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Information relevant to the identification of critical habitat for Leatherback Sea Turtles (*Dermochelys coriacea*) in Canadian Pacific waters

Edward J. Gregr[1], Rowenna Gryba[1], Michael C. James[2], Lucas Brotz[3], and Sheila J. Thornton[4]

[1]Institute for Resources, Environment & Sustainability
University of British Columbia
2329 West Mall
Vancouver, BC V6T 1Z4

[2] Fisheries and Oceans Canada
Maritime Region
P.O. Box 1035
Dartmouth, NS B2Y 4T3

[3] Fisheries Centre,
University of British Columbia
2202 Main Mall
Vancouver, BC V6T 1Z4

[4] Fisheries and Oceans Canada
Pacific Region
Suite 200 - 401 Burrard Street
Vancouver, BC V6C 3S4

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

In 1981, Leatherback Sea Turtle populations in Canadian waters were assessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) as Endangered. This status was confirmed in 2001, and in 2003, the Leatherback Sea Turtle was listed as Endangered on Schedule 1 of the *Species at Risk Act* (SARA). In May 2012, the species was reassessed as two separate populations (Atlantic and Pacific). Both populations continue to be designated as Endangered.

As part of the SARA recovery process, the “Recovery Strategy for the Leatherback Turtle populations in Pacific Canadian waters” was published on the *SARA* Registry in February 2007. For species listed as Threatened or Endangered, SARA requires identification of the habitat necessary for the survival or recovery of a listed wildlife species. Once this habitat is identified in the final recovery strategy or action plan, it is deemed the species’ “critical habitat” and afforded legal protection from destruction under the *Act*. Leatherback Sea Turtles feed on scyphozoan prey in temperate high latitude locales, such as the Canadian Pacific coast. We used an envelope model to locate suitable habitat for Leatherback Sea Turtle foraging, and describe the biophysical function and features of suitable habitat in Canadian Pacific waters.

Renseignements pertinents pour la désignation de l'habitat essentiel de la tortue luth (*Dermochelys coriacea*) dans les eaux canadiennes du Pacifique.

RÉSUMÉ

En 1981, le Comité sur la situation des espèces en péril au Canada (COSEPAC) a évalué les populations de tortue luth dans les eaux canadiennes et les a désignées comme étant en voie de disparition. Le statut a été confirmé en 2001 et en 2003, la tortue luth a été inscrite à titre d'espèce en voie de disparition sur la Liste des espèces en péril de l'annexe 1 de la *Loi sur les espèces en péril* (LEP). En mai 2012, l'espèce a été réévaluée et deux populations (du Pacifique et de l'Atlantique) ont été désignées, toutes deux comme étant toujours en voie de disparition. Les deux populations continuent d'être considérées comme en voie de disparition.

Dans le cadre du processus de rétablissement prévu par la *Loi sur les espèces en péril*, le Programme de rétablissement de la tortue luth (*Dermochelys coriacea*) dans les eaux canadiennes du Pacifique a été publié dans le Registre public des espèces en péril en février 2007. Pour les espèces considérées comme menacées ou en voie de disparition, La LEP exige la désignation de l'habitat nécessaire à la survie ou au rétablissement des espèces sauvages inscrites sur la liste. Après la désignation de cet habitat dans le plan d'action ou le programme de rétablissement final, cet habitat est considéré comme « habitat essentiel » et une protection juridique lui est accordée en vertu de la LEP. La tortue luth se nourrit de scyphozoaires (ou méduses) dans des zones tempérées situées à des latitudes élevées, comme la côte canadienne du Pacifique. On a décrit l'étendue spatiale et les fonctions biophysiques de l'habitat essentiel possible dans les eaux canadiennes du Pacifique à partir de l'habitat convenant à l'alimentation de la tortue luth.

1 INTRODUCTION

1.1 SPECIES AT RISK AND CRITICAL HABITAT

The Leatherback Sea Turtle is a highly migratory reptile that occurs on both the Pacific and Atlantic coasts of Canada. In 1981, Leatherbacks were designated as Endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), and a reassessment in 2001 confirmed this designation. This species was listed in Schedule 1 of the *Species at Risk Act* (SARA) at proclamation in 2003. The *Recovery Strategy for Leatherback Turtles (Dermochelys coriacea) in Pacific Canadian waters* was posted to the National SARA registry in 2006 (Pacific, 2006). In 2012, the species was reassessed and two separate populations (COSEWIC designatable units – Pacific and Atlantic) were identified, with both maintaining a designation of Endangered.

Under the *Species at Risk Act,* recovery documents for species listed as threatened, endangered, or extirpated must include an identification of the species' critical habitat, which is defined as "*the habitat necessary for recovery or survival of a listed wildlife species that is identified as the species' critical habitat in the recovery strategy or in an action plan for the species"* (SARA s.2(1)). At the time of Recovery Strategy preparation, there was insufficient information available to provide advice on the identification of critical habitat. Consequently, the recovery strategy contained a schedule of studies needed to obtain the information required for habitat identification.

The recommendations set forth in DFO's draft *Operational Guidelines for the Identification of Critical Habitat* (DFO, 2012) detail a number of methods used to define the habitat necessary to support the population and distribution objectives for a species at risk. With many species, identification of habitat begins with the repeated observation of individuals associated with a geospatial location, and an *area of occurrence* approach is undertaken. Based on the logical assumption that a high recurrence of individuals in an area indicates that the habitat is suitable, and possibly necessary for survival, the *area of occurrence* approach (AOA) is often the starting point for critical habitat investigations and assists in the development of the schedule of studies. Once the geospatial area has been defined, the function served by the habitat may be established and the features that support the identified function may also be identified. The AOA assumes that the functions and features necessary for the species' survival or recovery exist within the defined geospatial boundary, and follows the general principle in behavioural ecology that suggests consumers aggregate in the most profitable foraging areas where expected consumption rates are highest (Stephens and Krebs, 1986).

In the case of data deficient species, or those with an infrequent presence in Canada, the application of the AOA is problematic and the issue must be tackled from another direction. A second method, the *bounding box* approach (BBA), may be utilized when there is sufficient knowledge of the function that the habitat serves for the species, and the supporting features are present and describable. The BBA can be defined simply as "the area within which critical habitat is found." This approach may also be used when features and their attributes can be described but their location varies yearly or knowledge of their specific location does not exist or is not practical to obtain. Although this approach is often supplemented by sightings or survey data, it is not dependent on the presence of individuals, but instead relies on the identification of functions and features that support the survival or recovery of the species.

Leatherback Sea Turtle sightings in British Columbia are infrequent (Kermode, 1932; MacAskie and Forrester, 1962; McAlpine *et al.*, 2004; Spaven *et al.*, 2009; Stinson, 1984). Spaven *et al.* (2009) compiled data from sightings, strandings and entanglements from 1931 to 2009 and identified a total of 126 unique Leatherback sighting records from the waters of British Columbia. These data represent a compilation of the information collected through surveys, questionnaires, entanglement records, strandings, and observations obtained during ship-based cetacean surveys. As the majority of these sightings were opportunistic and therefore biased with respect to effort, it is difficult to draw conclusions as to the distribution and habitat use of Leatherbacks in Canadian Pacific waters. However, satellite tagging data from both the Atlantic and Pacific populations indicate that temperate waters serve as foraging grounds for Leatherback Sea Turtles, and the primary prey species are known to be gelatinous zooplankton (Bleakney, 1965; Den Hartog and Van Nierop, 1984; Eisenberg and Frazier, 1983). Information on the function and features of Leatherback Sea Turtle habitat in temperate waters is available; therefore, an envelope model was utilized to identify areas of suitable foraging habitat. The results of this model will provide information relevant to the identification of critical habitat for Leatherback Sea Turtles in Canadian Pacific waters.

This report documents the analyses undertaken in support of the identification and designation of critical habitat for Leatherback Sea Turtles in Canadian Pacific waters and provides information on further studies required to ensure that the habitat identified is sufficient to support survival or recovery of the species.

1.2 LEATHERBACK SEA TURTLE BIOLOGY

1.2.1 Leatherback populations in Canada

One of only seven species of marine turtle, the Leatherback (*Dermochelys coriacea*) is the sole member of the family *Dermochelyidae*, which diverged from other turtles 100-150 million years ago (Zangerl, 1980). While Leatherbacks may be found in the Atlantic, Pacific, and Indian Oceans, low genetic differentiation between these geographically isolated populations has led to the recognition of a single species.

Unlike other marine turtles, keratinized scutes are absent from the Leatherback’s carapace, and the front and rear flippers and head lack scales. Instead, the entire body is covered with a thin layer of skin, bluish-black on the dorsum and whitish-pink on the ventrum. Seven longitudinal keels are found on the carapace, which is spade-shaped and tapers to a blunt point. Sexual dimorphism in tail length can be used to visually distinguish mature male and female turtles, with the tails of adult males typically presenting 2-3 times longer than that of females of the same carapace length.

The Leatherback is the largest of the marine turtles. Morphometric data collected by Harris *et al.* (2011) from 19 Leatherbacks in California waters indicates a potentially longer mean curved carapace length (CCL) and greater mean mass (CCL: 158.04 ± 7.32 cm; mass: 499.4 ± 63.1 kg) than a much larger sample of Leatherbacks measured off Atlantic Canada (mean CLL: 148.1 cm; mean mass: 392.6 kg; (James *et al.*, 2007). If the size of Leatherbacks off British Columbia is assumed to be similar to those encountered off California, then the Leatherback foraging populations found off the east and west coasts of Canada are principally comprised of large sub-adult and adult turtles, a size class which confers advanced thermoregulatory capacity likely required for extended foraging in temperate through to sub-arctic waters (James and Mrosovsky, 2004).

In the Pacific, there are two principal nesting populations of Leatherbacks; one in the Eastern Pacific, including beaches in Mexico and Costa Rica; and one in the Western Pacific, including beaches in the Solomon Islands, Malaysia, Papua New Guinea, and Indonesia. A general long-term decline in the number of nesting females in the Pacific (Spotila *et al.*, 2000) has contributed to the designation of both populations as critically endangered under the IUCN criteria (Wallace *et al.*, 2013). However, while current numbers of nesting turtles are considerably lower than historical counts at several key nesting beaches, data from some sites suggest that site fidelity and nesting persistence in these areas has been maintained (Hitipeuw *et al.*, 2007).

Leatherback distributions are presumed to largely reflect foraging strategies designed to maximize exploitation of gelatinous zooplankton, the species' principal prey. Satellite telemetry data is consistent with genetic research in demonstrating spatial segregation in the foraging areas used by Eastern and Western Pacific nesting populations (Bailey *et al.*, 2012a; Dutton *et al.*, 2007). The Leatherbacks of Eastern Pacific origin principally forage in the southeast Pacific, while Western Pacific Leatherbacks forage in several disparate areas, including the South China Sea, southeastern Australia, the central North Pacific, and the coasts of California, Oregon and Washington (Bailey *et al.*, 2012b). Movement patterns of satellite-tagged animals from the Western Pacific Leatherback nesting population suggest that individuals foraging in the Canadian Pacific waters are part of the Western Pacific population (Benson *et al.*, 2007; Benson *et al.*, 2011).

Nesting intervals for Pacific Leatherbacks are considerably longer (by one or more years) than those of their Western Atlantic counterparts (Saba *et al.*, 2008). This is believed to largely reflect variations in environmentally-driven resource availability between the two ocean basins, with generally inferior and more variable Pacific Ocean foraging conditions also necessitating longer migrations between key foraging areas and nesting sites in order for turtles to acquire sufficient energy for reproduction (Wallace and Saba, 2009). Seasonal exploitation of gelatinous plankton in temperate coastal foraging areas is a key characteristic of many Leatherback populations, and this strategy has been highlighted by telemetry studies (Benson *et al.*, 2007; Benson *et al.*, 2011; Hays *et al.*, 2004; James *et al.*, 2005a), analysis of animal-borne video (Heaslip *et al.*, 2012), and through documentation of body condition changes not only between nesting and temperate foraging areas (James *et al.*, 2005a), but also through the northern foraging period (Davenport *et al.*, 2011).

Study of Leatherback foraging behaviour in temperate waters off Atlantic Canada reveals inter-annual fidelity to foraging areas (James et al, 2005), and acquisition of energy far in excess of metabolic requirements (Heaslip et al, 2012). Location of areas characterized by high jellyfish biomass is critical for sustaining energy requirements of this fast-growing species (Jones *et al.*, 2012). Therefore, Atlantic Canada and similar high-latitude coastal areas used by Leatherbacks in other parts of their range such as the Pacific coast of Canada, provide important foraging opportunities for the survival and reproduction of individual turtles and also for the recovery of associated nesting populations.

1.2.2 Threats to Recovery

The list of threats to recovery for the Leatherback Sea Turtle is extensive and reflects their behaviour, long migratory route across open ocean environments, and competition with development and encroachment on nesting areas. Although many of these threats impact portions of the species' life history that occur outside of Canada, Leatherback recovery requires a concerted international effort to mitigate threats to all aspects of this species' life cycle if recovery is to be realized. For clarity, threats have been identified according to habitat (nesting environment vs migrating/foraging).

1.2.2.1 Threats in the nesting environment

The population of Leatherback Sea Turtles that enter Canadian Pacific waters are believed to nest in the tropical western Pacific Ocean (Papua New Guinea, Indonesia, Solomon Islands, and Malaysia). A primary threat to recovery is the illegal harvest of eggs and nesting females. Conservation programs and prohibitions against harvest have been initiated at some of the nesting beaches (Tapilatu *et al.*, 2013), and initial reports indicate that Leatherback harvest of both females and eggs is on the decrease.

Anthropogenic threats to nesting success and hatchling survival include predation by introduced feral pigs and dogs, and loss of quality nesting habitat through erosion, development and/or disturbance by human activities. The reduction in availability of quality nesting habitat results in a portion of nests being established below the tide line, or in exposed locations where nests are subjected to desiccation and heat stress.

1.2.2.2 Threats in the foraging environment

The diet of Leatherbacks also makes them vulnerable to ingesting plastic debris that may resemble their gelatinous prey (Eckert and Luginbuhl, 1988; Fritts, 1982; Mrosovsky, 1981; Starbird, 2000). Mrosovsky *et al.* (2009) examined over 400 Leatherback necropsy reports and found evidence of plastic in the gastrointestinal tracts of 34% of the individuals, with a rapid increase after the first incidence in 1968. Consumption of plastic may have severe consequences for Leatherbacks, potentially resulting in death (Mrosovsky *et al.*, 2009).

Large migrations to and from temperate foraging grounds make Leatherbacks especially vulnerable to interactions and entanglement with fishing gear, which is now perceived as one of the greatest threats to Leatherback survival (Eckert and Sarti M, 1997; Ferraroli *et al.*, 2004; James *et al.*, 2005b; Kaplan, 2005; Lewison *et al.*, 2004; Spotila *et al.*, 2000). The potential for accidental capture and entanglement in Canadian Pacific waters is currently unknown due to the limited amount of sightings that occur in this region; however, information from other regions in the Pacific indicate that may types of fisheries pose threats, with impacts from pelagic (floating) longline, gillnet and high seas driftnet fisheries being identified (Wetherall *et al.*, 1993).

1.2.3 Leatherback Sea Turtle Prey

While dietary studies on Leatherback Sea Turtles are limited, direct observations, animal-borne video, and stomach contents analyses reveal that pyrosomes, salps, and scyphomedusae are among the gelatinous prey items consumed (Davenport and Balazs, 1991; Fossette *et al.*, 2012; Heaslip *et al.*, 2012; James and Herman, 2001). Jellyfish, a term which may include pelagic cnidarians, ctenophores, and pelagic tunicates, have historically been perceived to be unimportant food items for vertebrates and were often thought to be trophic dead ends in marine food webs (e.g., Sommer *et al.*, 2002; Verity and Smetacek, 1996). However, there is increasing awareness that jellyfish are prey for more than 100 species of fish, as well as seabirds and other organisms (Arai, 2005; Pauly *et al.*, 2009). Nonetheless, there are few obligate predators of jellyfish. One notable exception is the Leatherback Sea Turtle, which appears to forage almost exclusively on jellyfish, including many types of pelagic cnidarians, ctenophores, and pelagic tunicates, with a potential focus on scyphozoans in coastal waters (Dodge *et al.*, 2011; Eisenberg and Frazier, 1983; Fossette *et al.*, 2012; Fossette *et al.*, 2010; Heaslip *et al.*, 2012; Holland *et al.*, 1990; James and Herman, 2001; Jensen and Das, 2007).

Jellyfish are composed largely of water (>95%), and hence have a low energy density relative to other marine organisms. Leatherbacks frequently grow to hundreds of kilograms (James *et al.*, 2007; Paladino *et al.*, 1990; Rhodin *et al.*, 1981) and may potentially reach a tonne (Holland *et al.*, 1990). It is counterintuitive that such a large animal could subsist purely on a gelatinous diet. Nonetheless, Leatherbacks appear to survive entirely on jellyfish, and may embark on migrations of thousands of kilometres from breeding grounds in the tropics to forage on jellyfish in temperate environments.

When located, jellyfish are very easy to capture, as they have a negligible escape response, especially from an animal as fast and manoeuvrable as a sea turtle (Heaslip *et al.*, 2012). In addition, jellyfish are relatively easy to digest (Arai *et al.*, 2003), and many types of jellies occur in dense aggregations known as ‘blooms’, due to their unique life histories and behaviours (Dawson and Hamner, 2009; Hamner and Dawson, 2009). An individual Leatherback may eat tens or hundreds of kilograms of jellyfish in a single day (Duron-Dufrenne, 1987; Heaslip *et al.*, 2012; Jones *et al.*, 2012), potentially consuming in excess of 1000 tonnes in its lifetime (Jones *et al.*, 2012). This gelatinous diet appears to provide all of the Leatherback’s energetic demands, as well as allowing them to add mass for return migrations to breeding and nesting habitats (Heaslip *et al.*, 2012; James *et al.*, 2005b; Lutcavage and Lutz, 1986; Wallace *et al.*, 2006). Therefore, locating dense blooms of jellyfish in coastal waters may be vital for Leatherback foraging success, and thus understanding the association between Leatherbacks and their gelatinous prey is central to identifying critical habitat.

1.2.4 Features of Leatherback Sea Turtle foraging habitat

1.2.4.1 Prey in Canadian Pacific waters

The lion’s mane jellyfish, *Cyanea capillata* is the largest known species of jellyfish in Canadian waters, capable of attaining a bell diameter in excess of 2 m, but more typically approaching 0.5 m. This jellyfish is frequently observed along all of Canada’s coastlines, and forms the principal prey species for the Atlantic population of Leatherback Sea Turtles. In the Pacific, *C. capillata* is seldom found further south than 42°N latitude (Wrobel and Mills, 1998). The Pacific population of Leatherbacks that migrate from nesting beaches in Indonesia and the South Pacific often forage along the Californian coast south of 42°N. As such, these Leatherbacks are more likely feeding on other coastal scyphomedusae, including the sea nettle *Chrysaora fuscescens* and moon jellyfish *Aurelia* spp. In Canadian waters, *C. fuscescens, C. capillata* and *Aurelia* spp. are also frequently observed, but at present, Leatherback foraging observations from Canadian Pacific waters are few and little is known regarding prey preference. As knowledge of jellyfish abundance and species distribution in Canadian waters is poor, the development of appropriate survey methods to assess Leatherback Sea Turtle prey availability in Canadian waters is paramount.

Many jellyfish, including the scyphozoan species discussed herein, have a bipartite life history consisting of a sessile polypoid phase and a pelagic medusoid phase. Typically, external fertilization occurs as eggs and sperm are released from mature medusae (Arai, 1997). Fertilized gametes form semi-motile planulae, which usually settle on the undersides of hard substrates and metamorphose into polyps (Lucas *et al.*, 2012). In some cases, these polyps will asexually bud more polyps or produce dormant cysts resistant to harsh environmental conditions (Arai, 2009; Widmer, 2008). Triggered by a combination of factors that is not well understood, polyps asexually strobilate multiple jellyfish ephyrae (Arai, 1997; Fautin, 2002; Lucas *et al.*, 2012) , which then join the plankton community and rapidly grow into medusae (Palomares and Pauly, 2009). Adult medusae rarely live longer than one year in the Canadian Pacific and will usually senesce before the cold winter months; however, overwintering medusae of *Aurelia labiata* have been reported (Albert, 2005). On the contrary, polyp colonies likely survive for many years and may regenerate in a variety of ways (Lucas *et al.*, 2012). With such unique life cycles, the factors controlling jellyfish reproduction are numerous and complicated, and populations may be influenced by different factors at different times. Polyps of *C. capillata* and *C. fuscescens* have yet to be located in British Columbian waters, yet medusae can often be seen in summer and autumn, albeit with dramatic interannual variability (Brotz, 2011).

Factors controlling jellyfish reproduction, abundance, and distribution are not well understood. Generally, jellyfish are considered part of the plankton and drift with the currents. Many species exhibit vertical migration (VM), and in some cases, it appears VM may be used to take advantage of tidal currents to remain in a particular environment. Limited evidence from the

Wadden Sea suggests that such behaviour is more likely to be exhibited by hydrozoans and ctenophores (Kopacz, 1994; van der Veer and Sadee, 1984) than it is by scyphozoans (van der Veer and Oorthuysen, 1985; Verwey, 1966). In Roscoe Bay, British Columbia, *Aurelia labiata* medusae appear not to take advantage of tidally synchronized vertical migration to remain in the Bay (Albert, 2010) until they are swept across a sill and out of the Bay, after which they will adjust their depth in order to be carried back into the Bay (Albert, 2007). Other factors and behaviours have been shown to result in jellyfish aggregations (e.g., Graham *et al.*, 2001; Hamner *et al.*, 1994); however, it can generally be assumed that medusae are controlled by local currents, and therefore may be associated with fronts or areas of retention. Jellyfish with meroplanktonic life histories are also inherently linked (at least initially) with coasts and shallower depths where polyps are located on hard substrates. As coastal areas also tend to exhibit higher production, it might be suspected that coastal areas will harbour higher jellyfish biomass. Indeed, such a general trend has been identified both globally (Lilley *et al.*, 2011), and locally in the eastern North Pacific (Suchman and Brodeur, 2005).

1.2.4.2 Water depth

The Leatherback Sea Turtle is the only reptile that regularly exceeds diving depths of 100 m (Houghton *et al.*, 2006). In coastal regions, Leatherbacks feed on large shallow water scyphozoan jellyfish, while in oceanic areas, the primary prey species are believed to be other species of gelatinous zooplankton, which may be found throughout the water column. Leatherbacks are capable of lengthy (>1 hr) and extraordinarily deep dives (down to 1250 m); however, these deep dives occur primarily during transit and cease once the animals begin their seasonal residence on foraging grounds. The role of deep diving has not been unequivocally established, but it has been suggested that deep dives are periodically employed during transit to survey the water column for diurnally descending gelatinous prey (Houghton *et al.*, 2006; Shillinger *et al.*, 2011). As the animals approach temperate coastal areas, the deep diving behaviour shifts to favour extended periods of very shallow dives (Hays *et al.*, 2006), likely in response to scyphozoan prey availability.

Off the coast of California, satellite-tagged Leatherbacks exhibited foraging behaviour primarily over cool, shelf/slope waters (Benson *et al.*, 2011). Although little is known about the distribution of scyphozoan medusae in Canadian Pacific waters, their life cycle would suggest that densities are likely to be higher in relatively shallow waters. As accumulation of mature medusae is more likely to occur in proximity to the polyp beds, greater Leatherback foraging opportunities would be found at shallower depths. This trend has been confirmed along the Oregon coast by Suchman and Brodeur (2005), who analysed trawl data over several years and generally found higher abundances of medusa closer to shore.

1.2.4.3 Chlorophyll-A Concentration (Chla)

Chlorophyll-a concentration (Chla), as measured using remote sensors, can serve as a proxy for two ecologically relevant processes. The first is as an indicator of relative primary production, and is the prototypical use of such data (Longhurst, 2007). The second is entrainment, the process whereby plankton are concentrated to many times the background, or average levels, thereby creating potential foraging hotspots for plankton feeders (Bakun, 1996; Longhurst, 2007).

Benson *et al.* (2011) found that Leatherback Sea Turtles foraged in areas where Chla exceeded 1.26 mg/m^3. For the Western Pacific population, the probability of area-restricted search behavior (indicative of foraging) was positively correlated with Chla, and subsequently used as a proxy for productivity and hence potential prey availability (Bailey *et al.*, 2012a).

1.2.4.4 Currents

Ocean currents are critical to the creation of foraging patches for planktivores. Fronts and eddies in the surface layer of the ocean can concentrate plankton at 3 to 10 times background (Mackas and Tsuda, 1999). Localized concentrations of zooplankton increase foraging efficiency and serve to explain the strong covariation between planktonic prey and their predators (Russell *et al.*, 1992).

Such concentration features can be identified from a variety of remotely sensed data including sea surface temperature (SST), Chla, and sea surface height (SSH) (Longhurst, 2007). These data are collected at different resolutions, and provide somewhat different information on the nature of the front. For example, SST is most likely to capture wind-driven fronts such as upwelling, while SSH is more likely to capture larger features (e.g., mesoscale eddies) that are the result of the interactions between larger water masses (Longhurst, 2007).

Benson *et al.* (2011) found that off the US Pacific coast, Leatherback Sea Turtles foraged in waters where eddy kinetic energy (EKE) was less than 0.05 m^2/s^2, and Ekman pumping was high.

EKE (Equation 1) is a measure of turbulence, and is used to measure the variability of the flow.

$$EKE = \frac{1}{2}(u^2 + v^2) \qquad \text{Equation 1}$$

Where *u* and *v* represent the horizontal and vertical components of the current. This measure is associated with frequency of eddies in off-shelf waters (Ladd, 2007). As an indicator of upwelling, Ekman pumping can be expected to be correlated with surface temperature fronts, and corresponds to the general oceanographic conditions one might expect near shore in the California current ecosystem. In their analysis of telemetry-derived area restricted search (ARS) behaviour (a presumed indicator of foraging activity) Benson et al. (2011) found most ARS-identified telemetry locations were found in upwelling areas.

To facilitate the identification of critical habitat for Leatherback Sea Turtles in Canadian Pacific waters, the authors considered the range of oceanographic features potentially associated with Leatherback foraging behaviour, and proposed a model to delineate areas of foraging suitability. In addition, studies were undertaken to evaluate the caloric value of two scyphozoan prey species, and a survey method was developed to characterize the abundance, biomass, and distribution of scyphozoan medusae in Canadian Pacific waters.

2 METHODOLOGY

2.1 JELLYFISH SURVEY METHODOLOGY

Fisheries and Oceans Canada conduct integrated ecosystem surveys several times each year in the coastal waters of British Columbia, with consistent methods implemented since 1998. ‘Inshore’ surveys are conducted in the Georgia Strait and surrounding inlets. Similar ‘offshore’ surveys are conducted around Vancouver Island (offshore and in inlets), as well as along the west coast of British Columbia. Trudel *et al.* (2010) present some of the details of these surveys, which include trawls for juvenile salmon as part of the Georgia Strait Trawl Survey and the High Seas Salmon Survey. Surveys are conducted along repeated transects in all seasons of the year, and are therefore ideal for identifying seasonal and interannual trends. Both surveys use similar fishing gear; namely, a mid-water trawl net with an approximate mouth opening of 28 m wide by 16 m deep. Typical trawls are fished at the surface or at a measured depth below the surface for 30 minutes at 5 knots. In addition to enumerating information on salmonids and bycatch, oceanographic data is collected at some or all stations. This can include conductivitytemperature depth (CTD) casts, chlorophyll measurements, and water samples for later nutrient analyses. Zooplankton are also sampled frequently using vertical bongo tows. As such, these surveys provide an extremely valuable dataset of ecological information. The trawls frequently catch jellyfish, especially large scyphozoans including *Aurelia labiata, Cyanea capillata*, and *Chrysaora fuscescens*, all of which may be important food for Leatherback Sea Turtles. Bycatch of species other than salmonids are typically recorded; however, there is no standardized protocol for monitoring large gelatinous zooplankton, which are typically only recorded generally as ‘jellyfish’, if at all. While the trawl may inflict significant damage to the jellyfish in the catch, medusae are often intact and identifiable to species. Therefore, these trawls provide a cost-effective method for identifying several aspects of jellyfish ecology and population dynamics, including biomass, abundance, size, weight, species distributions, seasonal changes, and interannual trends. As knowledge of jellyfish in the waters of coastal British Columbia is relatively poor, especially for large scyphozoans, these surveys provide a unique opportunity to rapidly increase the understanding of jellyfish in this region. In addition to providing useful ecological information, such knowledge is crucial to understanding the relationship between endangered Leatherbacks and their gelatinous prey, including the identification of critical habitat.

In response to the need for further information on Leatherback prey species in Canadian Pacific waters, a jellyfish survey protocol was developed (Appendix 1 – Jellyfish Monitoring Protocol) in collaboration with Fisheries and Oceans Canada scientists, and with input from the crew of the CCGS W.E. Ricker. The protocol was designed to minimize the effort required for jellyfish processing, while at the same time maximizing the amount of useful information collected. Catches from individual trawls may vary widely from zero catch to an overwhelming amount of fish or jellyfish. As such, a step-wise approach to the processing of jellyfish bycatch is recommended, whereby scientists and technicians can collect a minimum amount of information on jellyfish if they are preoccupied with analyzing other catch, or collect more detailed information if processing time permits.

2.2 LEATHERBACK FORAGING MODEL

The data for Leatherback Sea Turtles along the Canadian Pacific coast is limited to a small number of opportunistic sightings (Figure 1), with no information of habitat associations or foraging behaviour. Observations from areas with higher turtle densities were therefore relied upon to develop inferences regarding habitat selection in Canadian Pacific waters. While the limitations in using oceanographic conditions associated with Leatherback foraging in other locales are recognised, such information nevertheless represents the best available data on this species.

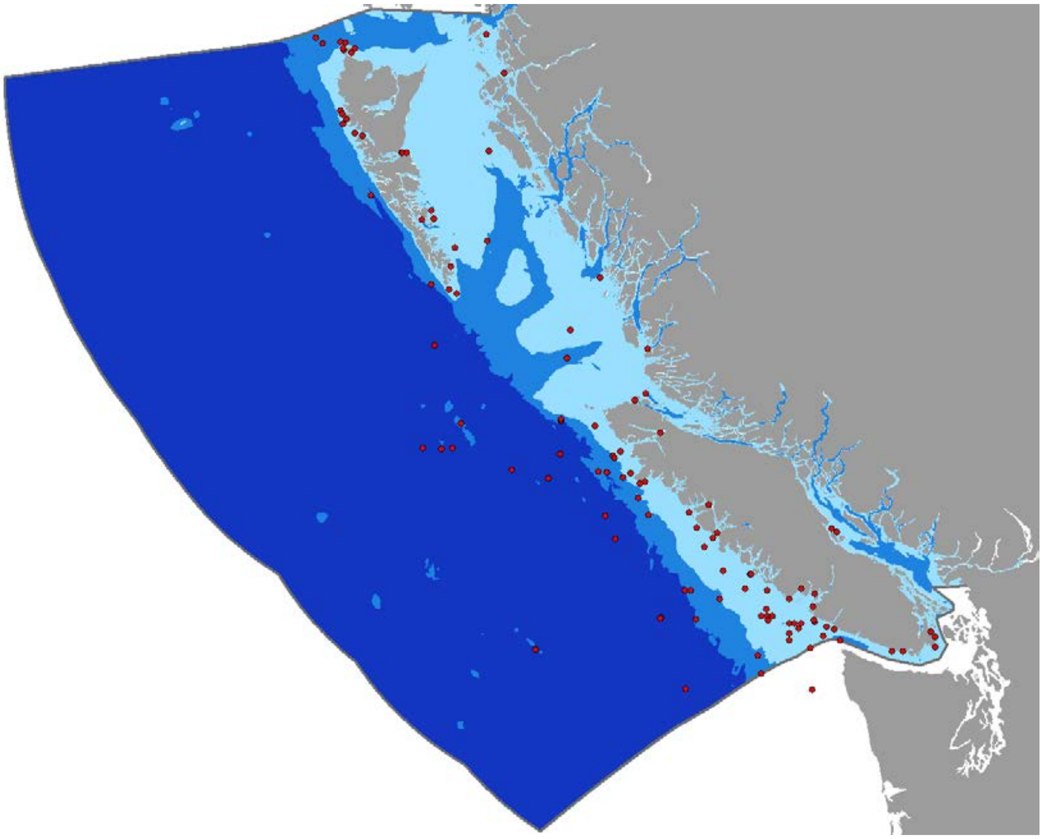

Figure 1. Live Leatherback turtle sightings (n=122) in the Canadian Pacific exclusive economic zone (EEZ) are shown as red dots (after Spaven et al, 2009). There are 111 unique locations as 11 locations have recorded sightings in multiple years. Areas of apparent high Leatherback density are biased to an unknown degree by observer effort. The depth categories are continental shelf to 200 m (light blue); 1500 m (moderate blue); and offshore waters (dark blue).

Given the paucity of sightings data, and the considerable biases associated with those available, the data do not support a correlational analysis relating the sightings with environmental variables. Instead, an envelope model was used to represent potential Leatherback Sea Turtle foraging habitat in Canadian Pacific waters. Based on hypotheses about how oceanography may influence the creation of foraging patches, integration of the most appropriate, available oceanographic data was undertaken.

2.2.1 Variable selection

Benson et al. (2011) combined satellite tracking and oceanographic databases to evaluate the importance of oceanographic variables previously associated with marine turtle distribution (Polovina *et al.*, 2004; Polovina *et al.*, 2001; Polovina *et al.*, 2000; Shillinger *et al.*, 2008). These variables included depth, SST, Chla, SSH, EKE, and Ekman pumping. Within the California Current Ecosystem, foraging behaviour was found to occur in regions that were cool, shallow, and characterized by high Chla, high Ekman pumping, and low EKE (Benson *et al.*, 2011).

While many oceanographic variables may be correlated with the distribution of foraging Leatherback Sea Turtles, these variables themselves are generally cross-correlated and thus often represent the same ecological process. Quantitative envelope models typically combine a suite of potential habitat predictors into factors (e.g., Elith *et al.* (2006)), and are understood to perform best when the variables they consider are independent. The authors reviewed the factors thought to be the most influential in delineating Leatherback Sea Turtle forging areas, and developed hypotheses for oceanographic drivers believed to serve as largely independent proxies for oceanographic processes that are likely to contribute to the production and aggregation of jellyfish.

The prey of Leatherback Sea Turtles is both planktonic, and a plankton predator; therefore, areas where entrainment occurs with a higher than average frequency are likely important in identifying potential foraging areas. The importance of these areas may be reinforced by the associated, elevated levels of primary production, which are expected to support more abundant zooplankton communities, suitable for jellyfish foraging.

Given the need to maximise independence among the variables, the authors assumed that high Chla was a sufficient proxy for both primary production and concentration features. Measures of SSH or Ekman pumping were therefore not included, since these variables are generally used for identifying frontal areas, and thus their inclusion would capture similar areas to those identified using Chla and lead to the over-representation of concentration features. Additionally, the resolution of these variables from the available sensors (~30 x 30 km^2) was relatively poor compared to the other variables available.

The suggestion that Leatherback Sea Turtles forage in low energy areas (Benson *et al.*, 2011) led the consideration of current energy as the second independent variable for the envelope model. RMS was modeled instead of EKE because while the two are directly correlated, RMS has the advantage of being conceptually simpler and thus more easily interpreted.

Finally, the importance of depth was examined, since several lines of evidence suggest that Leatherback Sea Turtles may preferentially forage in on-shelf areas in Pacific Canada. Research on Atlantic Leatherbacks supports the concept of shelf importance to foraging, as aerial transects demonstrate significantly higher density of turtles on the shelf during the foraging season (Shoop and Kenney, 1992). In addition, sampling on Atlantic turtles found that foraging behaviour was seldom exhibited in deep water areas off the shelf (James *et al.*, 2005a).

Habitat envelopes were created for each of these three physical variables. These individual envelopes were then integrated into a single, qualitative habitat prediction of Leatherback Sea Turtle foraging habitat.

Data on depth, Chla and ocean currents for the Canadian Pacific EEZ (Table 1) were collected and processed into ocean climate maps suitable for use in the envelope model. As the objective was to identify the potential (as opposed to realised) habitat for Leatherbacks, long term averages (climatologies) were created for the physical variables of interest to identify areas that, over time, have the greatest potential to serve as habitat.

Table 1 Physical variables used to develop Leatherback Sea Turtle Critical Habitat.

Variable	Units	Resolution (x,y)	Resolution (t)	Year range
Depth	m	100 x 100 m^2	na	na
Chlorophyll-a	mg chl-a/m^3	1.2 x 1.2 km^2	daily	2007-2011
RMS current velocity	m/sec	1/12° (2 x 2 km^2)	monthly	1998-2003

* The HYCOM current data were interpolated to a 2 x 2 km^2 grid.

2.2.2 Time frame

Leatherback Sea Turtles are seasonal foragers, known to forage in northern waters predominantly in summer. Satellite tagging of Leatherbacks (Benson *et al.*, 2011) indicated that seasonality was pronounced, with Leatherbacks arriving off the coast of California, Oregon, and Washington in April-July. Animals engaged in foraging behaviour 21% of the time and remained in the area through late November (Benson *et al.*, 2011).

The majority of sightings in Canadian Pacific waters occur in July through September. Recognising the summer bias associated with these observations, we selected the five month period June to October to capture the most likely foraging period of Leatherback Sea Turtles in Pacific Canada, considering the variability in the inter-annual development of the plankton community and Leatherback behaviour.

2.2.3 Depth

The Canadian Pacific shelf is generally considered to begin at 200 m depth; however, for the purpose of this model, a 1500 m depth was used to minimize the influence of the crenulated bathymetry in Pacific Canada (Figure 1). This created a relatively linear feature that allowed the model to emphasise the likely importance of the shelf as well as waters near upwelling regions.

To avoid entirely excluding offshore waters, the depth envelope was parameterised so that the defined shelf area contributed twice the utility to foraging as the offshore waters. A 100 x 100 m^2 bathymetric grid was used to define these regions, and served as the subsequent spatial framework for this analysis.

2.2.4 Chlorophyll-a

Daily Chla at kilometre-scale resolution were obtained from the Medium Resolution Imaging Spectrometer (MERIS), mounted on the ENVISAT platform operated by the European Space Agency. After extracting the data from the MERIS database, Python scripts and the spatial geoprocessing operations were used to merge the daily images into monthly Chla climatologies across the available years (2007 to 2011). The creation of climatologies removed most of the gaps due to cloud cover.

MERIS data are provided as daily swaths. Daily data were downloaded for the 5 potential Leatherback Sea Turtle foraging months (June to October) for all available years (2007-2011). The algal_1 band from the MERIS data was selected to represent Chla, and the mission-specific software (BEAM 4.10.3 - the ESA Envisat Project, Brockmann Consultants, 2011) was used to convert the downloaded Envisat N1 files to NetCDF files, which were then mosaiced within BEAM into 5-year, monthly climatologies. These NetCDF climatologies were imported into ArcGIS 9.3 as points, projected to an Albers projection, and gridded at the nominal resolution of the data (Chla - 1.2 x 1.2 km^2) using Nearest Neighbour interpolation. Finally, to make them compatible with the other data sets, the climatologies were re-sampled to a resolution 100 x 100 m^2, and clipped to the Canadian Pacific EEZ.

In summer months, virtually the entire Canadian Pacific shelf has Chla exceeding the 1.26 mg chl-a/m^3 threshold identified by Benson *et al.* (2011). The use of absolute measures was therefore avoided, as they are likely to exhibit considerable variability across regions and years. Instead, a classification approach was developed to reflect the relative, monthly values of Chla.

First, a mean smoothing window (radius = 1000 m) was passed over the monthly climatologies to create more contiguous regions of Chla and to reduce peak values. The smoothed monthly climatologies were divided into five classes (values 0 - 4), using the Jenk's classification (Jenks, 1977). This classification uses least squares to minimise the variability between classes and maximise the difference between them, thereby identifying natural breaks in the data. This minimizes within-class sum of squared differences, and thus identifies classes that are most homogeneous within. The five classified summer months were then summed, thereby identifying areas where high Chla occurred consistently over the presumed Leatherback Sea Turtle foraging period.

2.2.5 Root Mean Square Current Velocity

Root mean square (RMS) current velocity (Equation 2; *u* and *v* represent the horizontal and vertical components of the current) was selected to represent areas of lower current energy:

$$RMS = \sqrt{(u^2 + v^2)} \qquad \text{Equation 2}$$

Surface current data were obtained from the Hybrid Coordinate Ocean Model (HYCOM), a global ocean circulation model running at a resolution of 1/12° (approximately 10 km in Pacific Canada). The model has been run in various forms for the years 1979 to 2003 for the North Pacific. For this analysis, monthly averages for the six years 1998-2003 were obtained for the 5 months of interest. These monthly values were averaged across all years to create monthly surface climatologies.

HYCOM netCDF files were imported into R, and created the monthly values. The (x, y, z) point files for each monthly climatology were exported and then were imported into ArcGIS. After converting to monthly shape files, the points were projected to the BC Albers projection and were interpolated using Natural Neighbour to a 2 x 2 km^2 resolution. Finally, the data were re-sampled to the 100 x 100 m^2 resolution used in this study, and trimmed to the Canadian Pacific EEZ.

As with the monthly Chla climatologies, each month was divided into five classes (values 0 - 4) using the Jenk's classification, the five classified summer months were summed to identify areas where low RMS occurred consistently over the presumed LBST foraging period.

2.2.6 Envelope integration

For RMS and Chla, the summed foraging season envelopes were first reclassified to four levels, using equal interval classification. This then produced three envelopes, where Chla and RMS had four levels, and depth had two. Several ways of combining the three independent habitat envelopes were explored to investigate the robustness of the envelope model, given the three hypothesised predictor variables. Assuming an equal contribution from RMS and Chla and that, for lack of better information, the shelf region was assumed to be twice as important as pelagic areas. Two integration methods were considered:

First, RMS and Chla were added, and then multiplied by the shelf envelope. This assumed that RMS and Chla were reinforcing in a linear fashion, and that even a small contribution from either variable was important. The summed result was then multiplied by depth to emphasise the importance of the on-shelf region.

The second approach assumed that RMS and Chla have a more non-linear, synergistic effect, and that low values for either variable diminish the overall suitability of the habitat. Including depth in a consistent manner thus required that all three envelopes should be multiplied together.

The most parsimonious potential habitat model was then re-classified to 3 equal classes to give the final habitat prediction. Reducing the number of classes in this way facilitates the interpretation of the habitat classes as potential critical habitats by proposing possible thresholds for consideration. Other thresholds, identifying a greater or smaller portion of predicted habitat suitability, are possible.

3 RESULTS

3.1 JELLYFISH SURVEYS

A recommended procedure for surveying scyphozoans in Canadian Pacific waters is outlined in the included Jellyfish Monitoring Protocol (Appendix 1). However, it is suggested that the recommended procedures be flexible and accommodate feedback from scientists and technicians collecting the information. Jellyfish are often torn and may be caught in the net mesh, and pieces or whole medusae may fall on the deck during net retrieval. This ‘deck wash’ is sometimes, but not always, included with the analysed catch. In order to maintain consistent records, it is recommended that only the jellyfish bycatch that is retrieved from the cod end be analysed. Therefore, it is important for the science team to remind the deck crew to not place jellyfish that are part of the deck wash into the catch totes. The included Jellyfish Identification Guide covers species of jellyfish that are most likely to be encountered in the coastal waters of British Columbia and survive a trawl (Appendix 2). Information is adapted from Wrobel and Mills (1998) which should be consulted for additional detail.

3.2 INDIVIDUAL ENVELOPES

3.2.1 Chlorophyll-a

The Chla climatologies developed (Figure 2) suggest that the development of primary production on the Canadian Pacific shelf is well underway by June. The areas with highest Chla are on the north central coast, in the Strait of Georgia, and off southern Vancouver Island. This can be attributed to nutrient input, with the first two regions receiving considerable freshwater input, and the third receiving nutrients from both upwelling and the transport of nutrient rich water out of the Strait of Georgia. Upwelling off Vancouver Island likely also contributes to consistently high Chla in that region through the remaining months. By October, the signal is somewhat reduced, due to nutrient depletion and the consumption of phytoplankton by zooplankton.

Oceanographic features with the potential to generate retention features that would enhance this signal include the northward flowing Vancouver Island counter-current off Vancouver Island, and the interaction between shoreward currents and outflowing waters at the north end of Vancouver Island and in Dixon Entrance (Thomson, 1981).

3.2.2 Root Mean Square Current Velocity

The current climatologies (Figure 3) show the summer current regime largely established by June, and at its strongest in July and August. This coincides with the strongest northward flowing Vancouver Island counter-current, which extends along the entire length of Vancouver Island and into Queen Charlotte Sound. By October, the currents have relaxed, suggesting the transition to oceanographic winter has begun.

The entire nearshore area is classified as low energy in all months, and dominates the low energy class of the RMS envelope (SUM panel in Figure 3).

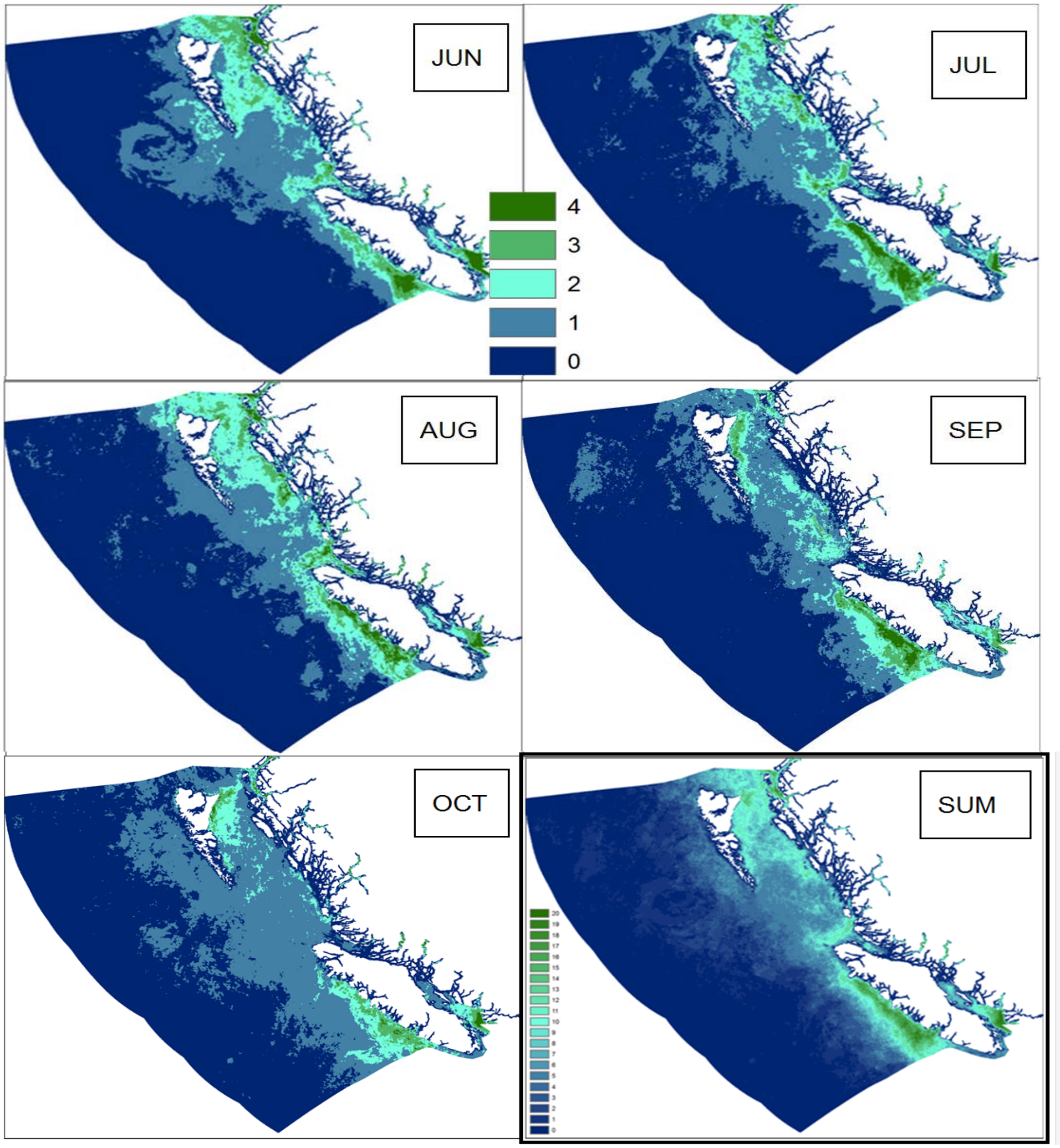

Figure 2. Monthly climatologies (for the 5 years from 2007 to 2011) of Chlorophyll-a (Chla) concentrations for June through October classified to 5 levels using Jenks methodology (Jenks, 1977). The combined Chla envelope (SUM) was obtained by summing across the classified months.

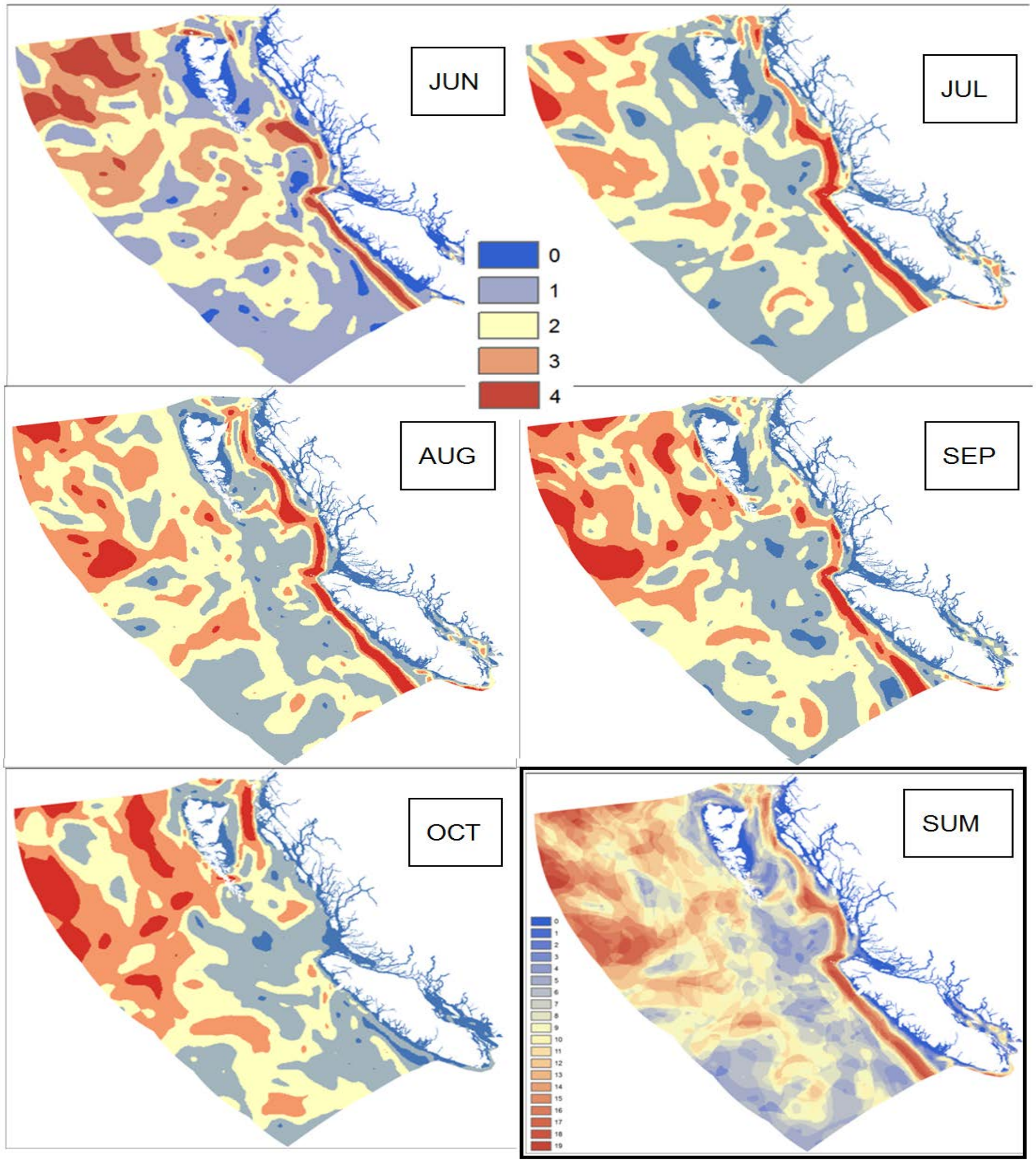

Figure 3. Monthly climatologies (for the 6 years from 1998 to 2003) of mean current speed (RMS) for June through October classified to 5 levels using Jenks method (Jenks, 1977). The combined RMS envelope (SUM) was obtained by summing across the classified months.

3.3 ENVELOPE INTEGRATION

Prior to integration, the depth, RMS, and Chla envelopes were simplified. Depth was divided into two classes, defining the relative contribution of the on-shelf and pelagic regions. Chla and RMS were aggregated into four classes each based on equal intervals to facilitate the interpretation of their relative contributions (**Figure 4**, left-hand column). Additionally, the RMS envelope was inverted, so that low current areas had the highest scores.

The two different methods (sum and product) of combining the habitat envelopes differ in detail only (Figure 4, right-hand column). And in the multiplicative model, the contribution of depth was considerably diminished. This implied that simply combining RMS and Chla would be sufficient (Figure 4; Chla*RMS).

Since a simpler model ought to be preferred over a more complex one if the benefits of the additional complexity are not clear, the simple, synergistic model of Chla * RMS (Figure 4; Chla*RMS) was selected as the preferred representation of potential Leatherback foraging habitat, given the information and data available.

The resulting suitable habitat prediction (Figure 5), obtained after pooling the Chla*RMS prediction into three classes, is dominated by a large area off Vancouver Island, where high Chla and low RMS occurred predictably during the months considered. Smaller areas in the Strait of Georgia and on the North Coast capture the regions of predictably high Chla due to fresh water input in these two regions. Other smaller areas of potential Leatherback habitat include the areas around Calvert Island and the Goose Group, both on the Central Coast and areas of known ecological importance. A third area east of Skidigate Inlet is also identified as an area of potential Leatherback habitat.

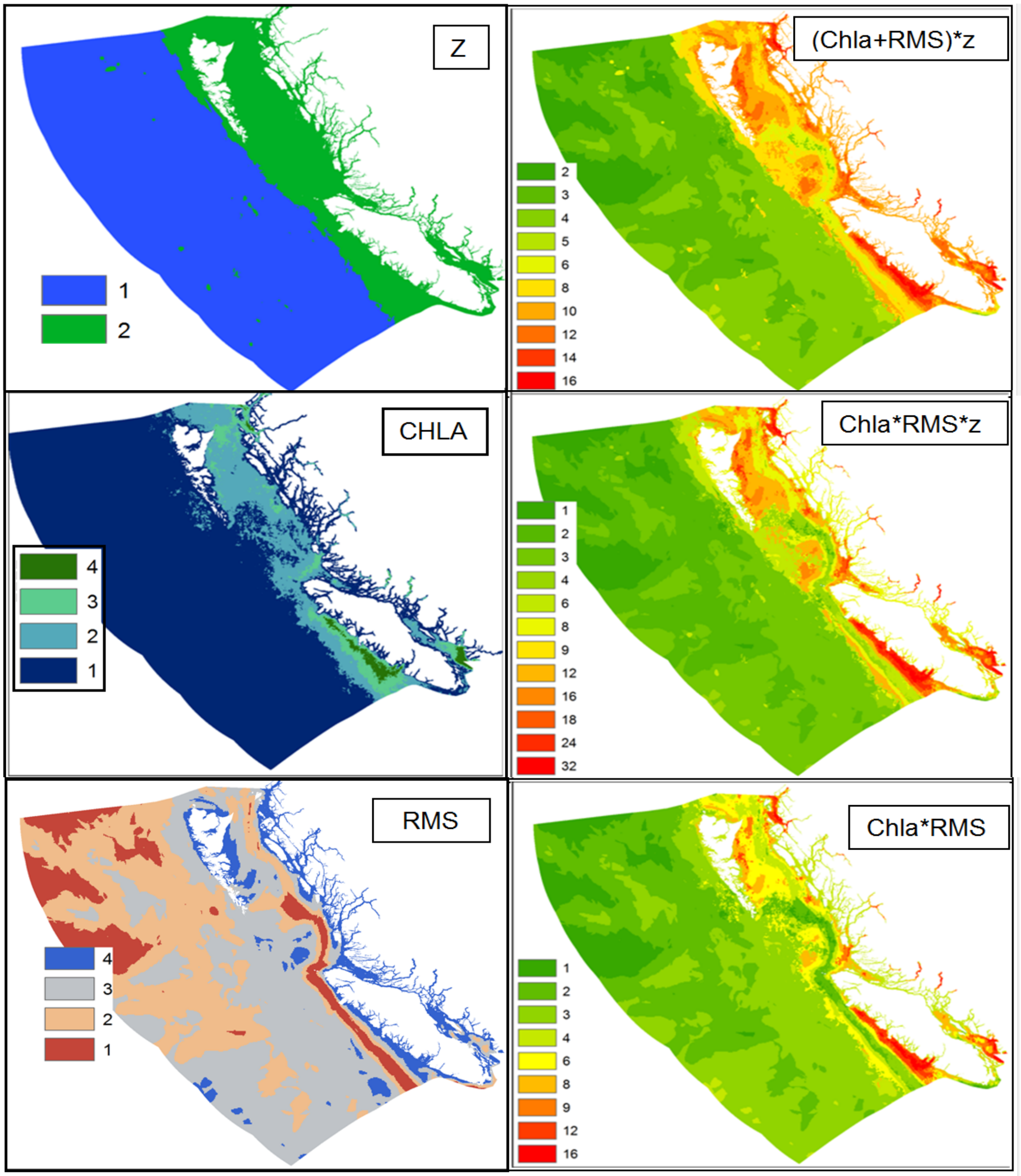

*Figure 4. Envelopes for the three independent variables (Z = depth, CHLA = chlorophyll-a concentration, RMS = root mean square tidal speed). CHLA and RMS were obtained by classifying the cumulated monthly envelopes into four equal classes. Integrated habitat envelopes (right-hand column) show the distribution of potential habitat pixels based on the two alternatives considered ([Chla+RMS]*z, and Chla*RMS*z), and the most parsimonious model (Chla*RMS), proposed as the most appropriate model of potential Leatherback Sea Turtle foraging habitat.*

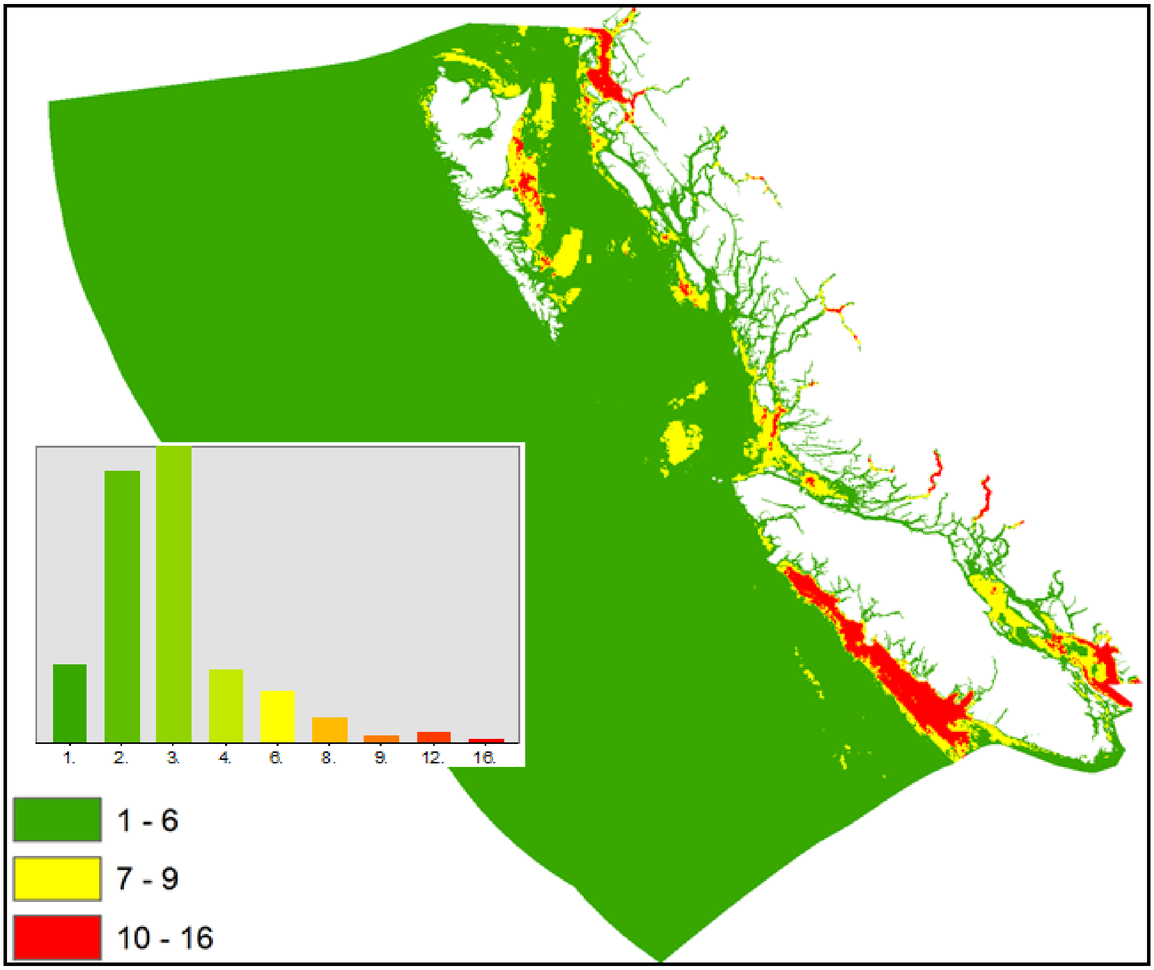

*Figure 5. Final predicted potential Leatherback Sea Turtle foraging habitat shown as low (green), medium (yellow) and high (red) suitability. Histogram (inset) shows the levels of the ([Chla*RMS panel, Figure 6) surface prior to re-classification to three levels.*

3.4 MODEL VALIDATION

The factors selected for the habitat model are those oceanographic features that are presumed to support the presence of jellyfish, thereby providing sufficient prey concentrations for foraging Leatherback Sea Turtles. A correlation between high densities of jellies and areas identified as having a high suitability for foraging Leatherbacks would provide evidence of model validity. However, at the time of this report, data on jellyfish were not available for inclusion in the model. A method for identification of scyphomedusae in Canadian Pacific waters was developed (Appendix 1) and a survey schedule was established. The survey tracks provide coverage in the areas of habitat high suitability (Figure 5), and once the database is sufficient for inclusion in the model, validation will be undertaken.

4 DISCUSSION

4.1 BIOPHYSICAL FUNCTIONS AND FEATURES

Central to the concept of critical habitat is a recognition of the specific life process, or function, which is supported by the identified habitat. In the case of the Leatherback Sea Turtle, migratory behaviour and attendance at high latitude temperate foraging grounds has been established through the use of satellite tagging studies.

The biophysical features of critical habitat are aspects of the habitat that have the functional capacity to support a life process. As foraging is the primary function supported by Canadian Leatherback habitat, availability of food is of paramount importance. Although direct observations on Leatherback Sea Turtle foraging in Canadian Pacific waters are not available, a number of studies from both the Atlantic coast of Canada and the Pacific seaboard of the United States provide evidence of prey selection and the conditions associated with foraging behaviour.

In the absence of foraging data for Leatherbacks in Canadian Pacific waters, the approach undertaken was to populate an envelope model to predict areas of habitat suitability. The selection of applicable criteria to support the envelope model involved a thorough review of the literature on oceanographic features and conditions associated with Leatherback foraging, as well as factors that support the presence and entrainment of scyphomedusae.

4.2 THE HABITAT MODEL

The suitability of potential habitat for Leatherback Sea Turtles is modeled for both Canadian Pacific coastal waters and in offshore portions of the EEZ. Along the coast of Vancouver Island, these habitats are divided by the northward flowing Vancouver Island coastal current, which in summer flows northward counter to the dominant, offshore California current. Based on the current speed climatologies, the location (and thus average speed) of the nearshore counter-current appears spatially consistent over time, making it a reasonable habitat boundary.

The other regions of potential habitat include the Strait of Georgia, the North Coast adjacent to Dixon Entrance, and three smaller locations in Queen Charlotte Sound. While meeting the oceanographic conditions, the Strait of Georgia may be a less suitable habitat because of its distance from the open ocean, and its high level of development. However, the remaining predicted habitats on the Central and North coasts may well serve as important secondary habitats for Leatherbacks if they perceive oceanographic conditions as suitable. Further, the areas near Calvert Island and the Goose Group on the Central coast are known ecological hotspots, making them reasonable candidates for multi-species critical habitat.

Low ocean current energy is evident throughout the nearshore region. However, this area represents a boundary condition for the HYCOM circulation model which, at ~ 10 km resolution, is not well resolved near shore. Nevertheless, the predicted low energy state reflects expectations that nearshore areas are less influenced by ocean currents, but rather dominated by tidal and wind-wave energy (Thomson, 1981).

The choice to focus on potential rather than realised habitat, and the consequent use of monthly climatologies, means that more ephemeral features such as eddies and jets that are known to occur along the shelf edge (Thomson, 1981) are not resolved in this model. Rather, the expectation is that such ephemeral features occur with a higher frequency in the areas identified by the Chla envelope.

Despite the lack of coherence between the RMS (1998-2003) and Chla (2007-2011) data, their integration is not unreasonable at this stage in the analysis because ocean current variability has a long period, and is thus less variable over short time periods. Further, any long-term shifts in ocean currents will be further mitigated by the 6-year climatology and the relatively coarse resolution, which is 1/10th that used for the more dynamic Chla layer. The current climatologies used here are believed to provide a reasonable representation of average summer ocean current conditions during the early part of this century.

As Leatherbacks are heterothermic, the common belief is that the animals will be restricted by a thermal threshold. However, Leatherback Sea Turtles have been observed as far north as Alaska in the North Pacific (Hodge and Wing, 2000), and do not seem to be thermally restricted in the eastern Atlantic, where they are regularly observed in waters below 13˚C. On investigation of temperature as a variable for the model, the average, basin-scale temperatures in Canadian Pacific waters were found to be similar to other regions where Leatherback Sea Turtles regularly occur.

In California, there are some indications that colder temperatures (i.e., <13˚C) may not be energetically advantageous to Leatherback Sea Turtles unless large quantities of prey are available (S. Benson, pers comm). As Canadian Pacific waters have temperatures comparable to regions where Leatherbacks are regularly observed (Figure 6), any potential range restriction due to temperature is unlikely to apply to Leatherbacks in Pacific Canada during the five month foraging range selected for this model.

Two reasons can be proposed for why SST may be more relevant to Leatherback Sea Turtle distributions off California when compared to the Canada's Pacific coast. Temperate waters are known for their high abundance of plankton populations that arise from annual spring booms and are maintained by summer upwelling of nutrient-rich waters. However, upwelling waters - commonly < 13˚C - occur close to shore in California. As the shelf is narrow and upwelling is often persistent, these waters are entrained near shore until the upwelling relaxes, which then allows mixing to occur. Until these waters become mixed, the nutrients they contain are unavailable to primary production. Thus, upwelled waters off California will retain their colder temperatures, and be less productive, until relaxation occurs. Thus, cold, unmixed upwelled waters are likely less attractive for foraging on jellyfish.

In contrast, upwelling off the Canadian Pacific shelf is not uncommon, but it occurs farther from shore because of the width of the shelf. These upwelled waters are likely mixed-in more quickly because there is no land barrier, and the current regime is more dynamic. This would imply that upwelled waters in Pacific Canada are more quickly mixed, reducing the time they are colder and less productive.

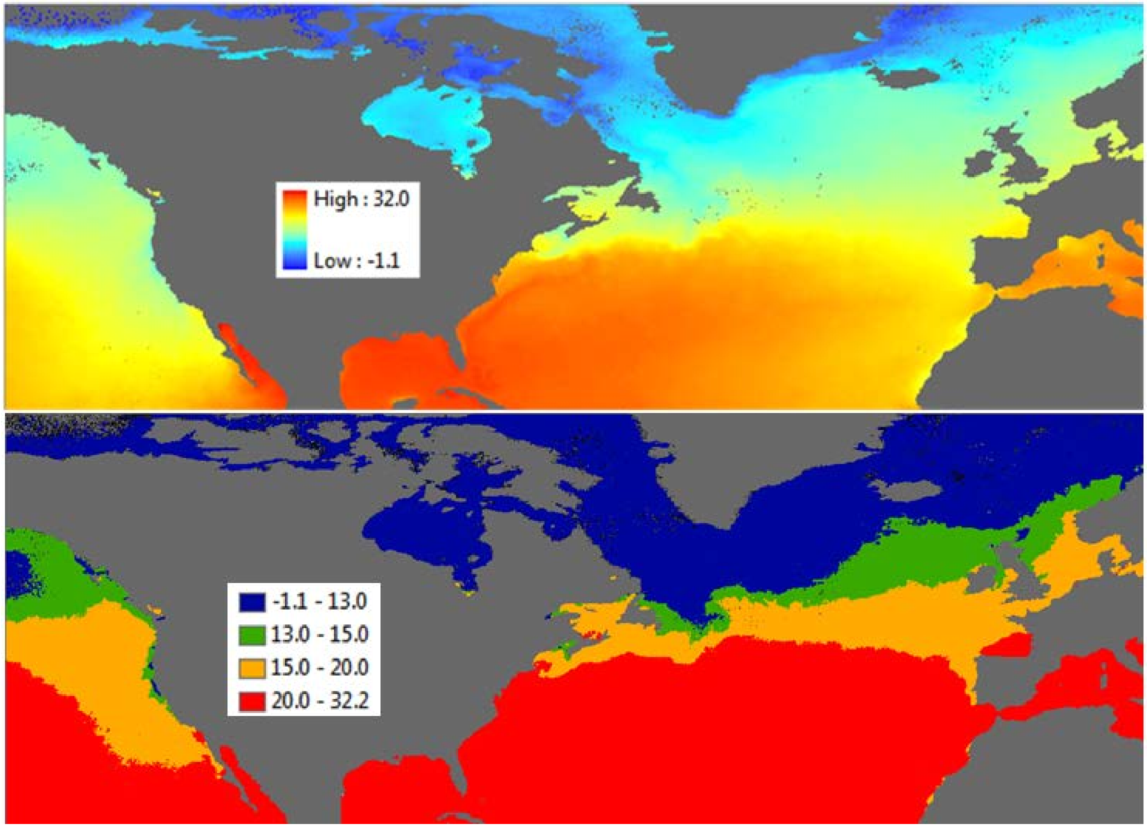

Figure 6. Mean August sea surface temperature (upper panel) averaged over 2009 to 2011 from 11 km AVHRR data. The classes in the lower panel are divided based on potential thermal limit (13°C) proposed by Benson (personal communication), the mean temperature observed for foraging Leatherbacks in the California coastal ecosystem (15.0°C - Benson et al. 2011), and a value (20°C) intended to capture known habitats on Canada's Atlantic coast.

Given that the models are intended to capture regions that support the presence of prey, and that *Chrysaora fuscescens* and *Cyanea capillata* have differing associations with temperature, it would seem that SST may not be a good indicator of jellyfish habitat in Pacific Canada.

The Jenk's classification used to initially categorise the monthly Chla and RMS climatologies is but one means of creating these relative suitability classes. However, it has the advantage that it identifies reasonable groupings in the data with a simple algorithm. Such groupings are ideal for the development of envelope models, which do not require normality. The Jenk's classification was preferable to an approach where a number of steps (e.g., data transformations and equal size bins) would need to be justified and combined.

4.3 JELLYFISH ABUNDANCE AND DISTRIBUTION

Jellyfish abundance and distribution, as well as their associated energy densities, are not well understood due to a number of factors. Jellies are often disregarded, damaged, or not captured in routine zooplankton surveys (Hay, 2006; Pugh, 1989) and can be difficult to sample even when targeted (Omori and Hamner, 1982; Pierce, 2009). This is especially true for scyphozoans, which tend to be too large to be sampled and studied by planktologists, while also being perceived as bothersome to fisheries scientists (Pauly *et al.*, 2009).

Given the low energy density of jellyfish, Leatherbacks must consume proportionately larger quantities than would be required for other prey. As such, locating dense concentrations of jellyfish is central to Leatherback foraging success, and may be an important determining factor for the health of a population (Bailey *et al.*, 2012b; Wallace *et al.*, 2006). Mature Leatherbacks need to build energy reserves before nesting, and remigration intervals are heavily influenced by foraging success (Saba *et al.*, 2007). In addition, Leatherbacks that visit Canadian Pacific waters have the longest migration of all Leatherback populations.

The relationship between jellyfish and Leatherbacks has been investigated in temperate environments outside of the Canadian Pacific. James *et al.* (2006) collected spatial observations of Leatherbacks in Atlantic Canada and concluded that Canadian foraging grounds should be considered critical habitat (DFO, 2012). Houghton *et al.* (2006) examined jellyfish “hotspots” between Ireland and Wales in the North Atlantic, and suggested that 22.5% of Leatherback distribution can be explained by these jellyfish hotspots. Another investigation by Witt *et al.* (2007) examined the possibility of using information on jellyfish occurrence from Continuous Plankton Recorder (CPR) data to identify foraging grounds for Leatherbacks. Grant *et al.* (1996) surveyed Leatherbacks and the occurrence of jellyfish off of North Carolina and found a strong correlation in 1992, but not in 1993-1995. Fossette *et al.* (2010) used satellite tracking to identify areas of high foraging success, which were generally in high latitude areas, and often near the coast. Heaslip *et al.* (2012) attached video cameras to Leatherbacks off of the coast of Nova Scotia and obtained recordings of successful foraging events on jellyfish. Moreover, 40,000 square miles of coastal waters were recently designated as critical habitat for Leatherbacks along the Pacific coast of the United States, deemed to be important foraging grounds for Leatherbacks feeding on jellyfish (Fimrite, 2012).

While knowledge of Leatherback foraging is limited, recent investigations are revealing some insights about feeding behaviour and metabolic demand of from several types of experiments, including the use of captive turtles in the laboratory (Jones *et al.*, 2012), captive release experiments (Salmon *et al.*, 2004), as well as observations of wild turtles (Fossette *et al.*, 2012; Heaslip *et al.*, 2012). Despite these advances, relatively little is understood about the relationships and interactions between Leatherback Sea Turtles and their jellyfish prey. Jellyfish populations appear to be increasing in the majority of the world’s coastal ecosystems and seas (Brotz *et al.*, 2012), which should provide increased prey for Leatherbacks. However, no such trend is evident in the Canadian Pacific, where knowledge of jellyfish populations remains limited (Brotz, 2011).

4.4 NEXT STEPS

A means of capturing potential ephemeral habitats would likely improve the model prediction by capturing habitat features around the north end of Gwaii Hanaas. This could be extracted from the daily MERIS data as average, monthly frequency of occurrence of Chla above a specified threshold. With the environmental data now in hand, the predictive performance of various configurations of the individual envelope models, as well as the integrated model, can be compared using the opportunistic sighting data. Boyce Index and adjusted Skewness (Gregr and Trites, 2008) are two methods developed for evaluating the relative performance of models using presence-only data.

The robustness of the model to variations in the climatologies and their temporal coherence due to year ranges should be explored. The robustness of the HYCOM model output should be compared to oceanographic data (e.g., the World Ocean Atlas) to confirm the HYUCOM model output.

Implementation of the jellyfish survey methodology and sampling schedule will provide a means of validating the model and potentially become another factor for inclusion. Ongoing sighting efforts for Leatherback Sea Turtles and greater detail on the oceanographic conditions when sightings are obtained are recommended.

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APPENDIX 1 JELLYFISH MONITORING PROTOCOL

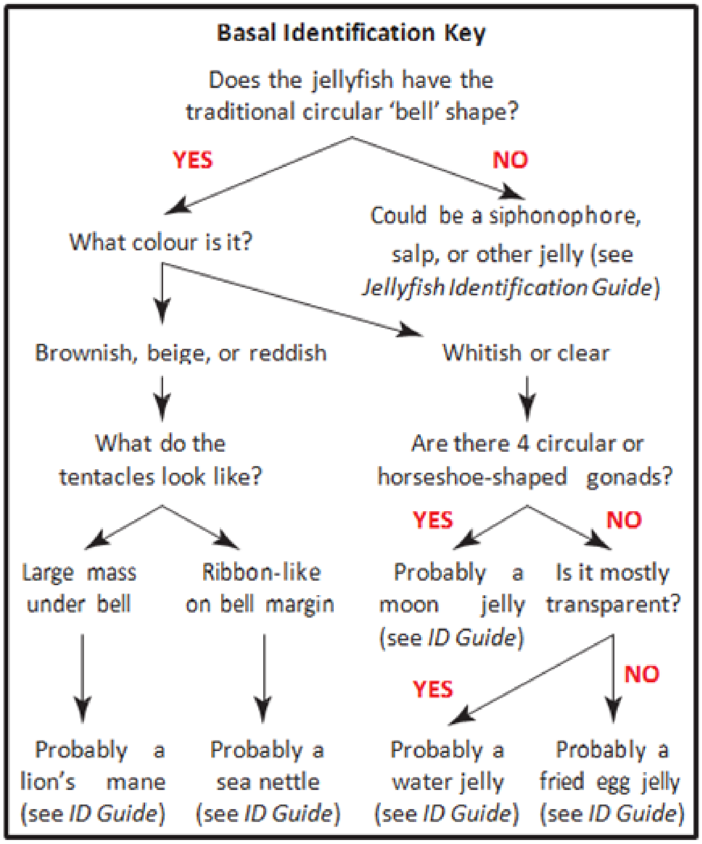
ALWAYS USE RUBBER GLOVES TO HANDLE STINGING JELLYFISH

For all catch:

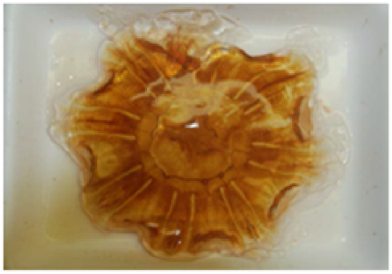
1. Instruct the deck crew to keep only jellies that come out of the cod end.
   Any jellyfish or pieces that are partially stuck in the net or that fall onto the deck should not be included in the processed catch.
2. Sort the jellyfish to species using the *Jellyfish Identification Guide*.
3. Measure and record the weight (total biomass) of each species.
   For large catches, this may require the use of the large Marel scale, which should be calibrated frequently. If the jellyfish catch fills more than one tote, record the volume (i.e., number of totes) in addition to the weight of jellyfish in each tote.
4. Weigh jellyfish pieces (i.e., non-individuals) separately.
   Note the species if possible. Otherwise, record separately as "unidentified jelly pieces".

If time permits:

5. Count the number of "individual" jellyfish for each species. If there are too many jellyfish to count, take a subsample and record the number of individuals and total weight of the subsample.
   "Individual" jellyfish should be considered those with a caudal peduncle attached, which is the meaty tissue that connects the bell with the oral arms (see below). In the case of moon jellyfish (*Aurelia labiata*), the four horseshoe-shaped gonads should be visible.
6. Take weight and bell diameter of as many individual jellyfish as possible (or a subsample).
   Bell diameter is measured by placing the jellyfish dorsal-side-down on a measuring board.
7. Photograph any unique, rare, or unidentifiable individuals, and note any additional observations.



caudal peduncle joins bell and oral arms on this sea nettle



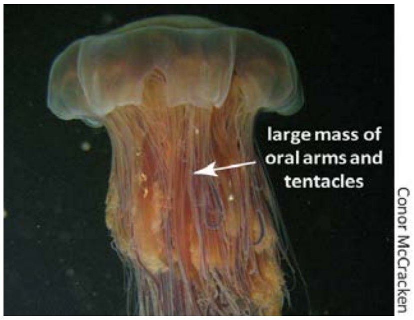
the top of this lion's mane jelly's bell has been separated during a trawl - no caudal peduncle, therefore it is not an 'individual' but should rather be included with the 'pieces'

Instructions for calibrating the large Marel scale:

1. Press and hold "Menu" and "Zero" simultaneously.
2. Wait for "Put 20" to appear on the display.
3. Place the 20 kg weight on the scale.
4. Press "Print".
5. A "Fit" reading between 0-100 should be displayed.

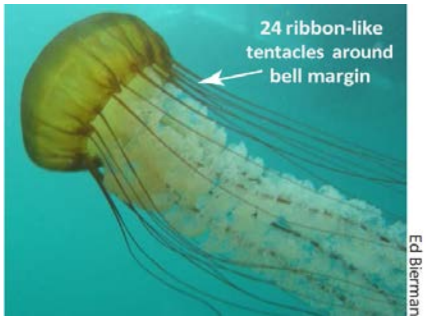
APPENDIX 2 JELLYFISH IDENTIFICATION GUIDE

ALWAYS USE RUBBER GLOVES TO HANDLE STINGING JELLYFISH



Conor McCracken

Lion's mane jellyfish
Cyanea capillata
WARNING: IRRITATING STING
Bell diameter: to 50 cm or more
Colour: ranges from deep red to purple or yellowish brown.
Large mass of tentacles and oral arms, often containing amphipods.

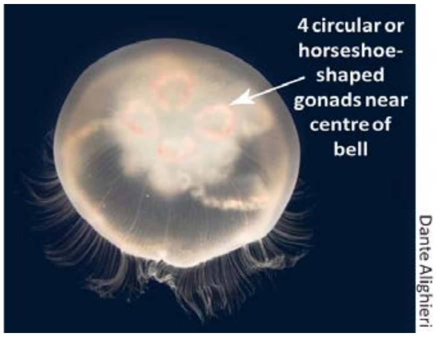


Ed Bierman

Sea nettle
Chrysaora fuscescens
WARNING: IRRITATING STING
Bell diameter: to 30 cm.
Colour: Bell is yellowish-brown and may be darker near margin with possible faint star pattern.
Oral arms tend to be white or beige and highly folded.

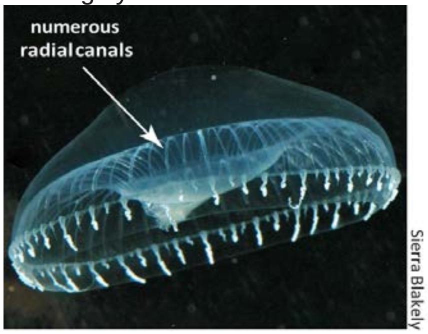
Tom Thai

Fried egg jelly
Phacellophora amtschatica
WARNING: MILD STING
Bell diameter: to 60 cm.
Colour: Central yellow gonadal mass surrounded by whitish bell gives appearance of a 'fried egg'.



Dante Alighieri

Moon jellyfish, *Aurelia labiata*
Bell diameter: to 40 cm, usually less
Colour: opaque white to colourless, although sometimes infused with pink, purple, or yellow.
Fine tentacles and frilly oral arms



Sierra Blakely

Water jelly, *Aequorea* spp.
Bell diameter: up to 25 cm, but usually <10 cm
Colour: generally colourless, with bioluminescence around the bell margin.

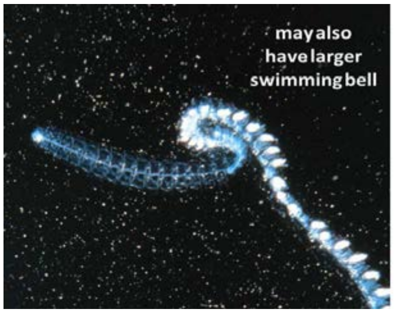
By-the-wind sailor, *Velella velella*
Floating hydroid colony covered with an elliptical blue float (usually < 6 cm long) and triangular sail.
May occur in dense aggregations as they accumulate along fronts.

Zeisterre

Comb jellies, Ctenophora
Colourless or translucent 'balls', often shaped like a sphere or grape. May range from pea-sized to longer than 10 cm.

Hartmut Olstowki

Salps, Salpida
Transparent organisms that may have coloured structures visible, up to 15 cm in length. Often occur in dense, connected aggregations.



Siphonophores, Siphonophora
WARNING: POSSIBLE STING
Often delicate and usually colourless, but central stem may connect to branching yellow structures.