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Basking Shark (*Cetorhinus maximus)* Literature Review, Current Research and New Research Ideas

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BASKING SHARK (*CETORHINUS MAXIMUS*) LITERATURE REVIEW, CURRENT RESEARCH AND NEW RESEARCH IDEAS

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Executive Summary

Basking sharks have a strong tendency to aggregate in coastal areas of continental shelves dominated by transitional waters between stratified and mixed water columns. In Scottish waters, peak numbers of basking sharks tend to be sighted at the surface between June and August. Two basking shark 'hotspots' have been identified at Hyskeir and Canna situated in the Sea of the Hebrides and Coll in the Inner Hebrides. However, due to the difficulties in counting basking sharks, no abundance estimates of basking sharks currently exist for north-east Atlantic waters.

Research currently underway on basking sharks includes a tagging project funded by Scottish Natural Heritage and the University of Exeter. The project aims to improve understanding of how basking sharks use sea areas within the Inner Hebrides and further afield in Scottish waters. There is also genetic work being carried out focussing on basking shark population connectivity within the Northeast Atlantic, how they respond to oceanic pollution, to changes in sea surface temperature and associated shifts in primary productivity. Work is being undertaken at Plymouth Marine Laboratory and the Marine Biological Association on ocean fronts as indicators of marine animals: expediting site selection and survey for offshore renewables focussing on basking sharks (and seabirds) and ocean fronts.

This report suggests that in order gain a better understanding of the distribution and abundance of basking sharks in the waters to the west coast of Scotland, a series of aerial surveys should be undertaken. Along with data collected by the SNH tagging project, this would allow basking shark abundance to be estimated. Research is also proposed that would allow insights in to the possible effects of noise and electromagnetic fields from offshore windfarm construction and operation on basking shark distribution and behaviour.

Introduction

Scotland has set the ambitious target of generating 100% of its electricity requirements from renewable sources such as offshore windfarms, tidal and wave energy by 2020, and marine renewables will play a role in that. Up to 10GW of offshore wind projects are currently planned for Scottish waters, together with about 2GW of wave and tidal energy. One of the roles of the Marine Scotland, Offshore Energy Environmental Advice (OEEA) group is to advise on the development of tools to assess environmental interactions of renewables developments, particularly with key receptors such as marine mammals, birds, habitats and fish. Basking sharks (*Cetorhinus maximus*) are listed as vulnerable worldwide, and endangered in the north-east Atlantic in the 2004 IUCN Red List (IUCN, 2004). In 2002, the species was listed on Appendix 2 of the Convention on International Trade in Endangered Species. They are also protected in British territorial waters under schedule 5 of the Wildlife and Countryside Act (1981). As a protected species, basking sharks are also considered a key receptor.

The waters off the west coast of Scotland are historically known to support significant populations of basking sharks and a recently commissioned report by SNH (Speedie *et al*., 2009) showed that the waters off Canna and Hyskeir situated in the Sea of the Hebrides and Coll in the Inner Hebrides are considered basking shark 'hotspots'. Off the west coast of Scotland, there are two short term option sites for developing offshore windfarms; the Argyll Array in the waters to the south-west of Tiree and the waters to the north-west of Islay. Due to the potential interaction between basking sharks and the development of offshore windfarms in these areas, Marine Scotland has undertaken this review to assess the status of basking shark research in Scottish Waters and to suggest research which will better enable us to assess the effects of offshore energy development on basking shark individuals and populations in the waters to the west of Scotland.

Brief Literature Review

The basking shark (*Cetorhinus maximus*) is the largest fish species in the Northeast Atlantic, growing to more than 11 metres in length and weighing around 4 tonnes (Sims, 2008). It is a coastal-pelagic shark known to inhabit the boreal to warm-temperate waters of the continental and insular shelves circumglobally (Sims, 2008). However, much of the basking sharks life history movements, population dynamics and general ecology have not been described. Individual basking sharks take 11-20 years to reach maturity; females have long gestation periods (1-3 years) and give birth to few large young. This vulnerability to exploitation, together with the strong possibility that populations are depleted as a result of exploitation by fisheries and the lack of scientific knowledge of the species has lead to the basking shark being listed as vulnerable worldwide, and endangered in the north-east Atlantic in the 2004 IUCN Red List (IUCN, 2004). In 2002, the species was listed on Appendix 2 of the Convention on International Trade in Endangered Species. They are also protected in British territorial waters under schedule 5 of the Wildlife and Countryside Act (1981) (Sims *et al.,* 2005).

Basking sharks are 'ram filter-feeding sharks' and in order to meet their energy requirements they must select and remain in areas of high plankton concentrations. Basking sharks are selective foragers of zooplankton, feeding predominately on energy rich calanoid copepods such as *Calanus finmarchicus* and *C. helgolandicus* (Sims *et al.,* 1997). Basking sharks have a strong tendency to aggregate in coastal areas of continental shelves dominated by transitional waters between stratified and mixed water columns (Sims *et al.,* 2006). These transition zones are known as tidal fronts and are often sites of enhanced zooplankton abundance (Sims & Quayle, 1998). Wherever fronts are well defined, for example, in the north-east Atlantic off south-west England, in the Irish Sea off the Isle of Man, and off north-western Scotland (e.g., Hebridean Sea, Outer Hebrides), annual sightings of basking sharks occur (Sims, 2008). These areas where basking sharks have been relatively frequently observed have been termed basking shark 'hotspots' (Speedie *et al.,* 2009).

Basking sharks are rarely sighted at the surface outside of the summer feeding season (Sims, 2008). Sims *et al.,* (2003) found that basking sharks conducted extensive horizontal (up to 3,400km) and vertical (>750m depth) movements to utilise productive continental-shelf and shelf-edge habitats during summer, autumn and winter. Basking sharks travelled long distances (390 - 460km) to locate temporally discrete zooplankton 'hotspots' at shelf-break fronts. Basking sharks have been tracked moving between waters off south-west England to Scotland, and vice-versa, sometimes over periods of only a few weeks (Sims *et al.,* 2003).

The population abundance and density of basking sharks in any sea of the world is not precisely known (Sims, 2008). The best available assessments of absolute basking shark abundance were provided by marine mammal aerial surveys flown between October 1978 and January 1982 (Kenney *et al.,* 1985) off New England, north-west Atlantic. These surveys indicated an abundance there of between 6,671 and 14,295 individual basking sharks. Estimates of absolute basking shark abundance from aerial surveys of whales in the Bay of Fundy, the Scotian Shelf/Gulf of St. Lawrence and Newfoundland waters suggest numbers of 4,200, 5,340, and 560, respectively, for a total of 10,100 in the summer of 2007 (Campana *et al.,* 2008: DFO, 2008). However, these estimates are uncertain due to the number of assumptions that were made in the calculations. Hoelzel *et al.,* 2006 examined the mitochondrial DNA of basking sharks and concluded that the estimate for the global population was very low with a population size of 8,200 individuals. Again, given the underlying uncertainties in the parameter estimates, it is a rough approximation. There are currently no population estimates for basking sharks within Scottish or UK waters due to the difficulties in counting basking sharks.

Three public sighting recording schemes for the basking shark are presently underway in the UK: The Marine Conservation Society's (MCS) Basking Shark Watch (Marine Conservation Society, 2003), Seaquest South-West and the Solway Shark Watch and Sea Mammal Survey. Basking shark sightings are usually recorded between April and October with the peak number of sightings between June to August (Witt *et al.,* 2012). It has been shown that there is a significant correlation between the duration of the sightings season i.e. the length of time that basking sharks can be seen at the surface each year and the North Atlantic Oscillation (NAO), an atmosphere-ocean climate oscillation that has been linked to forcing of marine ecosystems (Witt *et al.,* 2012). The effects of NAO are thought to differ somewhat on the dominant prey types for basking sharks; for example, during the NAO positive phase, *Calanus finmarchicus* abundance increases, while *C. helgolandicus* decreases, and vice-versa during the NAO negative phase (Fromentin & Planque, 1996). Whether the correlation between westward wind stress (described by the NAO index) and the duration of the basking shark sighting season is due to temperature or prey, an interaction of both or sightings probability due to weather conditions, has yet to be elucidated (Witt *et al.,* 2012).

Due to the nature of the methodology of sightings data, information can only be gathered on the surface behaviour of the basking sharks seen and this is likely to be only a partial reflection of the behaviour, abundance and distribution of basking sharks. Differing patterns of daily vertical movement in individual sharks in different ocean habitats in UK waters resulted in very different surfacing frequencies. Day-time surfacing of a shark feeding in an inner shelf area close to a front was over 100 times more frequent than another shark feeding in well stratified water. This has profound implications for the use of sightings data both in defining population distribution and estimating abundance trends (Sims *et al.,* 2005).

Research suggests that there is a tendency to observe females at the surface. The sex ratio from historical fisheries data indicates there to be ~1 male for every 18 females (Watkins, 1958). There is no reason to expect a population-level deviation from a 1:1 sex ratio, so this is disparity in sex ratio may indicate pronounced spatial and seasonal segregation by sex (Compagno, 1984). It is possible that females may engage in basking more often than males and therefore make up a greater percentage of the catch. In contrast, examination of 128 individual sharks caught incidentally off Newfoundland in Canada showed males comprised 70% of the sample (Lien & Fawcett, 1986).

The Wildlife Trust's Basking Shark Project conducted effort-corrected line transects surveys for the basking shark along the west coast of Scotland between 2002-2006, using an 11.7m sailing vessel. Over the five years, a total of 593 basking sharks were recorded whilst on transect in Scottish waters. The project established two hotspot sites conclusively: the islands of Hyskeir and Canna situated in the Sea of the Hebrides, and the island of Coll (Gunna Sound, between Coll and Tiree) in the Inner Hebrides (Figure 1).

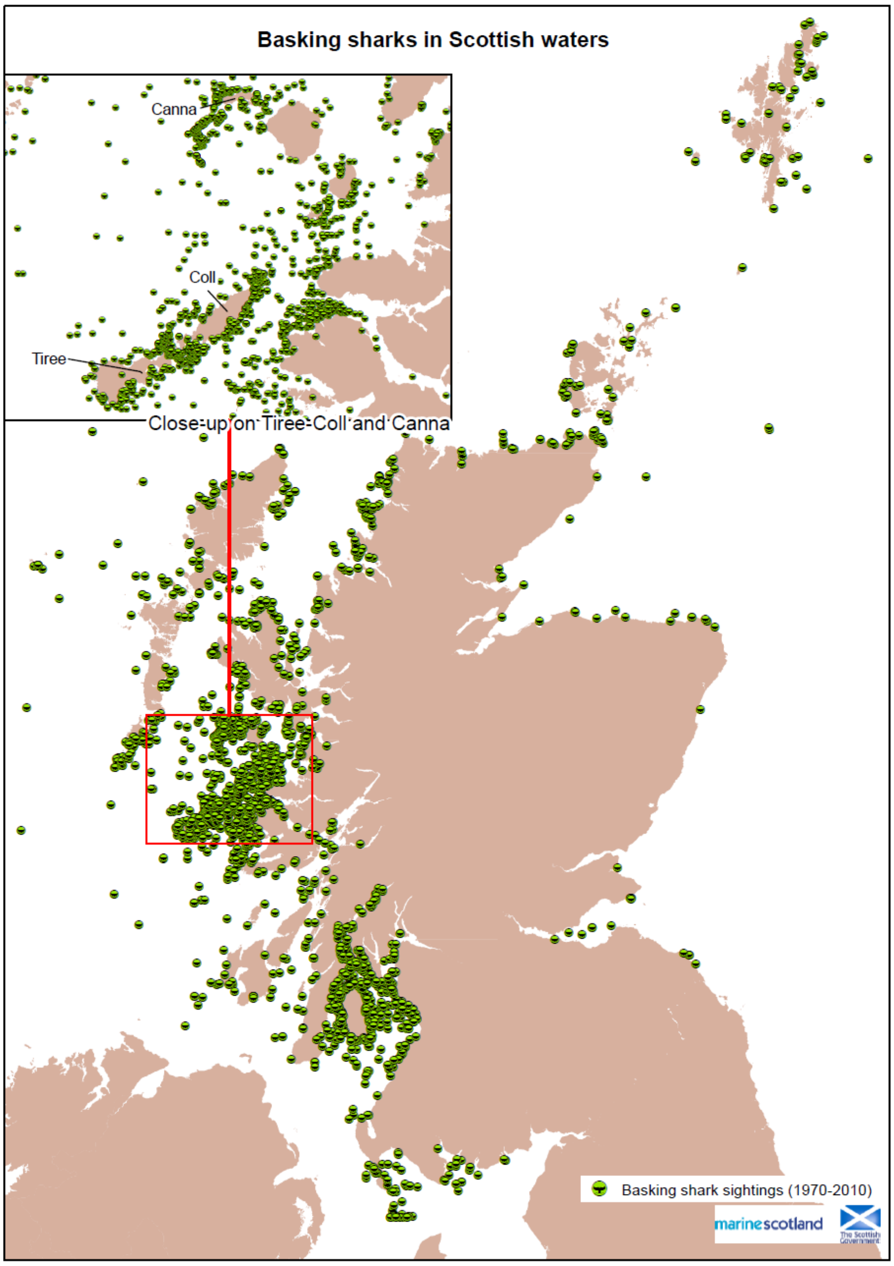

Figure 1. Basking shark sightings (1970-2010) in Scottish waters. Based on sightings and survey data the areas around Canna and Coll and Tiree have been declared basking shark 'hotspots'. Data is provided by the Marine Conservation Society and this data set was collated for the Priority Marine Features Geodatabase by JNCC and SNH.

The selection of hotspots was based on high numbers of sightings of sharks per hour of observation time (SPUE) consistently recorded (i.e. greater than $1.00h^{-1}$), high numbers of groups recorded and group-related social behaviour (courtship, breaching) (Speedie *et al.,* 2009). At the Hyskeir and Canna hotspot, high numbers of sharks were involved in courtship and it was also where most breaching activity was recorded. The average SPUE was $2.82h^{-1}$. The hotspot site with the highest SPUE in the English Channel is the Lands End peninsula, with an average of $0.48h^{-1}$ (Speedie & Johnson, 2008) demonstrating the high importance of the Hyskeir, Canna and Coll hotspots. It is worth noting that the Wildlife Trust's Basking Shark Project did not survey the waters to the south-west of Tiree (the location of the proposed Argyll Array offshore windfarm).

A previous SNH report (Nicholson *et al.,* 2000) identified two sites considered to be hotspots from examination of MCS public sightings data. These were the Isles of Arran and Mull. Neither of the hotspot sites established in the current SNH report; Coll, Hyskeir and Canna were mentioned (Speedie *et al.,* 2009). This may be a reflection of the lack of human activity around those sites and thus an under-reporting of sightings (to the MCS scheme), a widely recognised factor with public sightings schemes (Speedie, 2003; Doyle *et al.,* 2005).

Basking sharks may not exhibit discrete populations in UK waters, as tagging research indicates that basking sharks can travel the length of the UK in time periods of a few weeks (Sims *et al.,* 2003; 2005). There is one recorded incident of a basking shark transatlantic migration. An 8m long individual was tagged off the Isle of Man, Irish Sea in June, travelled south to south-west Britain and by late July crossed the mid-Atlantic ridge before the tag was released from the shark off Newfoundland in September (Gore *et al.,* 2008). This shark covered about 9,500km in 82 days and when in deep, mid-Atlantic water dived to over 1,200m. Genetic studies have shown no significant difference between the mitochondrial DNA of Atlantic and Pacific basking sharks and that basking sharks have the lowest level of genetic diversity of any shark (Hoelzel *et al.,* 2006). However, there is now evidence to suggest distinct genetic sub-groups of basking shark within UK waters: one population around the Isle of Man and another covering areas in the south-west of England and west coast of Scotland (L. R. Noble pers comm.). There is also evidence to suggest that basking sharks travel in extended family groups (L.R. Noble pers comm.). These data are expected to be published sometime in early 2013.

Current Research

Scottish Natural Heritage & University of Exeter (UoE)

One basking shark project currently underway is a tagging project funded by SNH in partnership with Dr Matthew Witt at the University of Exeter (UoE). The project is aimed at furthering the understanding of how basking sharks use sea areas within the Inner Hebrides and further afield in Scottish waters.

Twenty satellite communicating tags were deployed on basking sharks during July 2012. Eight of these were SPOT5 tags manufactured by Wildlife Computers, and provide information on the position of the shark each time it comes to the surface. The remaining tags were PAT-F transmitters, also manufactured by Wildlife Computers. These tags have an onboard a GPS receiver that will provide highly accurate estimates of shark locations. The tags have been designed to collect data over a nine month period and then detach from the shark. Once the tag detaches, it floats to the surface and transmits the collected data to over passing satellites.

The Satellite tags will provide information on the location and behaviour of individual basking sharks during the summer period, when survey data have highlighted that they occur in large numbers at the surface. The tags will also track the movement of basking sharks in the longer term (several months or more). The first PAT-F tags are not due to release from the tagged basking sharks until April 20th 2013, and therefore analysis and results from this project are not expected until sometime in late 2013.

University of Aberdeen

Dr Les Noble and Dr Cathy Jones head the Genetics Group at the University of Aberdeen and currently have a PhD student, Lilian Lieber, working on 'Basking Shark seascape genomics, spatial ecology and sustainability'. The project will be focussing on basking shark population connectivity within the Northeast Atlantic, and how they respond to oceanic pollution, as well as to changes in sea surface temperature and associated shifts in primary productivity.

Effective population size (*Ne*) is an important conservation measure for monitoring population size and genetic health. *Ne* evaluates the future evolutionary resilience of a species; e.g. the lower *Ne* becomes the greater the likelihood of deleterious allele fixation and loss of adaptive variation through genetic drift, thereby increasing the risk of population extinction. Short-term or contemporary *Ne* (denoted *CNe*) can be derived from the magnitude of recent genetic drift within a population, and approximates the mean number of breeding individuals contributing offspring per generation. The Aberdeen Genetics group are currently estimating *CNe* of basking sharks from Irish and Isle of Man waters. Lilian Lieber is analysing the first samples the group has from Scottish waters to obtain the microsatellite genotypes at 5 loci, to calculate a first crude estimate of breeding individuals from this area. The PhD began in September 2011 and should finish at the end of 2014.

Plymouth Marine Laboratory (PML) & Marine Biological Association, Plymouth (MBA)

Dr Peter Miller (PML) and Professor David Sims (MBA) are looking at Ocean fronts as an indicator of marine animals: expediting site selection and survey for offshore renewables focussing on basking sharks and ocean fronts (and seabirds and ocean fronts). The application of this research to offshore renewables is detailed below;

- Front technique could be applied to characterise the proposed sites of marine renewable installations
- Enable a cost-effective initial comparison of alternative sites in terms of potential impact on marine animals (and fishermen), and expedite the planning process
- Contribute to the environmental impact assessment, by estimating the likely abundance and distribution of key species known to inhabit the area
- During construction, use near-real time earth observation (EO) data to advise on operation times to minimise acoustic impacts on marine mammals (and basking sharks).

Publications related to this work are listed below:

Miller, P. I. 2012. Seasonal shelf-sea front mapping using satellite ocean colour for supporting Scottish marine protected areas. Report to the Scottish Natural Heritage. Contract No. PP560. Plymouth Marine Laboratory Applications, pp. 32.

Oppel, S., Meirinho, A., Ramírez, I., Gardner, B., O'Connell, A., Miller, P.I. & Louzao, M. (in press) Comparison of five modelling techniques to predict the spatial distribution and abundance of seabirds. Biological Conservation.

Miller, P.I. & Christodoulou, S. (in press) Frequent locations of oceanic fronts as an indicator of pelagic diversity: application to marine protected areas and renewables. Marine Policy.

Publications are also planned with the National Oceanographic Centre (NOC) and University of Exeter, comparing basking shark sightings compiled by the Marine Conservation Society with thermal front metrics and other environmental factors. The Hebrides is one of the key areas for the study and it is hoped this work will be published by the end of 2012, early 2013.

Joint Basking Shark Project: Population Estimates and Real Time Tracking

Dr Rupert Ormond is the project leader of this Save our Seas Foundation (SOSF) funded project in partnership with Marine Conservation Society and the Shark Trust, UK. The project aims to build a comprehensive photographic database of UK observed basking sharks, while simultaneously using satellite tracking to observe and investigate their migratory movements into international waters. The aims of the project are:

- To derive reliable estimates of population levels and trends for basking sharks in NW Europe, through boat-based surveys and photography for identification purposes, and collection of tissue samples for DNA analyses.
- To promote public awareness of basking sharks as a means of securing their protection and conservation through an environment exhibition at Breachacha Castle (Isle of Coll).

This project is funded from 2006 to 2012. There is no information available on when this project expects to publish results.

Scottish Power Renewables

RPS Group PLC is an international consultancy providing advice on the exploration and production of oil & gas and other natural resources. Since 2009, RPS has carried out visual surveys of basking sharks off the coast of Tiree at the Argyll Array site on behalf of Scottish Power Renewables (SPR). Surveys have been undertaken on a monthly basis with the exception of November 2009; January, August, September 2010 and May 2011 due to adverse weather conditions. In August 2012, in one day alone, 918 basking sharks were sighted off the south-west coast of Tiree near the Skerryvore lighthouse (T. Roberts pers comm.). A technical report from SPR is due sometime in December this year (2012) detailing data gathered as part of the RPS Group basking shark survey work undertaken at the Argyll Array site.

Marine Scotland – Potential Research

Basking Shark Population Abundance

Aerial Surveys

Aerial survey counts would provide data on regions where basking sharks are engaging in surface feeding behaviour. Aerial surveys will provide a ‘snapshot’ minimum abundance estimate for basking sharks in a particular region (Leeney *et al.,* 2011).

Canada is the only country that have carried out a population assessment of basking sharks (Campana, 2008; DFO, 2008). The absolute abundance of basking sharks on the south, east and north coast of Newfoundland out to the edge of the continental shelf was estimated from DFO's Trans North Atlantic Sightings Survey (TNASS) aerial survey of marine mammals in 2007 (Campana, 2008; DFO, 2008).

Development of University of Exeter/SNH Tagging Project

Dr Matthew Witt at UoE is currently working on a basking shark tagging project in partnership with SNH (mentioned above). The results from this project will provide information on depth utilisation by basking sharks. As such, the proportion of sharks available to be counted every hour (i.e. for each hour we know the likelihood of sharks being at the surface and hence available to be sighted) will be known. This information can be interfaced with aerial survey counts so to scale up what is counted to a more robust estimate of the total number of sharks likely to be present (given some/many might be at depth and hence not visible from the aircraft). Furthermore, satellite data will also provide suitable data for modelling basking shark environmental preference both vertically and horizontally. This model, interfaced with aerial survey counts, would further knowledge considerably allowing aerial surveys to be more suitably routed. For further information see Annex I.

Requirements:

- Suitable aircraft from which to conduct the survey
- Experienced, trained surveyors
- Suitable weather window
- Appropriate survey design
- Multiplication factor required to account for basking sharks not feeding at the surface and therefore not counted (results from the satellite tagged basking sharks should provide this data).

Genetic Sampling

To enable us to be confident that we know what part of the north-east Atlantic population the basking sharks present around Britain represent, genetic studies are being carried out aimed at describing stock characteristics in the north-east Atlantic in comparison with basking shark populations elsewhere in the world. However, we do not yet know if the results will enable us to distinguish a "British" population. To achieve this, additional archival tagging of sharks is required along different parts of the western seaboard, such as south Brittany, northwest Scotland and Norway to elucidate the extent of movement and mixing between local groups of basking sharks. Further archival tagging of mature

(>7 m) sharks is also required. The results will allow us to know whether exploitation outside the "normal" range of British basking sharks will affect them, and whether conservation measures around the UK will have any effect, either locally or on the north-east Atlantic population as a whole (Noble, *et al.,* 2006; Sims *et al.,* 2006).

Basking Shark Sensitivity to Electromagnetic Fields (EMF), Disturbance and Noise and Mitigation Options

There is no literature available specifically concerning the sensitivity of basking sharks to EMF, how they are affected by noise and what mitigation measures could be used to ameliorate these. However, there are some research ideas that could be conducted in order to answer such questions:

Electromagnetic Fields (EMF)

At present there is no research concerning the sensitivity of basking sharks to EMF. At offshore windfarms, EMF will be emitted into the water for several metres perpendicular to the axis of the cable, this has been estimated to be about 17m (Gill, 2005). Whether this will have any effect and more importantly any impact on basking sharks is purely speculation at the moment. Basking sharks do have the ability to detect minute electric fields. The ability to perceive electric fields is again an assumption but they do posses the ability to do so (Kempster & Collin, 2011). Basking sharks feed on zooplankton, which like all living organisms have bioelectric fields. Zooplankton induce small E fields through their swimming and interaction with the geomagnetic field. Other taxa related to sharks and that feed similarly to basking sharks are paddlefish (*Polyodon spathula*, a freshwater species found in the USA) that have been studied the most in this regard and they are able to detect the tiny electric fields from plankton (Pettigrew & Wilkens 2002; Wilkens *et al.,* 2001; Wojtenek *et al.,* 2001).

The anatomical features of a basking shark and similarity in feeding behaviour to paddlefish are the best clues there are. So it may be assumed that basking sharks use electric fields (and probably magnetic fields to some extent for navigating, linked with other attributes like ocean thermal fronts) and therefore based on the same reasoning behind other subsea cable EMF work they may detect the cables (A. Gill pers comm.) It is impossible to say they do because there is no information on levels of natural E field detection in basking sharks nor do we know if they are able to respond to artificial EMF (although other elasmobranches can). These are necessary pieces of information that are required before any assessment of effects of cable EMF on basking sharks can be properly considered. For further information see Annex II.

Disturbance and Noise

The technology is now available to attach ‘noise-recording’ tags to marine animals. Combined with acoustic listening stations and acoustic pingers, these noise detecting tags would be able to determine how basking sharks may/may not be affected by noise i.e. the construction and operation of windfarms. The acoustic listening stations and pingers will also allow insight into how basking sharks may/may not be disturbed by noise from other sources (such as boats) and indeed whether basking sharks are disturbed by the presence of boats and other construction traffic. For further information please see Annex I.

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Annex 1

Below is a brief outline of a new project proposal from Dr Matthew Witt at the University of Exeter. It builds on the tagging work currently underway in partnership with SNH.

Planning for renewables and Marine Conservation Zones (MCZ's) Gaining Detailed Insights into the Distribution of the Planktivorous Basking Shark

23rd October 2012

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Concept

To integrate data from state of the art biotelemetry techniques, including proximity loggers, animal-borne acoustic pingers and noise exposure recording technology, satellite telemetry units and forensic techniques (i.e. genetics) with data from traditional (e.g. boat-based and aerial surveys) and novel (i.e. sonar surveys) wildlife population census techniques. The strategic union of data from these methods would provide a significant advance in the understanding of basking shark population size, assumed foraging and courtship behaviour and seasonal distribution in Scottish waters. This knowledge would greatly facilitate decision-making processes with respect to the significant upscaling of marine renewable energy extraction in coastal waters. Our knowledgebase with respect to basking sharks is currently insufficient to make even simple predictions of likely impacts of renewable energy development construction, operation and decommissioning on this species of conservation concern.

Satellite Telemetry

This approach allows for an assessment of seasonal site fidelity for multiple individuals at highly resolved spatio-temporal scales. Data will be relevant to Marine Scotland and other statutory conservation agencies, including SNH and JNCC. Additional efforts in satellite telemetry deployment would build upon the considerable insights gained from tracking conducted in 2012, which was funded by SNH. While one year of tracking has highlighted novel movements in great detail, a multi-year data collection programme is advantageous, particularly for large planktivorous fish whose distribution is likely to change year-on-year dependent upon prey availability.

Population Census

Integrating basking shark depth preference data from satellite telemetry with data on the number of sharks sighted with a region gathered from simultaneous aerial survey offers a more robust estimate of population size, because knowledge on the proportion of the population visible becomes available (i.e. sharks can only be counted/seen when they are in the top 2-3 metres of the water column); resulting estimates of population size from more traditional survey methods can then be adjusted accordingly using data from state of the art data loggers. This approach might be further enhanced through the focused use of sonar to enumerate sharks throughout the water column so to increase knowledge on shark vertical distribution within sites of dense aggregation, which are often sites that receive aerial and boat-based survey attention.

Acoustic Tagging

Positional data from satellite telemetry can be limited in that they are only gathered when the shark and its associated tag are at the sea surface, as such knowledge on site residency, depth preference with a spatial context and phenology can be limited when sharks are in behavioural phases not associated with the sea surface. This problem can be obviated by the wide scale deployment of comparatively cheap and small acoustic pingers on basking sharks, these pingers can have long retention times in sharks (~years) and can be detected by statically moored listening stations. Data on acoustic detections of sharks can be collected by through-water modem from the listening stations using an over passing boat. The focused use of acoustic pingers with listening stations could provide knowledge on inter-annual site fidelity at proposed renewable energy sites (should listening arrays be installed at these locations). There is no knowledge on basking sharks inter-annual site fidelity, apart from a single photo-ID re-sighting, although we might predict that some form of fidelity across years exists, but the spatial scale of residency and the degree of plasticity is unknown. Use of this technology over several years would also yield knowledge on the seasonal departure and arrival times at the locations of the listening arrays.

Animal-Borne Noise Recording and Motion Tags - Quantifying the Behavioural Response of Basking Sharks to Anthropogenic Noise

The likely response of basking shark populations to the construction and operation of marine renewable energy developments is unknown. The population response, should there be one, is however, a cumulative response from the individuals within the population. Given that noise from construction has been associated to behavioural change in other marine vertebrate species it would be seem advantageous to gather data and therefore build an understanding of how basking sharks might respond to common sounds associated with the construction of marine renewable energy sites (e.g. pile driving noise from construction of wind turbines). This knowledge can be obtained through the deployment of animal-borne sound recording tags with associated motion recording tags and satellite telemetry. When combined these approaches will provide detailed insight on the behavioural responses of several sharks to anthropogenic noise and in particular what type of sound level and frequencies give rise to differing behavioural responses, this approach would provide a detailed dose-response curve for behaviour (including insights such as changes in depth preference, variations in swim speed, fleeing an area or remaining at a site, breaking off courtship etc.). It would be prudent to deploy such an approach at a renewable energy site before, during and following construction.

Plan of Work (over 3 years)

1. Deploy 30 x VR3 acoustic listening stations (with through water modems) at 3 sites in Scotland (all demonstrated to show basking sharks linkages)
2. Deploy 180 acoustic transmitters (pingers) over 3 years – to work with listening array
3. Deploy 90 proximity loggers over 3 years
4. Deploy 120 SPOT5 tags over 3 years
5. Deploy 30 acoustic recording tags (to investigate ambient sound field encountered/received by instrumented animals)
6. Genetically sample all individuals.
7. Conduct annual sonar surveys at Tiree (Argyll Array).

Procedure

1. Group A. Deploy proximity loggers and SPOT5 satellite tags on 10 sharks at each site (n = 3) in each of 3 years. Total: 90 proximity loggers and 90 SPOT5 tags.

2. Group B. In spring and summer of each year deploy the acoustic listening array and deploy 60 acoustic pingers (20 pingers at each site each year). Total: 180 acoustic transmitters.

3. Group C. Deploy 30 acoustic recording tags, each shark also receiving a SPOT5 satellite transmitter.

What Knowledge we will Gain from this Project

1. Knowledge on breeding / courtship system (from proximity loggers & genetics). Absolutely unknown what happens in the wild – but lots of suggestions [no facts].

2. Satellite telemetry allows for an assessment of site fidelity for multiple individuals (useful to the MMO and MS and other statutory conservation agencies; JNCC, SNH, NE, CCW). Builds upon 2012 data – multi-year data are crucial, particularly for large planktivores whose distribution is likely to change year-on-year dependent upon the prey field (which is highly dynamic, in magnitude and spatial distribution).

3. Using acoustic pingers on a large sample size we will gain knowledge on inter-annual site fidelity at proposed courtship/feeding ground (where a listening array would also be installed). No knowledge on inter-annual site fidelity, apart from a single photo-ID resighting. We would gain insights in to the seasonal departure and arrival times at the listening arrays given acoustic tags have longer retention periods than satellite tags.

4. Wide-scale genetic sampling will provide fine scale information of group assemblages. These data become even more useful when interfaced with proximity logger data and satellite tagging data.

5. Sonar work would allow for subsurface density estimation of sharks to be made, when interfaced with data on basking shark depth utilization from acoustic pinger and satellite tags more accurate estimates of density might be made.

Annex II

Below is a brief outline of some project ideas from Dr Andrew Gill at the Institute of Water & Environment at Cranfield University.

Basking Sharks and EMF
Project Ideas for Marine Scotland Science

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In order to answer the question(s) surrounding basking sharks and Electromagnetic Fields (EMF) it is important to have clearly defined objectives that can be met using the best available appropriate techniques. Knowledge on electromagnetic perception by Basking sharks is extremely scarce. They have the apparatus to detect both electric and magnetic fields. The projects summarised below highlight two types of approaches, field and laboratory, to address the objective of determining if basking sharks can respond to EMFs of the type associated with subsea cables. The ability to determine if there is an effect (i.e. a response) is the first step in then addressing whether there may be an impact (i.e. multiple individuals responding in a way that can be associated with subsequent changes to population status).

[The other research proposals from Dr Witt could be integrated here to provide a more cost-effective and scientifically robust assessment of how Basking shark individuals and population status may be affected by coastal and offshore developments such as marine renewable energy.]

Field Based

Determining if Basking Sharks Respond to EMF of the Intensity Emitted by Subsea Cables.

The research approach would be to locate basking sharks at the surface that are actively feeding and position an artificial EMF emitter in their path such that they will swim into the EMF emitted. The sharks need to be feeding in order to ensure they will be using their electrosense. The EMF emitter would have to be designed in a way that ensures the EMF emitted is encountered by the sharks. There are three potential options:

1. Aggregations of basking sharks are located through liaison with basking shark observation research groups. A team of researchers then turn up to deploy an EMF emitter and either through small boats/canoes/snorkelling locate the emitter in the path of the moving basking sharks. A separate observer boat/snorkeller would then record movement and behaviour according to a predetermined set of unambiguous behaviours. This is similar to marine mammal observer surveys. It would be important to have a control/placebo emitter that is exactly the same but does not have an EMF associated with it. The behavioural observer would not be aware of whether the actual emitter or placebo was being used.

2. Similar to above but putting a cable across a stretch of water, such as a loch narrows, where baskers move/migrate through. A camera system could collect data on behaviour or a set of observers.

3. Either of the above but using data logger tags with accelerometers which would be attached to a number of individuals to quantify speed and direction of movement changes which would be correlated with the position of the shark in relation to the EMF emitter.

Laboratory Based

Electroreception in Basking Sharks – Do Artificial EMFs Affect Movement and Feeding Behaviour?

The approach proposed here would take advantage of more controlled conditions associated with laboratory based studies. It would require either shallow water fish pens/nets or very large recirculating tanks or lagoon areas that could be netted off to provide an enclosed and therefore controllable area. It would be important, however, to ensure that any fish used were held captive only for a short period.

For the fish pens/tanks the basking sharks would have to be juveniles owing to the physical size of the fish in relation to the required size of pen to get appropriate behaviour exhibited. The advantage of this method is that magnetic field exposure studies could be conducted using Helmholtz coils to create a measurable and stable magnetic field to then assess the shark behaviour within. This method has been used successfully for hammerhead and sandbar sharks in 10m diameter fish tanks.

The lagoons (or natural bays) could be selected to be large enough to accommodate larger individuals. The study would be looking for any response by the fish to cables installed in the enclosed area. For statistical rigour the same individual could only be used a few times. Hence, there would need to be several individuals available that would be subject to the enclosed area for a short period. But this could be over a long period of time to take advantage of times when sharks are in the area.

The enclosure/tank would be partitioned in terms of areas where there were active EMF emitters (i.e. cables) and those with controls/placebos. Within these areas would be locate sets of cameras to record behaviour and spatial distribution and/or similar to the field study suggestion datalogger or acoustic tags could be used to quantify real time responses of each individual.

In addition to these enclosure studies the preferred food of basking sharks (i.e. species of zooplankton) could be introduced to measure how the sharks respond to food availability in light of the presence/absence of EMF. This would allow a set of quantifiable behaviours to be drawn up associated with the different environments that the fish encounter.

A parallel lab study could be conducted that uses EM sensors to measure the bioelectric emissions from the prey of basking sharks. A series of aquaria with sensors would be set up with different densities of zooplankton to determine the intensity and extent of the bioelectric fields, following procedures that have been used for paddlefish and zooplankton. The quantified emissions can be complemented by EMF measurements of subsea cables to compare the intensities, extent and geometries of the emitted fields.

No cost estimates have been included here but the principle cost will be researcher labour in all of the studies proposed. Detailed proposals and budget costs can be provided on request.

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Copies of this report are available from the Marine Scotland website at
www.scotland.gov.uk/marinescotland