
120500	SPOT	M	2012	2		D													
129435	SPOT	F	2013	2			D												
129438	SPOT	M	2013	2			D												
137648	SPLASH-F	F	2014	3			D												
137653	SPLASH-F	M	2014	3			D												
129446	SPOT	U	2013	3			D												
129447	SPOT	U	2013	3			D												
137645	SPLASH-F	U	2014	4				D											
119856	SPOT	M	2012	4				D											
120496	SPOT	F	2012	4				D											
129443	SPOT	F	2013	4				D											
137650	SPLASH-F	F	2014	5					D										
137652	SPLASH-F	U	2014	5					D										
120498	SPOT	F	2012	5					D										
137649	SPLASH-F	U	2014	6						D									
120499	SPOT	M	2012	6						D									
129450	SPOT	F	2013	8								D							
129441	SPOT	M	2013	9									D						
137654	SPLASH-F	U	2014	10										D					
137651	SPLASH-F	F	2014	10										D					
119854	SPOT	U	2012	11											D				
129445	SPOT	U	2013	11											D				
129444	SPOT	U	2013	13													D		
129437	SPOT	U	2013	13														D	
129449	SPOT	U	2013	14														D	
129448	SPOT	U	2013	14														D	
129436	SPOT	U	2013	14															D
129439	SPOT	U	2013	14															D
129440	SPOT	F	2013	15															D