

# Marine Biodiversity Records

## Basking shark breaching behaviour observations West of Shetland

--Manuscript Draft--

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<b>Full Title:</b>	Basking shark breaching behaviour observations West of Shetland
<b>Article Type:</b>	Marine Record
<b>Funding Information:</b>	
<b>Abstract:</b>	<p>This study reports observations of basking sharks (<i>Cetorhinus maximus</i>) sighted during an offshore geophysical survey conducted in July and August 2013, west of Shetland, UK. During the 38-day survey, trained and dedicated marine wildlife observers recorded 19 sightings of basking sharks (n=22 individuals). Of these observations, 17 were of single sharks, with one observation of two sharks and one observation of three sharks. All surface sightings occurred in water depths between 129 and 199 m, predominantly prior to noon local time (79%), and were mostly of sharks 6-8 m in length, although a young (2 m) individual was also recorded. Breaching behaviour was observed on 14 occasions, by individuals or in small groups. Breaching has been proposed as a male-male competitive behaviour during courtship displays and female basking sharks may breach to signal their readiness for mating. Aggregations of basking sharks at frontal systems are well documented and linked to the occurrence of prey patches; however, these oceanographic features may also be of importance to courtship. The high number of sightings of sharks recorded during a relatively short time frame in addition to breaching behaviour and presence of young individuals, suggests that this area west of Shetland may be an important habitat for the basking shark.</p>
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<b>Order of Authors Secondary Information:</b>	
<b>Response to Reviewers:</b>	<p>Reviewer 1: Comment 1</p> <p>Given the incredible amount of work on basking sharks in the Northeast Atlantic, the work could use some more exploration and contextualization. In particular, can you relate the oceanographic conditions, in particular, the fronts to the likelihood of observing a basking shark breaching? Do they breach during strong fronts or between strong fronts? While it is fine to report that you saw basking sharks in the area, it would be of greater utility to explore some of the relationships with the occurrence records and the environmental conditions. The records needed to be summarized and related as least correlatively to the observations.</p> <p>Answer 1</p> <p>To do a good job of what the reviewer asks we need a dataset of many tens to hundreds of records to ensure we don't get type 1 or 2 statistical errors. We picked the</p>

MBR as a journal because we wanted to share the information on shark detection in the study region, but yet we knew the dataset was likely not robust enough to do very detailed work as is being requested here.

Comment 2

"...discrete zooplankton 'hotspots' at shelf-break fronts that form continental shelf and shelf..." odd phrasing

Answer 2

Re-phrased.

Comment 3

"In shallow inner-shelf regions..." of the Northeast Atlantic. The same patterns do not occur worldwide.

Answer 3

Inserted 'of the Northeast Atlantic'.

Comment 4

These were never related to your observations of basking sharks breaching.

Answer 4

Weather is summarised as favourable (lines 95-97). Yet we are not sure how to tie this in with breaching behaviour as suggested.

Comment 5

This is very speculative as the animals can easily swim 50-200 km a day.

Answer 5

Deleted sentence.

Comment 6

Can the frontal boundary be added to the plot. It would highlight the importance of fronts in the work.

Answer 6

There are several frontal boundaries already visible; pixels indicate the number of times a boundary was present in the cell; this symbology is necessary as the frontal data are summed over the period of the study, rather than showing a frontal boundary for a single day (which would then not be temporally relevant to whole sightings dataset)

Comment 7

Labels needed to be larger. Especially the legend on Figure 1D.

Answer 7

Done.

Comment 8

Cite and integrate: Crowe et al. (2018)- Characterization of large basking shark *Cetorhinus maximus* aggregations in the western North Atlantic Ocean

Answer 8

Integrated into the Background section

Comment 9

A histogram of the sighting time of day or the breaching time of day would be useful.

Answer 9

Not possible. Reasons outlined in the Answer 1.

Reviewer 2:

Comment 1

Is it possible that any of the breaching behaviour could have been a startle response from the seismic airgun? There isn't a lot of research done in this field for elasmobranchs yet, although a fairly recent review eludes to the possibilities of impacts on physiology and behaviour of sharks:

Carroll, A., Przeslawski, R., Duncan, A., Gunning, M., Bruce, B., 2017. A critical review of the potential impacts of marine seismic surveys on fish & invertebrates. *Marine Pollution Bulletin* 114, 9-24.

Answer 1

A paragraph added to address this (lines 126-129)

Comment 2

Is there a measure of shark sighting density that you could compare your study with other known aggregation areas, to give the reader some context of how dense sightings are in this area? This may further bolster your argument for the importance of this area for basking sharks.

Answer 2

CR339 from SNH by Speedie, Johnson and Witt provides an indication; we have updated Fig. 1D to express effort by hours and converted hexagon grid resolution to 25km<sup>2</sup>. This means the grid is now at the same spatial resolution as CR339 and the

	survey effort is expressed using hours too.
<b>Additional Information:</b>	
<b>Question</b>	<b>Response</b>
<p><b>Is this study a clinical trial?</b></p> <hr/> <p>A clinical trial is defined by the World Health Organisation as 'any research study that prospectively assigns human participants or groups of humans to one or more health-related interventions to evaluate the effects on health outcomes'.</p>	No

[Click here to view linked References](#)

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6 1 **Basking shark breaching behaviour observations West of Shetland**

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26 10 **Abstract.** This study reports observations of basking sharks (*Cetorhinus maximus*) sighted  
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28 11 during an offshore geophysical survey conducted in July and August 2013, west of Shetland,  
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30 12 UK. During the 38-day survey, trained and dedicated marine wildlife observers recorded 19  
31 13 sightings of basking sharks (n=22 individuals). Of these observations, 17 were of single  
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33 14 sharks, with one observation of two sharks and one observation of three sharks. All surface  
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35 15 sightings occurred in water ~~with~~ depths between 129 and 199 m, predominantly prior to noon  
36 16 local time (79%), and were mostly of sharks 6-8 m in length, although a young (2 m)  
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38 17 individual was also recorded. Breaching behaviour was observed on 14 occasions, by  
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40 18 individuals or in small groups. Breaching has been proposed as a male-male competitive  
41 19 behaviour during courtship displays and female basking sharks may breach to signal their  
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43 20 readiness for mating. Aggregations of basking sharks at frontal systems are well  
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45 21 documented and linked to the occurrence of prey patches; however, these oceanographic  
46 22 features may also be of importance to courtship. The high number of sightings of sharks  
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50 24 presence of young individuals, suggest that this area west of Shetland may be an important  
51 25 habitat for the basking shark.

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**Keywords.** Basking shark, *Cetorhinus maximus*, west of Shetland, breaching, courtship.

**Background.** The basking shark (*Cetorhinus maximus*) is the largest fish in UK waters and the second largest fish globally, reaching 12 m in length and weighing up to 4 tonnes [1]. Basking sharks have been shown to feed where water masses meet, such as at interfaces between bodies of water, including tidal and oceanic fronts, typically with strong thermal gradients [1,2]. At these fronts, plankton are typically found in higher concentrations [3]. Basking sharks follow their prey horizontally and vertically, and are known to forage over large distances often observed singly, or in pairs, but can be also found in large groups ~~numbering over fifty individuals forming aggregations~~ [4,5]. Sightings in the ~~North~~east Atlantic are usually recorded between April and October, with the peak number of sightings between June and August [6].

The European continental shelf is a particularly important habitat for basking sharks and although they can demonstrate acute site fidelity to coastal regions, movements can be widespread [7-10]. In the northeast Atlantic area they are considered *Endangered* by the IUCN [11]. Basking sharks have been shown to travel long distances to locate ~~temporally discrete aggregated~~ zooplankton ~~'hotspots', that can occur at-at shelf break- \_frontal systems~~ that can form in continental shelf and shelf-edge habitats [3,12]. In shallow inner-shelf regions of the Northeast Atlantic, near thermal fronts, sharks have been known to exhibit reverse diel vertical migration (DVM), where they are typically near the surface during daylight hours. This is most likely due to the reverse DVM of basking sharks prey, *Calanus* sp. in the area [13].

In the UK, high relative densities of surface sightings occur on the west coast of Scotland, around the Isle of Man and on the southwest coast of England [6,14,15]. There are two established hotspot sites in Scotland, which are 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

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the Inner Hebrides [76,154]. The Hyskeir and Canna hotspot support high numbers of sharks involved in putative courtship behaviour and is a site where breaching activity has been recorded [154]; the functional role of breaching has however yet to be resolved, but might involve intra-species communication to find mates or deter competing conspecifics for breeding opportunities [165]. The occurrence and distribution of basking sharks to the west of the Shetland Islands (Fig. 1a; 60.5° N, 2.1° W), remains poorly understood with only few sightings documented in this region over the past 20 years [65]. A paucity of data potentially reflects the remote nature of this island archipelago, but also that data from ~~more~~ offshore regions is necessarily limited by reduced sightings effort and subsequent reporting to public recording programmes, such as those operated by the Marine Conservation Society (UK) and the Shark Trust (UK). This study reports upon the sighting of basking sharks breaching to the west of Shetland, observed during marine wildlife observations made during 2D seismic survey activity.

**Methods.** Marine wildlife observations were conducted by experienced Marine Mammal Observers (MMOs) on an 80 m long seismic source vessel from July 2<sup>nd</sup> to August 9<sup>th</sup> 2013 in an area to the west of Shetland during hours of daylight. The survey route followed linear transects of between ~15 and ~25 km length travelling either in a south-east to north-west (and reciprocal) or south-west to north-east (and reciprocal) direction; approximate travel speed during line transects was 4 knots; and approximate distance between transects was 2.5 km (Fig. 1a). Observers stationed 11 m above water level surveyed 360 degrees of visible seascape first searching by the naked eye for visual cues followed by focused following using binoculars. Locations of basking shark sightings were determined from the vessel location on first detection along with information on the bearing (degrees; 0 to 360) and distance (m) to the sighting. Distance to sharks was estimated using a range finder [16]. Information on environmental conditions was recorded at either 60-minute intervals or if weather or acoustic source activity changed. The observers recorded data on wind force (Beaufort scale; 0 to 12), sea state (glassy, slight, choppy, rough), visibility <1 km, 1-5 km,

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6 79 >5 km), sun glare (weak, strong, variable/forward, behind) and swell condition (<2\_m, 2-4 m,  
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8 80 >4\_m). The instantaneous location of the survey vessel in decimal degree latitude and  
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10 81 longitude (World Geodetic System, 1984) was determined by an on-board GPS (at 1-second  
11 82 interval) and were archived to retrospectively calculate spatial-temporal search effort. Survey  
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13 83 location data (GPS) were transformed to Universal Traverse Mercator Zone 30 prior to  
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15 84 analysis. Survey effort was expressed as cumulative ~~minutes-hours~~ across the survey region  
16 85 using a ~~hexagonal~~ grid (25 km<sup>2</sup> cell area) to facilitate comparison with estimates of basking  
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18 86 shark density (sharks h<sup>-1</sup>; SPUE) on the West Coast of Scotland (Speedie et al 2009).  
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20 87 Seismic survey airguns operated continuously during the survey period ceasing occasionally  
21 88 during line turns and periods of adverse weather conditions. Acoustic impulses were made  
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23 89 by a source array, which consisted of four air gun elements (total volume 160 inch<sup>3</sup>).  
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25 90 Cumulative presence of daily thermal fronts (0.5°C threshold) for the study period (38 days)  
26 91 were calculated from GHRSSST L4 daily surface temperature data using the MGET Cayula-  
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28 92 Cornillon fronts detection algorithm [187].  
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31 93 **Results.** During the survey period (July 2<sup>nd</sup> to August 9<sup>th</sup> 2013; n=39 cumulative survey  
32 94 days), 19 sightings of basking sharks (n=22 individuals) were recorded (**Fig. 1**). Weather  
33  
34 95 conditions during this time were mostly favourable characterised with predominantly slight  
35 96 sea state (6165%), low swell (7684%), wind Beaufort force between 2 and 4 (7978%) and  
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37 97 visibility exceeding 5 km (630%). Effort-corrected basking shark density ranged from 0 - 0.75  
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39 98 sharks (mean: 0.05) per cumulative hour of survey across the survey region. Distance from  
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41 99 the survey vessel to sighted sharks on first detection ranged from 30 m to 3 km (median 800  
42 100 m, interquartile range 1450 m). Sightings ranged from momentary observations up to 24  
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44 101 minutes in duration (median 1 min., interquartile range 9 min.). Of the observations, 17 were  
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46 102 of single sharks, with one observation of two sharks and one observation of three sharks  
47 103 within close proximity of each other. The survey was conducted in linear transects thus  
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49 104 reducing the probability of double counting basking sharks, which could result in  
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51 105 overestimation. Basking sharks were observed breaching clear of the water on 21/4

Commented [EH1]: 15 sightings included breaching behaviour. There was a total of 21 breaching events hence the correction.

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occasions (**Fig. 2A**). All sightings were in waters ~~with~~ depths ranging from 129 to 199 m. The majority of sightings (79%) and breaching eventsees (95%) occurred prior to noon local time and were mostly of sharks approximately 6-8 m in length. Other observed behaviours were slow and directed swimming and surfacing (**Fig. 1D, Fig. 2B**). On one occasion an individual basking shark was sighted breaching three times in succession followed by another single breach approximately 20 minutes later. ~~Two~~ other basking sharks were sighted breaching twice on ~~two~~ separate occasions, and a young basking shark (~2\_m total length) was observed breaching after a nearby adult had breached.

**Discussion.** Breaching has been proposed as a male-male competitive behaviour during courtship displays and female basking sharks may breach to signal their readiness for mating [165]. Basking sharks can aggregate in prey patches near fronts to feed, and as such this behaviour increases the likelihood of mature individuals meeting to initiate courtship [165]. Frontal systems may therefore be oceanographic features of importance for feeding and for courtship. ~~Young basking sharks (~2 m) are thought to be born in the season of their sighting [18], indicating births may occur within or near this area too.~~ Should such breaching behaviour form part of courtship in the mating system of *C. maximus* then regions which support this behaviour may benefit from further research and enhanced wildlife management measures. Estimates of basking shark density for this survey are consistent with those from the West Coast of Scotland, where Speedie et al. (2009) [14] reported densities ranging from 0 to 4.46 sharks per cumulative hour of survey.

Although startle responses to acoustic sources have been recorded in some elasmobranch species, research in the behaviour of basking sharks and other elasmobranch species to seismic sources is poorly understood and yet to be investigated [19,20]. This dataset is not of sufficient size to conduct a robust analysis and draw any conclusions.

**Conclusions.** Taking into consideration the number of sightings of basking sharks recorded during this survey, the breaching behaviour, the presence of young individuals as well as the



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suitability of the region in terms of oceanographic features, it is possible to suggest that this area west of Shetland may be an important habitat for basking sharks. Given the limited nature of this dataset, it is highly recommended that additional studies are conducted in the area to support these findings.

**Fig. 1.** Basking shark breaching behaviour recorded west of Shetland. (A) Shetland Islands, (B) presence of thermal fronts (shown as cumulative days front present within study period), (C) survey transects by seismic vessel and (D) cumulative survey effort (minutes) and sightings of breaching basking sharks (black filled circle), sharks observed slow swimming (white filled star) and surfacing (grey filled triangle) for the period July 2<sup>nd</sup> to August 9<sup>th</sup> 2013.

**Fig. 2.** Basking shark breaching (A) and surface behaviour (B) observed west of Shetland.

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**Availability of data and materials.** All data made accessible during this study are included in this published article.

**Author's contributions.** All authors contributed to data analysis and manuscript preparation.

**Competing interests.** The authors declare that they have no competing interests.

**Consent for publication.** The authors declare that the owners of the data have consented to publication.

**Ethics approval and consent to participate.** Permissions to conduct seismic surveying, from which this data resulted were acquired from relevant authorities by the data owners.

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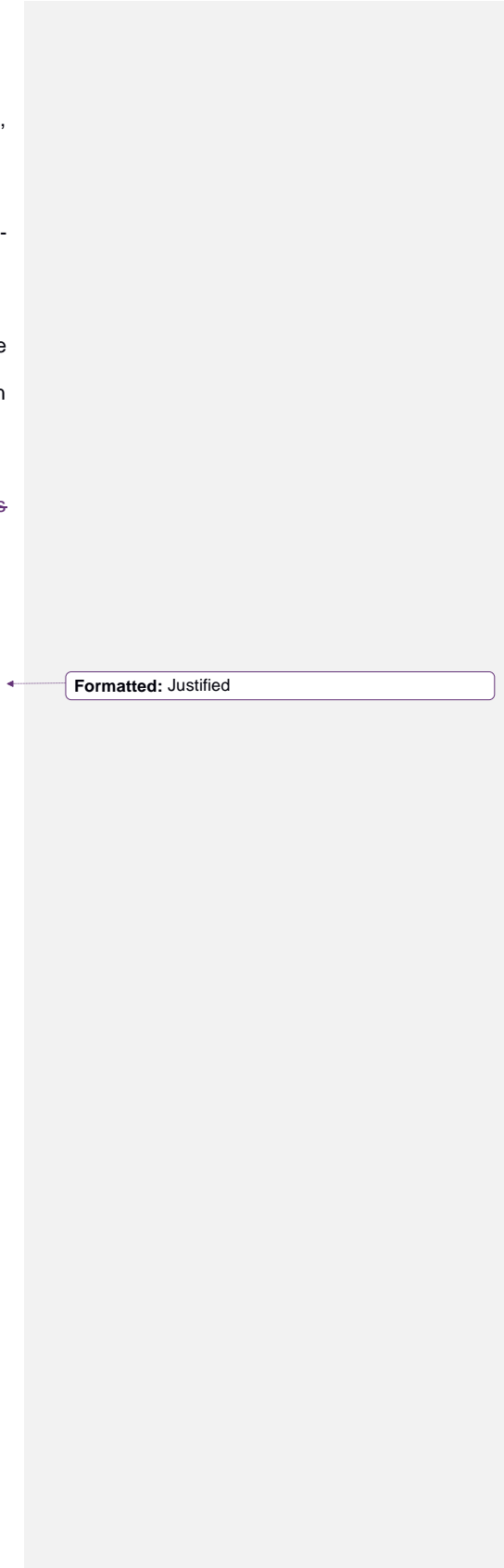
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