Fisheries and Oceans Canada | Pêches et Océans Canada
Ecosystems and Oceans Science | Sciences des écosystèmes et des océans

Pacific Region

Canadian Science Advisory Secretariat
Science Response 2016/046

EVALUATION OF INFORMATION AVAILABLE TO SUPPORT THE IDENTIFICATION OF HABITAT NECESSARY FOR THE SURVIVAL AND RECOVERY OF BASKING SHARK IN CANADIAN PACIFIC WATERS

Context

When an aquatic species is listed on Schedule 1 of the *Species at Risk Act* (SARA) as Threatened, Endangered or Extirpated, Fisheries and Oceans Canada (DFO) is required to identify and protect habitat required for the survival and recovery of the species, which is linked to the population and distribution objectives established in a species recovery strategy. The identification is based on the best available information and is typically provided in the form of scientific advice (peer-reviewed research document and scientific advisory report).

Basking Shark are currently listed under SARA as an Endangered species. Both a Recovery potential assessment (DFO 2009) and a Recovery Strategy have been completed for this species (DFO 2011). The Recovery Strategy notes that “Adequate information does not exist to identify critical habitat at this time” (p. iii). A schedule of studies was identified in the Recovery Strategy, outlining research required to contribute to the future identification of critical habitat, with the recognition that it “may take decades to address the issue of identifying critical habitat, given the long lived nature of the species, a lack of documented recent sightings in Canada, and the associated long-term scope of this recovery strategy” (p. iii).

In support of the requirements under SARA, DFO Science has been asked to undertake an assessment and update of the information available for Basking Shark, in support of a potential future habitat assessment based on the national Guidelines for the Identification of Critical Habitat for Aquatic Species at Risk (Fisheries and Oceans Canada, 2015[1]). This advice may be used to inform the identification of habitat necessary for the survival and recovery of Basking Shark, and/or be used in an action plan for this species.

This Science Response results from the Science Response Process of May 2016 on the Evaluation of Information Available to Support the Identification of Habitat Necessary for the Survival and Recovery of Basking Shark.

Background

This Science Response provides a review of available information that would support the identification of habitat necessary for the survival and recovery of Basking Shark within Canadian Pacific waters. The three objectives listed below were identified to support this review, and are responded to in further detail within this document:

[1] Fisheries and Oceans Canada. 2015. Species at Risk Act (SARA) Guidelines for the Identification of Critical Habitat for Aquatic Species at Risk. Unpubl. report, January 2015, Ecosystem Management Branch, Ottawa, Canada, 43 p

1. Present the best available information on the habitat necessary for survival and recovery of Basking Shark in Canadian Pacific waters, including progress updates with respect to the schedule of studies identified in the Recovery Strategy.
2. Identify and describe gaps in data and knowledge that preclude full identification of habitat necessary for the survival and recovery of Basking Shark.
3. Review the schedule of studies and provide advice on changes or additions to the schedule that would be necessary to address data gaps if possible.

This assessment and update is in support of a potential future habitat assessment based on the national Guidelines for the Identification of Critical Habitat for Aquatic Species at Risk (DFO 2015).

The Basking Shark (*Cetorhinus maximus*) is the world's second largest fish, reaching a maximum recorded length of 12.2 metres. Basking Sharks exhibit life history characteristics of overall low productivity, namely longevity (~50 years), slow growth and maturation, and low fecundity. They are filter-feeders, feeding primarily on copepod zooplankton. Basking Sharks are found circumglobally in coastal shelf waters. In Canadian Pacific waters, they are considered to be part of a population which migrates into British Columbia waters in spring and summer, and winters off California (McFarlane et al. 2009). Current abundance in Canadian Pacific waters is unknown, but it is estimated that some proportion up to the full range-wide population (321-535 individuals) seasonally utilizes Canadian Pacific waters (McFarlane et al. 2009). These numbers are, however, highly uncertain. Historically, large aggregations of Basking Sharks numbering in the hundreds or possibly thousands were seasonally common and widely distributed in Canadian Pacific waters (McFarlane et al. 2009). The use of photo-identification and analyses of re-sighted Basking Sharks in the northeast Atlantic support the premise that Basking Sharks utilize favourable feeding zones that extend over large regions (Gore et al. 2016). They are not dependent on restricted feeding locations, but rather continuously move between areas on spatial-scales of tens of kilometers on time-scales of days (Gore et al. 2016). At present, Basking Sharks appear infrequently in Canadian Pacific waters with only 33 confirmed sightings since 1996. It is important to note that most of these sightings are of Basking Sharks in surface waters, and it is estimated that individuals spend, on average, only 19% of their time near the surface (Westgate et al. 2014).

The Canadian Pacific population of Basking Shark was assessed as 'endangered' in 2007 by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). In February 2010 the population was listed as 'endangered' under Canada's *Species at Risk Act* (SARA), affording it legal protection. The *Recovery Strategy for the Basking Shark (*Cetorhinus maximus*) in Canadian Pacific Waters* was completed in 2011, which outlined the key factors limiting the recovery and survival of Basking Sharks, identified population and distribution objectives and broad strategies to guide recovery efforts, and provided a schedule of studies to identify critical habitat for Basking Sharks within Canadian Pacific waters (DFO 2011). Critical habitat is defined under SARA as "the habitat that is necessary for the survival or recovery of a listed wildlife species" and must be identified within a SARA recovery strategy or action plan. Further, habitat in respect of aquatic species is defined as "spawning grounds and nursery, rearing, food supply, migration and any other areas on which aquatic species depend directly or indirectly in order to carry out their life processes, or areas on which aquatic species formerly occurred and have the potential to be reintroduced". Information to support identification of habitat necessary for the survival or recovery of Basking Shark should include the geographic location (e.g. coordinates); biophysical function, features, and attributes; and a summary of habitat identification relative to population and distribution objectives within the recovery strategy (DFO 2015).

The habitat features and associated life functions that they support are unknown for Basking Sharks in Canadian Pacific waters, and specific locations have been not been identified for reproduction, pupping or rearing (DFO 2011). In the Atlantic, there has been speculation that aggregations of Basking Sharks, in addition to foraging, also represent group courtship behavior (Harvey-Clark et al. 1999; Sims et al. 2000). Sims et al. (2000) suggest that persistent thermal fronts are important areas for Basking Shark courtship and mating.

Critical habitat has not been defined for this population's southern range (e.g. the U.S. and Mexico) or elsewhere in the world, even in locations where dedicated research and science has been ongoing for this species (e.g. the United Kingdom). In the Atlantic ocean, Basking Sharks tend to aggregate in the transition zones of coastal shelves where there is enhanced copepod zooplankton abundance (Sims et al. 2006), but these habitat characteristics vary over temporal and spatial scales and specific habitat features essential for foraging have not been identified. In Atlantic populations, when foraging in surface waters, Basking Sharks prey primarily on calanoid copepods (small, ~2 mm, zooplankton, Sims 2008). Globally, Basking Sharks exhibit a preference for waters between 8 and 18ºC, with a high affinity for temperatures 15-18 ºC (Sims et al. 2003, Skomal et al. 2004). However, in the Bay of Fundy, sea surface temperature was not a statistically significant predictor of Basking Shark survey sightings (Hoogenboom et al. 2015). In that study, sightings were best predicted by a large-scale climate index (North Atlantic Oscillation index) although the mechanisms behind the correlation were unclear (Hoogenboom et al. 2015). In the eastern North Atlantic, Basking Shark surface observations were more probable in frontal zones, with thermal front activity having a stronger influence over the probability of observing a Basking Shark than productivity front activity, as measured by chlorophyll a (Miller et al. 2015).

Critical habitat was not identified in the Basking Shark Recovery Strategy (DFO 2011) due to insufficient information at that time; however, the Recovery Strategy included a schedule of studies outlining the research required to gather information that would contribute to the identification of critical habitat (Table 1). The Recovery Strategy noted that it may take decades to address the issue of identifying critical habitat, given the long-lived nature of the species, the relative scarcity of documented recent sightings in Canada, and the long-term scope of recovery efforts. This Science Response provides progress updates with respect to the schedule of studies identified in the Recovery Strategy. Outstanding gaps and knowledge that preclude full identification of habitat necessary for the survival and recovery of Basking Shark are identified and recommendations are made on changes or additions to the schedule that would be necessary to address these data gaps.

Table 1. Schedule of studies to identify critical habitat as listed in the Recovery Strategy for the Basking Shark (*Cetorhinus maximus*) *in Canadian Pacific Waters (DFO 2011).*

Description of Activity	Outcome/Rationale	Timeline
1. Maintain and promote the Basking Shark sightings network. Develop the Basking Shark Sightings Database (2010). Maintain and promote the Basking Shark Sightings Network.	Determine extent of species' distribution and potential habitat in Canadian Pacific waters.	2010-2015 Ongoing
2. Basking Shark Tagging Program Opportunistic satellite tagging of Basking Sharks in Canadian Pacific waters.	Confirm location(s) of Basking Shark presence in Canadian Pacific waters; determine seasonal distribution, movement, abundance and residency of species.	2010-2015 Ongoing
3. Opportunistic sampling program Biological sampling from live sightings and mortalities.	Species distribution, population structure, sex, biophysical features, stomach contents, habitat use by life stage.	2010-2015 Ongoing
4. Overflights Use of real time satellite imagery to identify high plankton blooms for targeted overflights (May-September).	Biophysical features and species distribution.	2010-2015 Ongoing
5. Definition of Critical Habitat Determine and characterize occupied high-use habitat and define potential critical habitat regions with similar characteristics.	Define high use occupied habitat.	To be determined

Analysis and Response

Review of Schedule of Studies

Maintain and Promote the Basking Shark Sightings Network

Methods and Data Sources

The Basking Shark Sightings Network (BSSN) was established in 2008 to solicit and document sightings of and encounters with Basking Sharks in Pacific Canadian waters. The target audience included First Nations, commercial and recreational fishers, adventure tourism operators and their clients, float plane operators, water taxi drivers, and any member of the general public who might be on the water and able to observe a shark. The BSSN was advertised internally within DFO and externally primarily through a mail-out campaign which targeted the above audiences, and included a letter explaining the program and a poster that the recipient could post in a visible location. In addition, DFO staff were interviewed by newspaper and radio media following the assessment of the Canadian Pacific population of Basking Shark as 'endangered' by COSEWIC (COSEWIC 2007), providing further advertising of the BSSN. To facilitate reporting by members of the public, a dedicated email address and toll-free phone number were set up, a webpage with information about the program, contact information, and an online reporting form was developed under the DFO Pacific Region Science internet page. Members of the public were encouraged to report any recent or past sightings of

Basking Sharks, and were asked to provide details such as the date, location, and a description of the sighting, as well as any photos or video that could be used to confirm the sighting.

In response to the 2010 SARA listing of the Canadian Pacific population of Basking Shark as 'endangered', increased resources were applied to the sightings network, and a series of themed printed materials were commissioned from a professional graphic designer. Printed materials included glossy posters available in both Official Languages, business cards with identification and contact information, brochures advertising the program, and a large banner which could be used for displays. DFO staff gave oral presentations on Basking Sharks and the sightings network at community events, campgrounds, and marine festivals on Vancouver Island. Further media interviews were conducted. A modest "reward" program was developed, with promotional materials such as hats, jackets, and embroidered badges being available to send to members of the public who reported sightings. The original contact list from the mail-out campaign was expanded, and new materials were sent out.

Sighting reports which were accompanied by photographic or video evidence from which positive identification of a Basking Shark could be made were designated as "confirmed." Other sightings were assigned qualitative reliability ratings by DFO staff (Table 2).

Table 2. Reliability ratings for sightings of Basking Sharks reported to the Basking Shark Sightings Network.

Reliability Rating Code	Description
1	Confirmed Sighting (photos/video)
2	Reliable Sighting (no photos/video but description sufficient for positive ID, taking into account the reporter's historical expertise with Basking Sharks and/or other large marine animals)
3	Possible (description suggests a Basking Shark but insufficient for positive ID)
4	Unlikely (description/circumstance/time of year indicates not a Basking Shark)
5	Unknown (insufficient information)

In addition to anecdotal live sightings of Basking Sharks, the sightings network also included historic (1999-2011) bycatch data from the BC commercial Groundfish bottom trawl fishery. This fishery has been subject to 100% observer coverage since 1996, and bycatch records are considered reliable. Since 2011, a condition of all BC commercial fishery licenses is the mandatory reporting of Basking Shark bycatch. There have been no encounters with Basking Sharks in commercial fisheries since 2011.

Results and Discussion

There were 33 confirmed or reliable Basking Shark sightings reported to the BSSN from 1996 – 2015 (Table 3, Figure 1). The Recovery Strategy (DFO 2011) lists 13 confirmed/reliable sightings from 1996 – 2010, of which six confirmed sightings in 1996 – 2005 were previously reported by COSEWIC (2007). Additional reports, and further analysis of existing reports has resulted in removal of some records previously thought to be confirmed sightings, as well as addition of new records to the 1996 – 2010 time period. In addition to the confirmed and reliable sightings, the BSSN received 66 additional reports for sightings which occurred between 2008 and 2015, of which 46 were deemed to be possible Basking Sharks, 11 were unknown, and 9 were unlikely to be Basking Sharks. Possible sightings are included in Figure 1. Sighting reports were received from recreational boaters and fishers, fishing charter operators and kayak guides, independent kayakers, water taxi and ferry operators, lightkeepers, DFO and Coast Guard staff, commercial fishers, hikers along coastal trails (e.g. the West Coast Trail), and others.

The Recovery Strategy identified entanglement with commercial fisheries as a potential threat to Basking Sharks (DFO 2011). Of the four records of Basking Sharks originally reported from the BC Commercial Groundfish Trawl fishery in 1996 – 2000, two records have been deemed unlikely to be Basking Sharks, as they occurred in February and March, when Basking Sharks are thought to be absent from BC waters. This interpretation is consistent with that of other sightings which have been rated as unlikely to be Basking Sharks due to time of year (Table 2). There was one confirmed record of an entanglement with fishing gear, which was reported to the BSSN in August 2014; a Basking Shark was entangled in gillnet gear in an Aboriginal fishery for food, social and ceremonial purposes in Barkley Sound, but the shark broke free and was apparently unharmed.

The number of sightings reported to the BSSN from 2008 – 2015 has ranged between 3 and 29 reports per year (Table 4), with peak reporting occurring in 2008 (29 reports) and 2010 – 2012 (17 – 22 reports per year). It is not possible to know if any of these sightings are re-sightings of the same individual. However, photo identification of individual Basking Sharks is possible (Darling and Keogh 1994; Hoogenboom et al. 2015; Gore et al. 2016) so re-sightings of individuals could be evaluated if high resolution photos of dorsal fins were available. Reports to the BSSN each year include current-year sightings, as well as sightings that occurred in previous years. The reporting of past sightings was greatest in 2008, when there were 18 reliable reports of Basking Shark sightings from 1945 – 2007 (Table 4), which outnumbered the reports of sightings for that current year. It is assumed that the publicity associated with media reports and novelty of the initial BSSN campaign resulted in the large number of historical reports in 2008; similarly, increased effort in the promotion of BSSN as well as publicity surrounding the SARA listing of Basking Shark as endangered in 2010 resulted in the increased reports from 2010-2012.

Table 3. Confirmed or reliable sightings of Basking Sharks in Canadian Pacific waters in 1996 – 2015. Annual totals in 1999 – 2007 indicated with an asterisk (*) were revised subsequent to the publication of the Recovery Strategy (DFO 2011), following re-evaluation of existing records and the addition of new records.

Year	West Coast Vancouver Island	Hecate Strait	Strait of Georgia / Juan de Fuca Strait	Queen Charlotte Sound / Queen Charlotte Strait	West Coast Haida Gwaii	Total
1996	-	-	-	1	-	1
1997	-	-	-	-	-	0
1998	-	-	-	-	-	0
1999	2	-	-	-	-	2*
2000	-	-	-	-	-	0*
2001	-	-	-	-	-	0
2002	-	1	-	-	-	1
2003	-	-	-	-	-	0
2004	-	-	-	1	1	2*
2005	-	-	-	-	-	0
2006	-	1	-	-	-	1*
2007	2	-	-	-	-	2*
2008	1	1	1	-	-	3
2009	-	-	3	-	-	3
2010	1	-	-	-	-	1
2011	2	-	-	-	-	2
2012	4	-	-	-	-	4
2013	3	1	1	1	-	6
2014	2	-	1	-	-	3
2015	2	-	-	-	-	2
Total	19	4	6	3	1	33

Table 4. Total annual (1945 – 2015) sightings reported as Basking Sharks in each reporting year (1996 – 2015) for all report ratings: confirmed, reliable, possible, unlikely, and unknown. The annual number of confirmed / reliable sightings are indicated in brackets for each reporting year. Sightings could be reported in the same calendar year in which the sighting occurred (reporting year = sighting year) or sightings could be reported in subsequent years, sometimes many years later (reporting year > sighting year).

Sighting Year	Reporting Year									Total
	1996-2006	2008	2009	2010	2011	2012	2013	2014	2015	
1945-1992	4 (4)	15 (15)	-	4 (1)	1 (1)	1	2 (1)	-	-	27 (22)
1996	1 (1)	-	-	-	-	-	-	-	-	1 (1)
1998	-	6	-	-	-	-	-	-	-	6
1999	2 (1)	1 (1)	-	-	-	-	-	-	-	3 (2)
2000	2	1	-	-	-	-	-	-	-	3
2002	1 (1)	-	-	-	-	-	-	-	-	1 (1)
2004	2 (1)	1 (1)	-	-	-	-	-	-	-	3 (2)
2005	1	-	-	-	1	-	-	1	-	3
2006	-	-	-	1 (1)	-	-	-	-	-	1 (1)
2007	-	2 (1)	-	1	1 (1)	-	-	-	-	4 (2)
2008	-	3 (3)	-	-	1	-	-	-		4 (3)

Sighting Year	Reporting Year									Total
	1996-2006	2008	2009	2010	2011	2012	2013	2014	2015	
2009	-	-	3 (2)	1 (1)	-	1	-	-	1	6 (3)
2010	-	-	-	10 (1)	2	1	-	-	-	13 (1)
2011	-	-	-	-	16 (2)	1	-	-	-	17 (2)
2012	-	-	-	-	-	13 (3)	1 (1)	-	-	14 (4)
2013	-	-	-	-	-	-	9 (6)	-	-	9 (6)
2014	-	-	-	-	-	-	-	8 (3)	-	8 (3)
2015	-	-	-	-	-	-	-	-	9 (2)	9 (2)
Total	13 (8)	29 (21)	3 (2)	17 (4)	22 (4)	17 (3)	12 (8)	9 (3)	10 (2)	132 (55)

There are historical areas in Canadian Pacific waters that were regularly occupied by large numbers of Basking Sharks (e.g. Barkley Sound, Clayoquot Sound, and Rivers Inlet); however, the importance of these areas for foraging or other habitat functions is unknown. It is also unknown if these areas were the only areas used by Basking Sharks, or if rather these observations were due to human use of these areas. Information from the BSSN indicates that the west coast of Vancouver Island continues to be occupied by Basking Sharks, with 19 of the 33 confirmed or reliable sightings since 1996 occurring off the west coast of Vancouver Island, many within the Barkley Sound and Clayoquot Sound region (Figure 1). Three confirmed or reliable sightings since 1996 have occurred in coastal areas around Queen Charlotte Sound, including one sighting near Rivers Inlet (Figure 1). Basking Sharks also occur in Hecate Strait, the west coast of Haida Gwaii, Juan de Fuca Strait, and the southern Strait of Georgia, based on confirmed sightings. The distribution of sightings undoubtedly reflects the distribution of the target audience of the BSSN, with eco-tourism and wilderness tourism highly concentrated on the West Coast of Vancouver Island, and also corresponds to higher human-populated areas. The peaks in reporting which occurred in 2008 and 2010 – 2012 suggest that awareness of the BSSN also plays a role in the number of reports received per year.

The BSSN fulfills an important role in providing information on a species which is not otherwise routinely observed on any existing systematic surveys of the BC coast. Although confirmed or reliable sightings are relatively scarce, these sightings have confirmed Basking Shark presence throughout BC waters in April – September, including in areas of known historical abundance. The relatively larger number of actual reports compared to confirmed or reliable sightings indicates that the target audience for the BSSN is engaged and willing to collaborate with DFO in opportunistic reporting; increased awareness of the BSSN and the need to provide detailed descriptions including photographs or videos to confirm identification could increase the number of confirmed and reliable reports. In addition, increased public awareness of the utility of rapid reporting of Basking Sharks might provide opportunities for research sampling or tagging. The correlation between the number of reports received by the BSSN and increased publicity and resources applied to promoting the BSSN in 2008 and 2010 – 2012 highlights the importance of continuing to promote the BSSN.

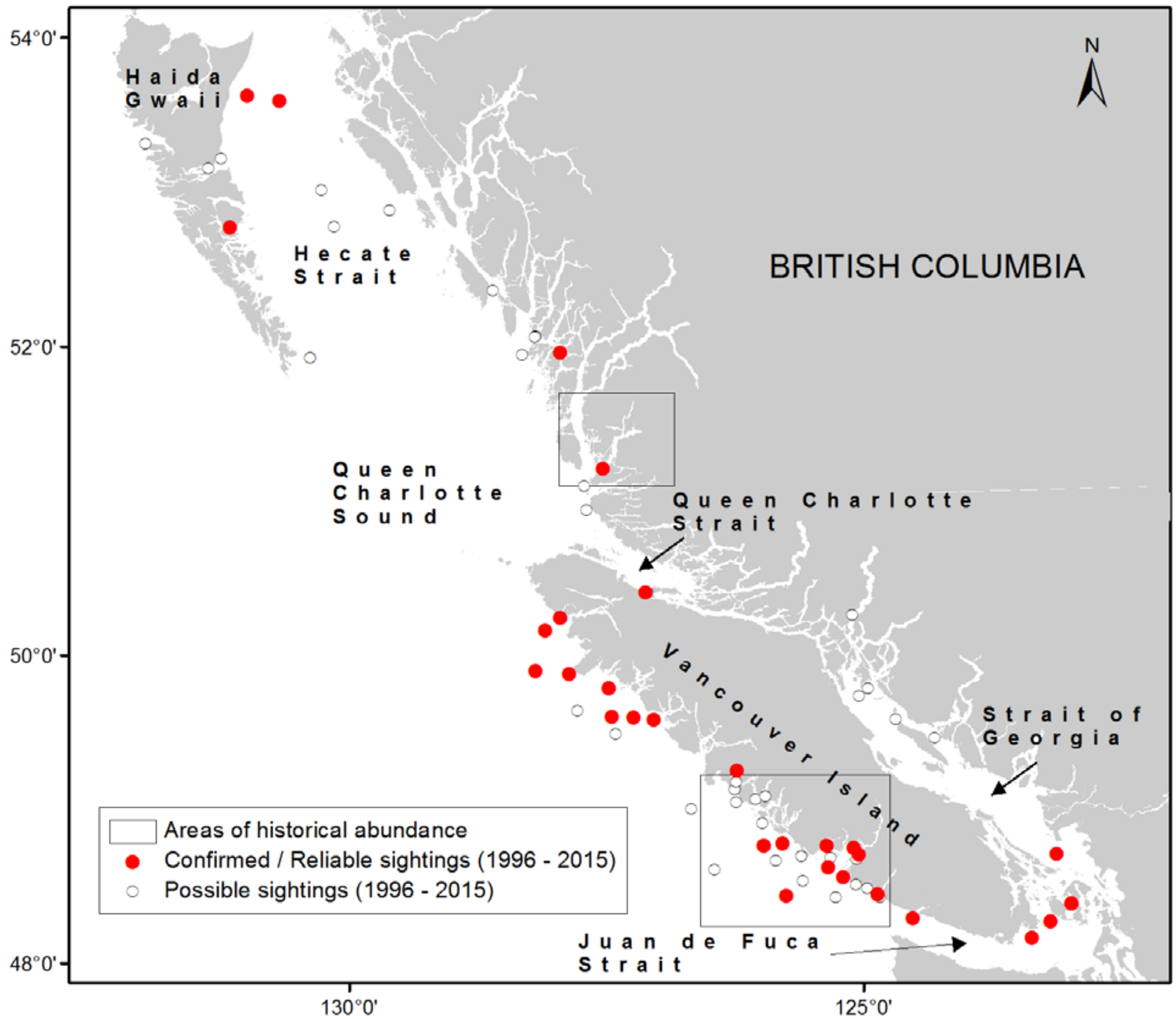

Figure 1. Basking Shark sightings in 1996 – 2015 reported to the Basking Shark Sightings Network. Confirmed sightings were associated with a photo or video for positive identification; reliable sighting did not have an associated photo or video, but the descriptions were sufficient and the reporter had historical expertise with either Basking Sharks or large marine animals; possible sightings were associated with descriptions that suggested a Basking Shark, but were insufficient for a positive identification.

Basking Shark Tagging Program

A satellite tag equipped with a Global Positioning System receiver is available for deployment. The tag is capable of recording depth and temperature throughout the programmed deployment, and geolocation data while at the surface. All required permits have been approved, including approval of the Animal Use Protocol for the tagging methodology, and are renewed annually. Opportunistic tagging of Basking Sharks did not occur since there were no Basking Sharks reported in a location where, or timeframe in which logistic support could be arranged.

Opportunistic Sampling Program

A sampling protocol has been developed and is in place for an at-sea observer program for the groundfish bottom trawl fishery, and for DFO research survey programs. Permits for DFO research personnel and at-sea observers have been obtained and are renewed annually.

Opportunistic sampling did not occur since there were no Basking Sharks captured in commercial fisheries or DFO research surveys.

Overflights

Aerial surveys were identified as one method for search and enumeration of Basking Sharks in historic areas of abundance. Twenty five aerial surveys for Basking Sharks were conducted between 2007 – 2011 on the west coast of Vancouver Island and in Rivers Inlet, British Columbia (Surry and King 2015). In addition, one offshore aerial survey was conducted in 2011 on the west coast of Vancouver Island (Surry and King 2015). Methodology is documented in Surry and King (2015). Briefly, aerial surveys for Basking Sharks were conducted aboard chartered Cessna 180 and 182 float planes operating out of Port Alberni (for west coast of Vancouver Island) or Courtenay (for Rivers Inlet), flying at an airspeed of approximately 185 km/hr. The planes accommodated up to three observers in addition to the pilot; most flights had two observers. The survey timing was intended to coincide with the peak periods of historical encounters with Basking Sharks in British Columbia (McFarlane et al. 2009). Between two and eight surveys were conducted each year, as resources permitted. A grid or transect pattern was not followed, as most areas surveyed were sufficiently narrow (e.g. inlets) or close to shore that the full area of interest was visible with a single pass or return loop. A zig-zag path was flown over wider areas such as Barkley sound to ensure full visibility of the area. Altitude during the observation part of each flight ranged from approximately 90 – 300 m (300 – 1000 feet) depending on weather conditions, location, and visibility. No Basking Sharks were observed. Marine mammals and Blue Sharks (*Prionace glauca*) were observed (Surry and King 2015), indicating that these surveys were effective for spotting animals when they were present.

Habitat Features Modeling

This project was not on the schedule of studies (Table 1), but application of habitat modeling using satellite-derived oceanographic data to elucidate potential critical habitat features for leatherback sea turtles during their foraging season (Gregr et al. 2015) suggested that this modeling approach could be applied to Basking Shark. As a preliminary study, the derivation of potential habitat maps for Basking Sharks in Canadian Pacific waters for the foraging months (May – September) were produced based on the approach of Gregr et al. (2015). As in Gregr et al. (2015), data were summarized by foraging season. Higher temporal resolution data, i.e. daily, were not investigated since there were only 5 confirmed Basking Shark sightings available for the satellite data period. Therefore, the Basking Shark habitat features modeling focused on *potential* habitat rather than realized habitat. As such, use of monthly climatologies (as outlined below) does mean that emphemeral features, such as productivity fronts, cannot be resolved with this model. It is assumed that such ephemeral features occur with a higher frequency in the potential areas identified by the productivity envelope. Satellite chlorophyll data were used to identify areas of high productivity, with the assumption that high chlorophyll concentrations (i.e. phytoplankton) tend to be associated with high zooplankton abundance. High chlorophyll concentrations are also frequently associated with oceanographic fronts. Satellite sea surface temperature (SST) data were used to identify areas with Basking Shark preferred temperatures. Limited zooplankton data and the Basking Shark sightings data were used to validate potential habitat maps.

While the relative scarcity of current sightings of Basking Shark in Canadian Pacific waters precludes definition of critical habitat, published knowledge on supporting habitat features for Basking Shark foraging and distribution can be used to model potential habitat availability. Basking Sharks tend to be associated with high zooplankton concentrations and temperature fronts (Sims et al. 2009). At small spatial and temporal scales, Basking Shark distribution and occurrence in the North Atlantic appears strongly linked to zooplankton abundance; evidence from throughout their global range indicates that Basking Sharks prey primarily on calanoid copepods (small, ~2 mm, zooplankton) while feeding in surface waters (Sims 2008). A single, limited study conducted off Monterery, California and Clayoquot Sound, British Columbia confirm that Pacific Basking Shark diet is also dominated by calanoid copepods (Baduini 1995). However, in British Columbia there was no difference in calanoid copepod density between waters where Basking Sharks were observed to be feeding and waters outside feeding activity (Baduini 1995). In the northeast Atlantic, long term trends in surface sightings are correlated with sea surface temperature that may also influence zooplankton abundance and distribution (Sims 2008). Globally, Basking Sharks have been observed in surface waters ranging from 6-30°C with a preference for waters between 8 and 18ºC and limited archival tag data suggesting a high affinity for temperatures 15-18 ºC (Sims et al. 2003, Skomal et al. 2004, Skomal et al. 2009).

Chlorophyll Data

Level-2 reduced resolution (1.2 km^2) data from the European Space Agency's (ESA) MERIS sensor onboard ENVISAT satellite were used to make monthly composites (maps) of Chlorophyll-a (mg/m^3). The MERIS standard chlorophyll product (Algal1) uses the blue to green ratio to derive the chlorophyll-a concentration in clear (case-1) water. Algal1 monthly composites were processed by European Space Agency's Grid Processing on Demand (GPOD) initiative by special request. The time range used was May through September for years 2002 to 2011. GPOD processed the MERIS monthly composites at 1.3 km spatial resolution using the arithmetic mean binning processor. Monthly climatologies were produced from the individual monthly composites as the average of valid pixels in a given bin for a given month (May – September) across years. 'No-data' values were not included in the average.

SST Data

SST (°C) data (May through September for years 2002 to 2011) from NASA's MODIS Aqua satellite were used to make monthly composites. All available daily 4-micron nighttime SST data at 1.2 km^2 resolution were downloaded from NASA's Ocean Color bulk data ordering service. The 4-micron SST data were used instead of the 11-micron data because they are less prone to water-vapour contamination (Brown et al. 1999). Nighttime SST data were used instead of daytime data because they more likely to represent the temperature of the mixed layer and will not be as influenced by daytime solar heating.

The monthly composites were processed for the available time period, July 2002 to June 2011 and used to produce monthly climatologies as the average of valid pixels in a given bin for a given month (May – September) across available years. Only SST data with quality levels 0 and 1 (best and good) were used and 'no-data' values were excluded.

Classification of Monthly Climatologies

Chlorophyll

The monthly climatologies for chlorophyll were classified using the Jenks Natural Breaks data classification method in ArcGIS version 10.0. This classification system identifies natural breaks by reducing variance within classes and maximizing variance between classes. Five classes, values 1 to 5, were identified (Table 5) and pixels in each monthly climatology were assigned the value of the class (1 to 5) using ArcMap's Reclassify tool to produce classified monthly chlorophyll maps (Figure 2).

Table 5. Chlorophyll-a (mg/m3) range for each Jenks class for chlorophyll climatologies used to produce the chlorophyll foraging season potential habitat envelope. The minimum and maximum values vary across months reflecting the use of each month's variability to define natural breaks.

Jenks Class	May		June		July		August		September	
	min	max	min	max	min	max	min	max	min	max
1	0.1185	1.5407	0.1185	1.3037	0.1185	1.5407	0.1185	1.4222	0.1185	1.3037
2	1.5407	4.1480	1.3037	3.6740	1.5407	4.2666	1.4222	4.0295	1.3037	3.4369
3	4.1480	7.9405	3.6740	7.4665	4.2666	8.5331	4.0295	8.2961	3.4369	6.8739
4	7.9405	14.5774	7.4665	15.6440	8.5331	15.5255	8.2961	16.2366	6.8739	14.1033
5	14.5774	30.1029	15.6440	30.1029	15.5255	30.1029	16.2366	30.1029	14.1003	30.1029

The chlorophyll classes exhibited seasonal and spatial variability in productivity (Figure 2). The spring bloom was evident in May, with productivity diminishing through the foraging season (Figure 2). High productivity areas in Hecate Strait, Queen Charlotte Sound and the upwelling domain of the west coast of Vancouver Island were evident (Figure 2).

SST

The SST monthly climatologies were assigned into 3 classes (Table 6) based on published preferred temperature ranges that suggest a preference for waters between 8 and 18ºC, and high affinity for temperatures 15-18 ºC (Sims et al. 2003, Skomal et al. 2004). The valid pixels in each SST monthly climatology were classified into these 3 classes using the Reclassify tool in ArcMap (Figure 2).

There is very little spatial or seasonal variability in SST classes (Figure 2). Throughout most of the foraging season, all waters are generally classified in SST class 2, the medium preference temperature range. The exception is most of the Strait of Georgia and some coastal inlets on the north, central coast and the west coast of Vancouver Island which are classified in SST class 3, along with the large offshore SST signal in August and September at the continental slope off Vancouver Island

Table 6. Temperature (°C) range (and preferences) for each assigned class for SST climatologies used to produce the SST foraging season potential habitat envelope.

Assigned class	Temperature range (preference)
1	<7.9999 (low)
2	8.0 – 14.9999 (medium)
3	15.0 – 17.9999 (high)
1	>18.0 (low)

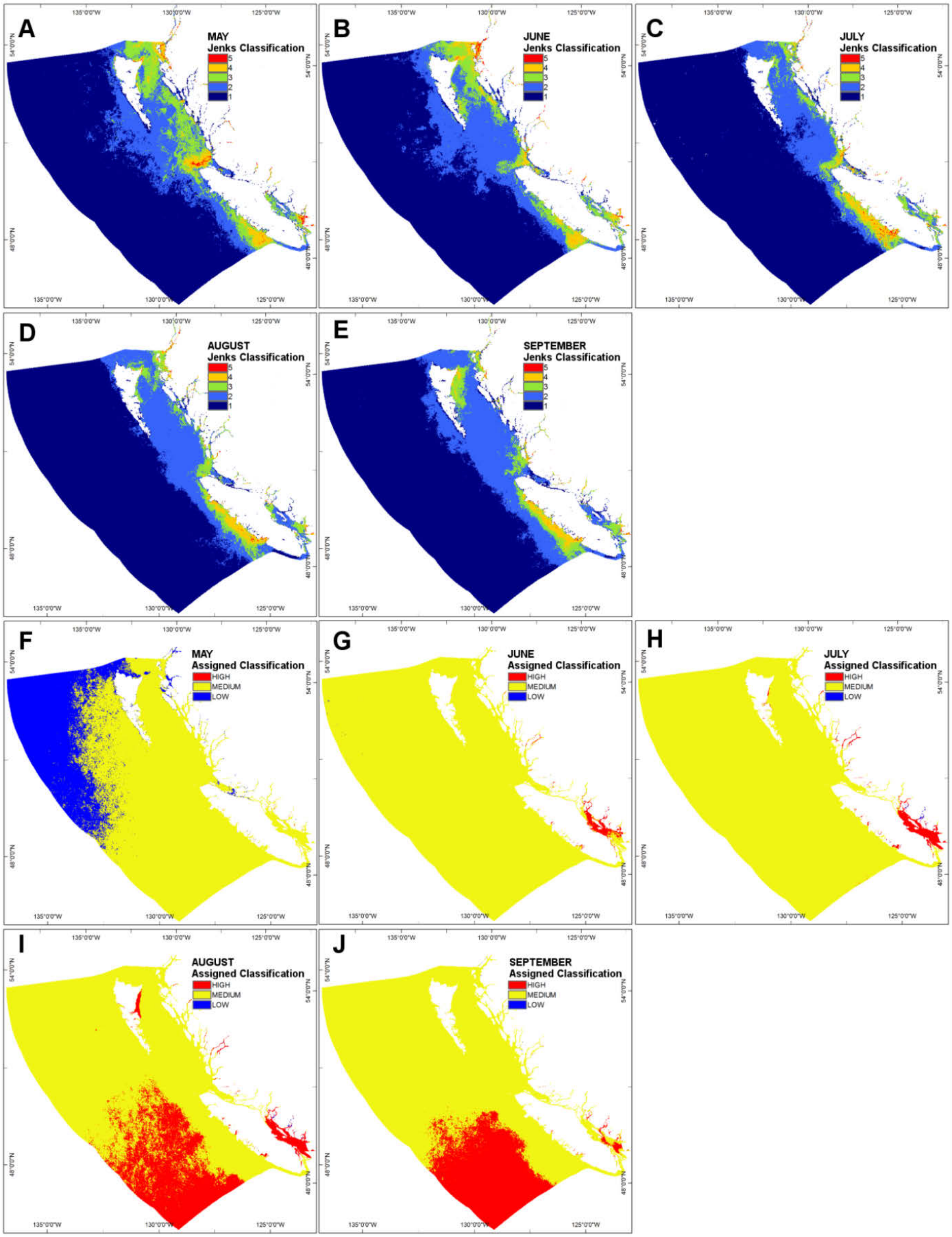

Figure 2. A-E) Monthly chlorophyll climatologies classified into five classes based on data ranges in Table 5. F-J) Monthly SST climatologies classified into three assigned classes based on preferred temperature data ranges in Table 6.

Foraging Season Potential Habitat Maps

Foraging season (May-September) potential habitat maps (Figure 3) were modeled based on assigned suitability categories for:

1. mean May-September classified chlorophyll climatologies only;
2. mean May-September classified SST climatologies only;
3. linear combination (additive) of mean May-September chlorophyll and SST classified climatologies; and
4. non-linear combination (multiplicative) of mean May-September chlorophyll and SST classified climatologies (Table 7).

Table 7. Foraging season (May – September) potential habitat map classification into low, medium and high suitability categories based on the classes in the mean seasonal classified chlorophyll and SST climatologies. For linear and non-linear combinations, the second number represents chlorophyll Jenks class (Table 5) and first number represents SST assigned class (Table 6).

	Foraging season habitat suitability category		
	Low	Medium	High
Chlorophyll	1	2	3, 4, 5
SST	1	2	3
Linear combination	1+1; 1+2; 2+1	1+3; 2+2; 3+1	1+4; 1+5; 2+3; 2+4; 2+5; 3+2; 3+3; 3+4; 3+5
Non-linear combination	1*1; 1*2; 2*1; 1*3; 3*1	1*4; 2*2	1*5; 2*3; 2*4; 2*5; 3*2; 3*3; 3*4; 3*5

The foraging season potential habitat maps are strongly influenced by the spatial variability in chlorophyll classes and the lack of spatial variability in SST classes (Figure 3). For the chlorophyll model, areas of low habitat suitability are noted in Johnstone Strait, waters offshore of the continental shelf and slope, the west coast of Haida Gwaii, some sections of the central coast, and waters around Jervis Inlet (Figure 3). These low suitability areas are a result of low chlorophyll in the climatologies. For the SST model, most of the BC waters are considered to be medium habitat suitability, with the exception of the Strait of Georgia and some coastal inlets where higher SST classes result in high habitat suitability (Figure 3). As expected, the linearly and non-linearly combined models are similar to the chlorophyll model except for in the Strait of Georgia, where the high SST increases the relative suitability in the combined models (Figure 3). The linear and non-linear models are also similar to each other except for Jervis Inlet in the Strait of Georgia which is classified as medium suitability in the linear model and low suitability in the non-linear model (Figure 3).

Validation of Foraging Season Potential Habitat Maps

Basking Shark Sightings

Historical confirmed Basking Shark sightings (1945-2012) were intersected with the foraging season habitat suitability class data to determine the sightings per habitat suitability category. Results were the same for the linear and non-linear chlorophyll and SST combination models. Only 56% of Basking Shark sightings were in areas classified as high foraging season habitat suitability (Table 8).

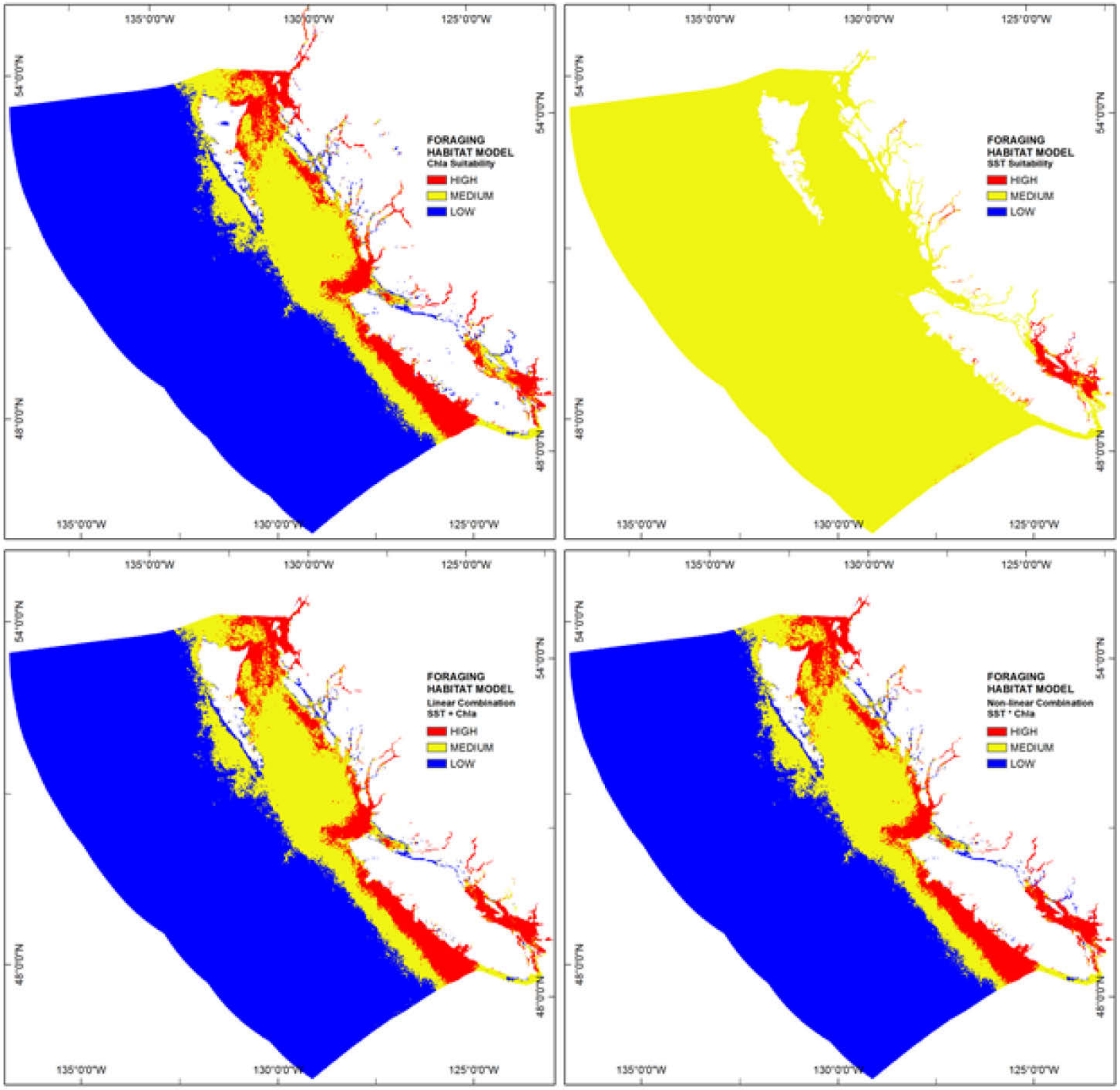

Figure 3. Foraging season potential habitat maps of Basking Shark foraging suitability derived from satellite chlorophyll (top left), satellite SST (top right), the linear combination of satellite chlorophyll and SST (lower left), and the non-linear combination of satellite chlorophyll and SST (lower right) climatologies.

Table 8. The number of confirmed Basking Shark sightings per foraging season potential habitat suitability category for linear and non-linear chlorophyll and SST combination models (the results are the same for the linear and non-linear models).

	Foraging Season Habitat Suitability		
	Low	Medium	High
Number of Sightings	2	10	18

Zooplankton Data

Total zooplankton and calanoid zooplankton biomass (mg/m^3) estimates from DFO research surveys (2002-2012) were used to compare to foraging season potential habitat maps. It was anticipated that high zooplankton biomass, particularly calanoid zooplankton, should correspond to higher chlorophyll production areas reflected as high suitability foraging habitat for Basking Sharks. Biomass estimates were derived as the product of number of specimens and the average dry weight for each species per cubic meter (Galbraith et al. 2014). Day and night biomass estimates for May to September were used in this analysis. Biomass data were summarized into the BC Marine Ecosystem Classification Ecosections (Ministry of Sustainable Resource Management 2002) as per Galbraith et al. (2014) in order to account for regional differences in long-term trends, species composition and biomass. For example, a biomass of 50 mg/m^3 in one region might be considered high, but in another region the same biomass might be considered average compared to long-term trends. Zooplankton biomass samples were classified as low (class value 0), low-medium (class value 1), medium-high (class value 2) and high (class value 3) based on region-specific quartile ranges <25%, 25-50%, 50-75% and >75% respectively. The zooplankton data were spatially (cell size of 5 km^2) and temporally averaged (2002-2012) using ArcGIS Point Statistics tool. Means were calculated for total zooplankton biomass and calanoid biomass, using both day and night samples. Classified zooplankton data were intersected with the foraging season habitat suitability category data to determine the number of zooplankton classes per habitat suitability category.

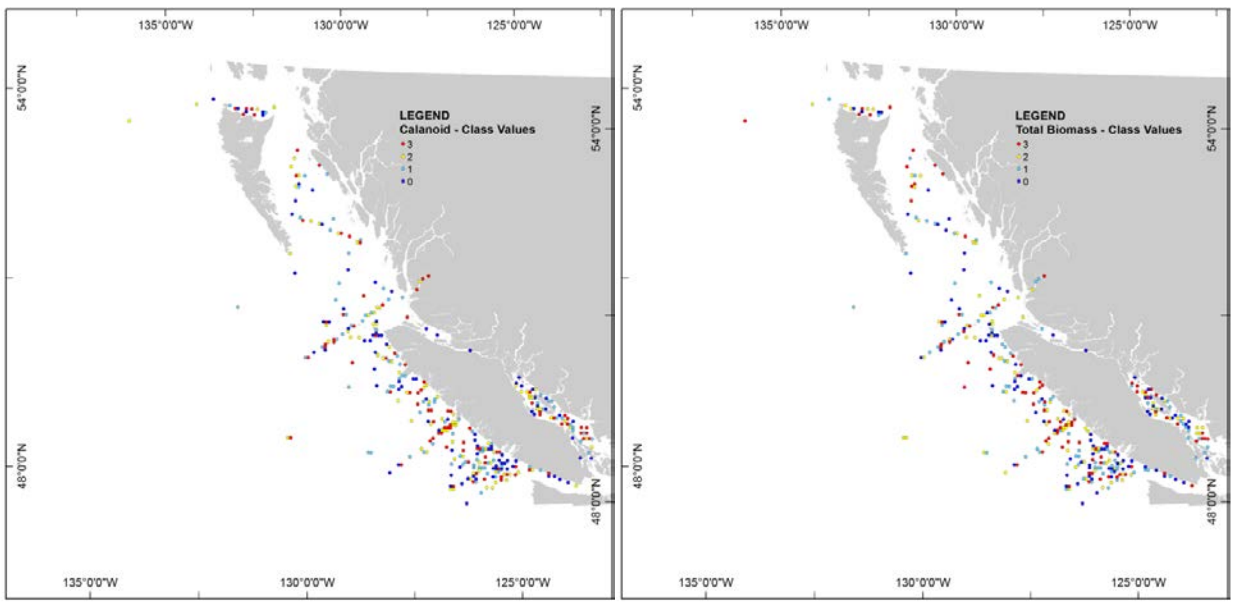

Figure 4. Classified zooplankton biomass data (May-September, 2002-2012) averaged on a 5 km grid for total zooplankton biomass (left panel) and calanoid zooplankton biomass (right panel). Data are classified based on quartiles for each of zooplankton regions as per Galbraith et al. (2014).

Areas that appear to have some clusters of 'high' class total biomass samples are northern Hecate Strait, the Strait of Georgia and the north and west coasts of Vancouver Island (Figure 4). The pattern is similar for calanoid zooplankton, although there seem to be more 'high' class samples in the southern Strait of Georgia and central Hecate Strait compared to high-class total biomass samples (Figure 4). When zooplankton classes are summarized by habitat suitability categories, no clear trend is apparent (Table 9). For example, it was expected that a greater number of high class zooplankton biomass samples would be located in cells classified as high foraging season habitat suitability, but there are a similar number of samples from each zooplankton class in the high suitability category (Table 9).

Table 9. The number of classified zooplankton biomass samples in each foraging season habitat suitability category for linear and non-linear chlorophyll and SST combination models (the results are the same for the linear and non-linear models). The assigned class values used for mapping (Figure 4) are indicated in parentheses.

Zooplankton Biomass Class	Foraging Season Habitat Suitability		
	Low	Medium	High
Total zooplankton			
Low (0)	9	45	39
Low-Medium (1)	9	35	45
Medium-High (2)	7	31	49
High (3)	9	37	44
Calanoid zooplankton			
Low (0)	9	39	45
Low-Medium (1)	9	37	43
Medium-High (2)	7	35	45
High (3)	9	37	44

Summary

As was noted in the Recovery Strategy (DFO 2011), it will likely take decades to identify critical habitat for Basking Sharks in Canadian Pacific waters; however, this remains a key objective and should remain on the schedule of studies with the date “To Be Determined”. The low frequency of occurrences in BC waters in 2010-2015 has precluded some activities in the schedule of studies, namely opportunistic tagging and biological sampling of Basking Sharks. It remains unknown, aside from foraging, what biological functions are supported by habitat in BC waters. Spawning, nursery, and rearing locations remain undocumented throughout the geographic range for this population. At this time, features and attributes of Basking Shark foraging habitat cannot be identified in BC waters. Potential foraging habitat maps based on satellite chlorophyll provide indication of productivity hotspots. However, low resolution zooplankton data and low frequency Basking Shark sightings data could not provide validation that these productivity hotspots represent characteristics that allow Basking Shark to successfully forage on zooplankton.

The Basking Shark Sightings Network has been successful in engaging the public. The annual number of likely or confirmed reported sightings has increased since 2010, as a result of continued promotion and media attention. There remains a lag time between encounters with Basking Sharks and reporting of the encounter to the Sightings Network, thereby reducing the likelihood that confirmed reports can be acted upon by DFO personnel to opportunistically tag or biosample a specimen. Outreach could focus on informing the public of the need for photos to help confirm identification, and the need of immediate reporting. The Basking Shark Sightings Network has provided confirmed sightings of Basking Sharks, and has successfully engaged the public. It should remain an activity on the schedule of studies.

Satellite tagging technology remains a viable means for obtaining detailed geolocation, depth and temperature information for Basking Sharks in BC waters and throughout their geographic range, which would help fill information gaps on habitat usage. A satellite tag has already been obtained by DFO for Basking Shark tagging opportunities, and this should remain an activity on the schedule of studies.

Biological sampling protocols have already been developed and are in place for use by at-sea observers on commercial fishery vessels and by DFO research personnel on surveys. Information on size, sex, stock structure and diet could be obtained from these opportunities, all of which would help fill gaps on habitat usage in BC waters. Opportunistic biological sampling should remain an activity on the schedule of studies.

Marine mammals and other shark species have been observed on the aerial overflights for Basking Shark indicating that, if present in surface waters, their occurrence would likely be observed. There have been no observations of Basking Sharks on the 25 flights conducted to date. These data do provide a baseline of information, and comparative flights would provide confirmation of relative density increases. It is recommended that overflights for Basking Shark observations remain on the schedule of studies, but that the date be revised to "To Be Determined". Overflights should be resumed when reports of Basking Shark sightings (through the Sightings Network, fisheries observer programs, and through DFO research survey programs) indicate an increase in density in BC waters. It is important to note that DFO currently conducts overflights for marine mammal enumeration and observations, and for creel survey support, and that personnel have received information for identification of Basking Sharks and for reporting any occurrences.

The potential foraging habitat maps could not be validated by the available low-resolution zooplankton data, or with the low numbers of confirmed Basking Shark sightings. Although 56% of the Basking Shark sightings corresponded to habitat identified as high foraging season habitat suitability, the remaining 44% did not. The modeling project was a preliminary study, and the utility of the approach, particularly using daily-scale data, could be reassessed when a greater number of confirmed sightings are available.

Conclusions

Aside from foraging, the biological functions of Basking Shark supported by habitat in BC waters remain unknown. Spawning, nursery, and rearing locations remain undocumented throughout the geographic range for this population. Through modeling, areas of high primary productivity have been identified; however, they do not correlate with copepod productivity. The low resolution of zooplankton data and the low numbers of Basking Shark observations do not support the identification of the foraging habitat. At this time, a recommendation cannot be made for the habitat needed for survival and recovery of Basking Sharks within Canadian Pacific waters.

The schedule of studies listed in the Recovery Strategy (DFO 2011) and further described in this document is still current and should be continued.

Contributors

Contributor	Affiliation
Heather Brekke	DFO SARA, Pacific Region
Heidi Dewar	Southwest Fisheries Science Center, NMFS, NOAA
Jackie King	DFO Science, Pacific Region
Stephanie King	Sea This Consulting, Nanaimo
Sean MacConnachie	DFO Science, Pacific Region
Gordon McFarlane	DFO Science, Pacific Region
Tammy Norgard	DFO Science, Pacific Region
Maria Surry	DFO Science, Pacific Region
Scott Wallace	David Suzuki Foundation, Vancouver

Approved by

Carmel Lowe
Regional Director
Science Branch, Pacific Region
Fisheries and Oceans Canada

August 4, 2016

Sources of information

COSEWIC. 2007. COSEWIC assessment and status report on the Basking Shark *Cetorhinus maximus* (Pacific population) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 34 pp.

Darling, J.D. and Keogh K.E. 1994. Observations of basking sharks, *Cetorhinus maximus*, in Clayoquot Sound, British Columbia. Canadian Field Naturalist 108(2):199-210.

DFO. 2009. Recovery Potential Assessment for Basking Sharks in Canadian Pacific waters. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/046.

DFO. 2011. Recovery Strategy for the Basking Shark (*Cetorhinus maximus*) in Canadian Pacific waters. *Species at Risk Act* Recovery Strategy Series. Fisheries and Oceans Canada, Ottawa. v + 25 pp.

Galbraith, M., Mackas, D., and Young, K. 2014. Zooplankton along the BC continental margin: a near-average year. pp 52-58, *In* Perry, R.I. (Ed.). State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2013. Can. Tech. Rep. Fish. Aquat. Sci. 3102: vi + 136 p.

Gore, M. A., Frey, P. H., Ormond, R. F., Allan, H. and Gilkes, G. 2016. Use of Photo-Identification and Mark-Recapture Methodology to Assess Basking Shark (*Cetorhinus maximus*) Populations. *PloS one*,*11*(3), e0150160.

Gregr, E.J., Gryba, R., James, M.C., Brotz, L., and Thornton, S.J. 2015. Information relevant to the identification of critical habitat for Leatherback Sea Turtles (*Dermochelys coriacea*) in Canadian Pacific waters. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/079. vii + 32p.

Harvey-Clark, C. J., Stobo, W. T., Helle, E. & Mattson, M. 1999 Putative mating behaviour in basking sharks off the Nova Scotia coast. Copeia 3, 780–782. (doi:10.2307/1447614)

Hoogenboom, J. L., Wong, S. N., Ronconi, R. A., Koopman, H. N., Murison, L. D. and Westgate, A. J. 2015. Environmental predictors and temporal patterns of basking shark (*Cetorhinus maximus*) occurrence in the lower Bay of Fundy, Canada. J Exp. Mar. Bio. Ecol., 465, 24-32.

McFarlane, G.A, King, J.R., Leask, K. nd Christensen, L.B. 2009. Assessment of information used to develop a Recovery Potential Assessment for Basking Shark *Cetorhinus maximus* (Pacific Population) in Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2008/071. vi + 98 p.

Miller, P. I., Scales, K. L., Ingram, S. N., Southall, E. J. and Sims, D. W. 2015. Basking sharks and oceanographic fronts: quantifying associations in the north-east Atlantic. *Functional Ecology*, 29(8), 1099-1109.

Ministry of Sustainable Resource Management. 2002. British Columbia Marine Ecological Classification: Marine ecosections and ecounits. Version 2.0. Decision Support Services Branch for the Coastal Task Force Resources Information Standards Committee. The Province of British Columbia. 63p. ISBN 0-7726-4811-5.

Sims, D.W. 2008. Sieving a living: a review of the biology, ecology and conservation status of the plankton-feeding Basking Shark *Cetorhinus maximus*. Adv. Mar. Biol. 54, 171–220.

Sims, D.W., Southall, E.J., Quayle, V.A., and Fox, A.M. 2000. Annual social behaviour of basking sharks associated with coastal front areas. Proc. R. Soc. Lond. 267, 1897–1904.

Sims, D.W., Southall, E.J., Richardson, A.J., Reid, P.C., and Metcalfe, J.D. 2003. Seasonal movements and behaviour of Basking Sharks from archival tagging: no evidence of winter hibernation. Mar. Ecol. Prog. Ser. 248, 187–196.

Sims, D. W., Witt, M. J., Richardson, A. J., Southall, E. J., and Metcalfe, J.D. 2006. Encounter success of free-ranging marine predator movements across a dynamic prey landscape. Proc. R. Soc. B 273, 1195–1201.

Skomal, G.B, Wood, G. and Caloyianis, N. 2004. Archival tagging of a basking shark, *Cetorhinus maximus*, in the western North Atlantic. Journal of the Marine Biological Association of the UK, 84, pp 795-799.

Skomal, G.B., Zeeman, S.I., Chisholm, J.H., Summers, E.L., Walsh, H.J., McMahon, K. W. and Thorrold, S.R. 2009. Transequatorial migrations by basking sharks in the western Atlantic Ocean. *Current Biology*, 19(12), 1019-1022.

Surry, A.M. and King, J.R. 2015. Surveys for Basking Sharks (*Cetorhinus maximus*) and other pelagic sharks on the Pacific Coast of Canada, 2007 – 2011. Can. Tech. Rep. Fish. Aquat. Sci. 3108: v + 27 p.

Westgate, A.J., Koopman, H.N., Siders, Z.A., Wong, S.N.P., Ronconi, R.A. 2014. Population density and abundance of basking sharks (*Cetorhinus maximus*) in the lower Bay of Fundy, Canada. *Endanger.* Species Res. 23, 177–185.

This Report is Available from the

Centre for Science Advice
Pacific Region
Fisheries and Oceans Canada
3190 Hammond Bay Road
Nanaimo, BC V9T 6N7

Telephone: (250) 756-7208
E-Mail: csap@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

ISSN 1919-3769

Correct Citation for this Publication:

DFO. 2016. Evaluation of Information Available to Support the Identification of Habitat Necessary for the Survival and Recovery of Basking Shark in Canadian Pacific Waters. DFO Can. Sci. Advis. Sec. Sci. Resp. 2016/046.

Aussi disponible en français :

MPO. 2016. Évaluation de l'information disponible pour la désignation de l'habitat essentiel à la survie et au rétablissement du requin-pèlerin dans les eaux canadiennes du Pacifique. Secr. can. de consult. sci. du MPO, Rép. des Sci. 2016/046.