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

USING SATELLITE TRACKING DATA TO DEFINE IMPORTANT HABITAT FOR LEATHERBACK TURTLES IN ATLANTIC CANADA: 2019 UPDATE

Context

This Science Response Report results from the Science Response Process of January 22, 2019, on the Review of Important Habitat for Leatherback Turtle in Atlantic Canadian Waters. The Leatherback Turtle (*Dermochelys coriacea*) was designated as Endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in April 1981 and reassessed as Endangered in 2001 (COSEWIC 2001) and 2012 (COSEWIC 2012). The species was listed under Appendix A of the *Species At Risk Act* (SARA) in June 2003, and a Recovery Strategy for the Leatherback Turtle in Atlantic Canada was published in February 2007 (Atlantic Leatherback Turtle Recovery Team 2006). The Recovery Strategy did not identify critical habitat for the species, but it did include a corresponding schedule of studies. SARA requires the competent minister to report on the implementation of a Recovery Strategy and progress toward meeting its objectives within five years of when it is included in the public registry. This prompted initiation of a Zonal Advisory Process (ZAP) in 2012 to define important habitat for Leatherback Turtles in Atlantic Canada using satellite tracking data. Results of the ZAP were summarized in a Canadian Science Advisory Secretariat Science Advisory Report (DFO 2012). The ZAP was referenced in the Report on the Progress of Recovery Strategy Implementation for the Leatherback Sea Turtle in Atlantic Canada 2007–2012 (DFO 2013); however, formal identification of critical habitat was deferred for inclusion in an amended Recovery Strategy.

The objective of this Science Response Process (SRP) was to identify persistent areas of important habitat for Leatherback Turtles in Canadian waters (Figure 1) by updating the earlier analysis of satellite telemetry data (DFO 2012) to reflect an enhanced sample size and longer-term dataset. The information generated in this SRP will be used by the Maritimes Region Species at Risk Management Division in the upcoming amended Recovery Strategy, and in the proposal of critical habitat for designation by the Minister of Fisheries and Oceans.

Background

Leatherback Turtle Biology

The Leatherback Turtle is the most widely distributed and largest of all marine turtles. In the Canadian Atlantic, Leatherback Turtles may attain curved carapace lengths of 175 cm and weights of 640 kg (James et al. 2007). Tag-recapture data and genetic studies confirm that Leatherback Turtles in Atlantic Canadian waters originate from western Atlantic rookeries encompassing nesting beaches in the wider Caribbean; South and Central America; and Florida, USA (James et al. 2007; Stewart et al. 2013). The species primarily feeds on soft-bodied, gelatinous organisms such as medusae (jellyfish), salps, and siphonophores, prey that are seasonally abundant in temperate shelf and slope waters off eastern Canada. Some Leatherback Turtles in the western Atlantic undertake annual migrations to Atlantic Canadian waters (James et al. 2005b), where they acquire abundant fat reserves (Davenport et al. 2011) while foraging on scyphomedusae, including lion's mane jellyfish, *Cyanea capillata*, and moon jellyfish, *Aurelia aurita* (Heaslip et al. 2012, Wallace et al. 2015). A single foraging season in Canadian waters can support 59% of a non-breeding Leatherback's annual energy budget, and 29% of the energetic requirements of mature female on a 2-year reproductive cycle (Wallace et al. 2018). Reducing threats and maintaining habitat quality in important Canadian Leatherback foraging areas should be considered high conservation priorities.

While in Atlantic Canadian shelf waters, Leatherback Turtles generally restrict foraging activity to daylight hours (Casey et al. 2014) and relatively shallow depths (approximately <50m) within the photic zone (James et al. 2006a; Hamelin et al. 2014; Wallace et al. 2015), suggesting that prey-search behaviour is visually-mediated. Fine-scale analyses of foraging behaviour corroborate the use of visual cues by Leatherback Turtles to enhance foraging success, as prey appears to be regularly located and captured when silhouetted against the ocean surface as Leatherbacks ascend from dives (Wallace et al. 2015).

Investigating Leatherback Turtle Movements with Satellite Telemetry

As sea turtles are air breathers, conventional satellite-linked tags, which transmit directly to a network of polar-orbiting satellites (ARGOS system), are ideally suited to studying their movements. ARGOS uses the Doppler shift of radio transmissions from tags to estimate satellite tag locations, and enables near-real-time tracking. ARGOS location accuracy has been assessed from stationary tests of satellite tags where position can be verified via Global Positioning System (GPS) (e.g., Vincent et al. 2002) and from comparison of ARGOS location estimates to GPS positions acquired from free-ranging marine animals equipped with GPS-linked satellite tags (e.g., Costa et al. 2010). An increased quantity and quality (lower error) of ARGOS location estimates occurs at high latitudes, as a result of both enhanced ARGOS satellite coverage (i.e., more satellite passes per day) and, in the case of marine turtles, extended surfacing activity (James et al. 2005b; Wallace et al. 2015).

Satellite tags have been successfully used to track Leatherbacks over broad spatial and temporal scales, and to collect location, environmental, and dive data (James et al. 2005a; Benson et al. 2011; Dodge et al. 2014; Bond and James 2017). Since 1999, satellite data from Leatherbacks utilizing Canadian waters have been collected from tag deployments on Leatherbacks off Nova Scotia and at western Atlantic nesting areas through collaborations with research groups, conservation organizations, and the fishing community (e.g., James et al. 2005a; Eckert et al. 2006; Casey et al. 2014).

In the present analysis, satellite telemetry data serve as a proxy for direct sampling of important habitat, under the explicit assumption that the amount of time Leatherbacks spend in different areas of Canada's Exclusive Economic Zone (EEZ) is positively correlated with foraging habitat quality. It is important to recognize that, while time-in-area will be used here to inform potential identification of critical habitat under Canada's *Species at Risk Act* (SARA), the functional components of critical habitat are what require protection (e.g., gelatinous prey).

Rationale for Assessment

The objective of this advisory process was to identify persistent areas of important habitat for Leatherbacks in Canadian waters (Figure 1) by updating an earlier analysis of satellite telemetry data (DFO 2012) to reflect an enhanced sample size and longer-term dataset. The present analysis focuses on discerning spatial and temporal patterns in species' distribution from a sample of satellite-tagged animals, and it does not integrate consideration of habitat variables. It should be noted, however, that biological and environmental correlates of Leatherback distributions in Atlantic Canada have been inferred from telemetry data (Hamelin et al. 2014; Wallace et al. 2015); public sightings data (e.g., James et al. 2006b); and more recent research contributions, including two seasons of coastline surveys of stranded jellyfish (Nordstrom et al. 2019), and one season of aerial surveys (Mosnier et al. 2018). Marine megafauna surveys by Fisheries and Oceans Canada (DFO) Science in 2007, 2016, and 2018 also recorded Leatherback Turtles, and related analyses are underway (J. Lawson, pers. comm). These studies, and others outside of Atlantic Canadian waters (e.g., McMahon and Hays 2006; Bailey et al. 2012; Gregr et al. 2015) present alternative approaches to expanding the understanding of Leatherback Turtle habitat.

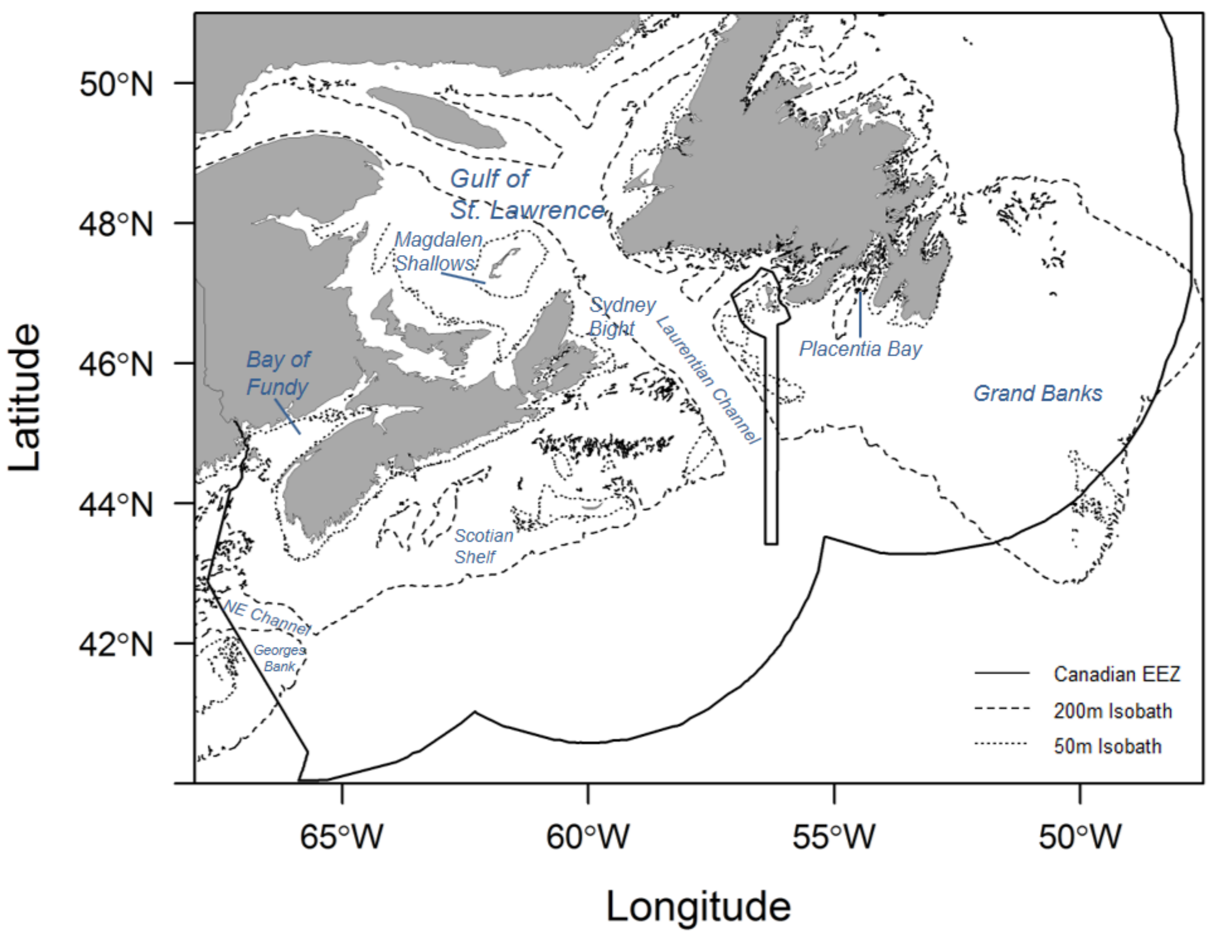

Figure 1. Study area.

Analysis and Response

Using Satellite Tracking Data to Define Important Habitat

Satellite telemetry data from 128 Leatherbacks tracked in Atlantic Canadian waters were used to identify important habitat for the species over a period of 19 years and 140 individual

Leatherback Turtle northern foraging periods. Leatherback Turtles were tagged on nesting beaches (n=23), or at one of two at-sea field sites off Nova Scotia: Halifax (approximately 44°N, 64°W, n= 66); and northeastern Cape Breton Island (approximately 47°N, 60°W; n=39). Ten individuals were tracked through two summers and one was tracked through three summers. These return tracks, plus the tracks of the 23 Leatherbacks departing nesting beaches, were particularly valuable, as location data were collected from the time of first entry into Atlantic Canadian waters each season (versus tagging at some time after entry into Atlantic Canadian waters). To further maximize the spatial and temporal distribution of Leatherback telemetry data collected in the Canadian EEZ, beginning in 2005, in-water tagging efforts focused on deploying tags in early summer, when most Leatherbacks begin their seasonal foraging period in Canadian waters.

While approximately 40% of the ARGOS calculated positions of tagged Leatherback Turtles in the present sample were estimated to be within less than 1,500 m of the tag's true position (ARGOS location class 1-3; a very high location accuracy), to make use of these data at relatively fine spatial resolutions (e.g., 0.25 degrees), a State-Space Model (SSM, Jonsen et al. 2019) was used to filter the tracking data. Note that an earlier analysis (DFO 2012) applied a behavioural Switching State-Space Model (SSSM; Jonsen et al. 2007) to ARGOS locations to infer Area-Restricted Search (ARS) behaviour versus transiting behaviour. A simpler SSM was applied to the present data as recent finer-scale Leatherback foraging ecology studies in Canadian Atlantic waters (Casey et al. 2014; Wallace et al. 2015) suggest that some SSSM assumptions based on non-linearity versus linearity of movements as they relate to foraging may not always apply, and that inference of ARS may sometimes reflect error associated with satellite-derived location estimates.

The SSM accounts for the uncertainty (error) in the raw ARGOS locations and provides a set of estimated locations for each Leatherback at a regular 6-hour time interval that is comparable across individual tracking datasets. Tracks with substantial runs of missing data (i.e., >7 days) were split into sub-tracks prior to filtering to avoid unrealistic interpolations. After filtering, the first 7 days of tracking data post-deployment were removed to reduce potential bias in the distribution of time-in-area due to tagging location.

To evaluate Leatherback Turtle use of space in Canadian waters, the total number of 6-hourly location estimates corresponding to 0.25 × 0.25 degree grid cells, north of 40 degrees latitude, was calculated. This is an unweighted estimate that treats all Leatherback Turtle tracks equally, regardless of track duration (Figure 2). Time-in-area was also calculated for each Leatherback, weighting the counts of locations within cells by the proportion of time each Leatherback spent north of 40 degrees latitude relative to the total time spent by all Leatherbacks north of 40 degrees latitude. This weighting accounts for the different durations each Leatherback spent in Canadian waters. Cell values were mapped to visualize the relative use of different cells by all Leatherbacks tracked in Atlantic Canadian waters for the period 1999–2018 (Figures 2 and 3), and on a monthly basis (Figure 4).

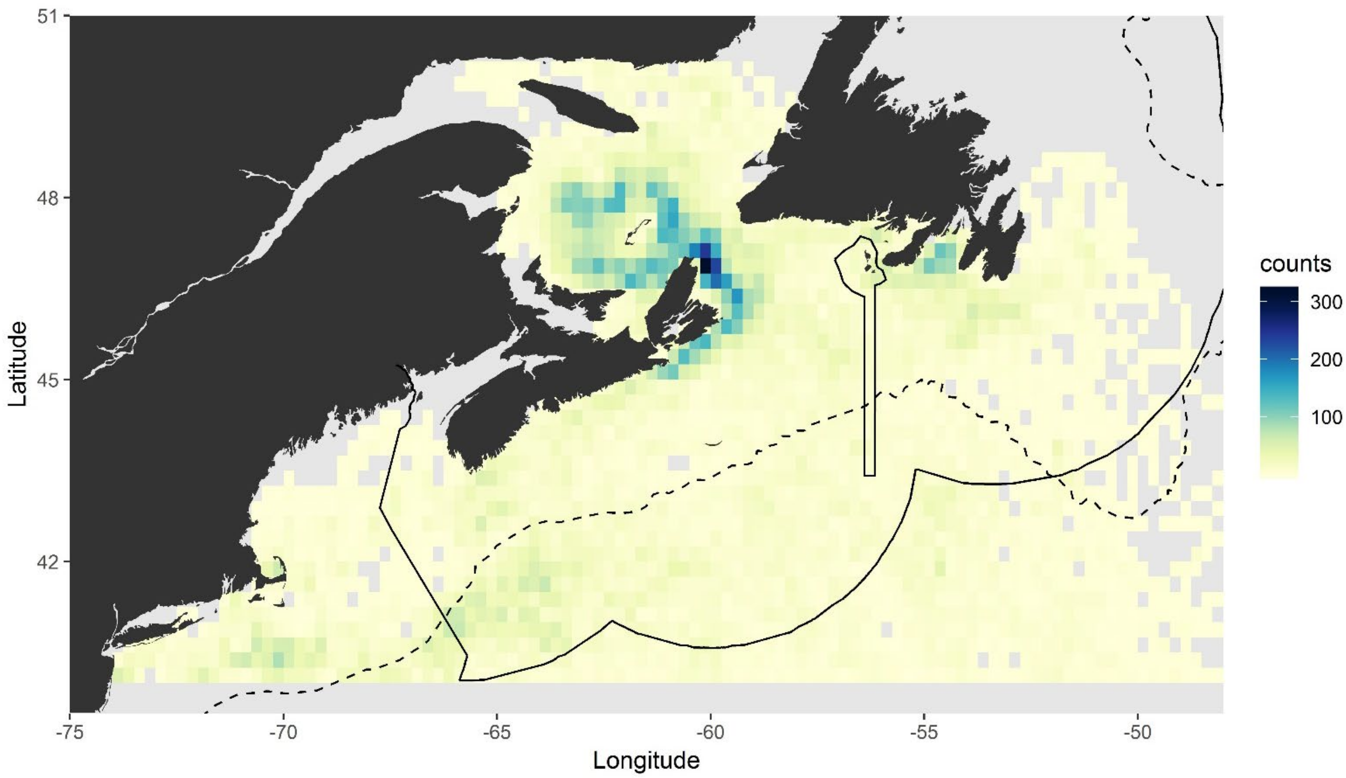

Figure 2. Leatherback turtle spatial use based on unweighted location estimates from 128 turtles equipped with satellite tags. Note that all but those areas shaded in light grey were sampled by turtles. Thick black line indicates Atlantic Canadian EEZ boundary; dashed black line indicates 1,000 m isobath. (Unpublished data; not to be cited outside the context of this zonal advisory process.)

Areas of High-use Likely Associated with Foraging Activity

Two primary areas of important habitat were identified: (1) GSL – the southeastern Gulf of St. Lawrence and waters off eastern Cape Breton Island, including Sydney Bight, the Cabot Strait, portions of the Magdalen Shallows and adjacent portions of the Laurentian Channel; and (2) PB – waters south and east of the Burin Peninsula, Newfoundland, including parts of Placentia Bay (Figure 3).

A third high-use area, corresponding to waters east and southeast of Georges Bank (GB), was identified in an earlier spatial use analysis (DFO 2012) based on a smaller (n=70) and less diverse sample, as well as application of probability of residency thresholds based on behavioural estimation from a SSSM. While GB remains evident in the present unweighted time-area analysis derived from SSM location estimates (Figure 2), it is less apparent in the weighted time-area analysis (Figure 3). This suggests the area is relatively less important than GSL and PB overall, but it may be especially relevant to Leatherbacks very early or late in the foraging season (see below). Note too that GB could potentially be considered part of a broader area of use extending from southwest Nova Scotia to Georges Bank and southern New England. Satellite tagging of Leatherbacks in Massachusetts (Dodge et al. 2014), and recent DFO marine megafauna aerial surveys (2018), have recorded turtles in this area (J. Lawson pers. comm.).

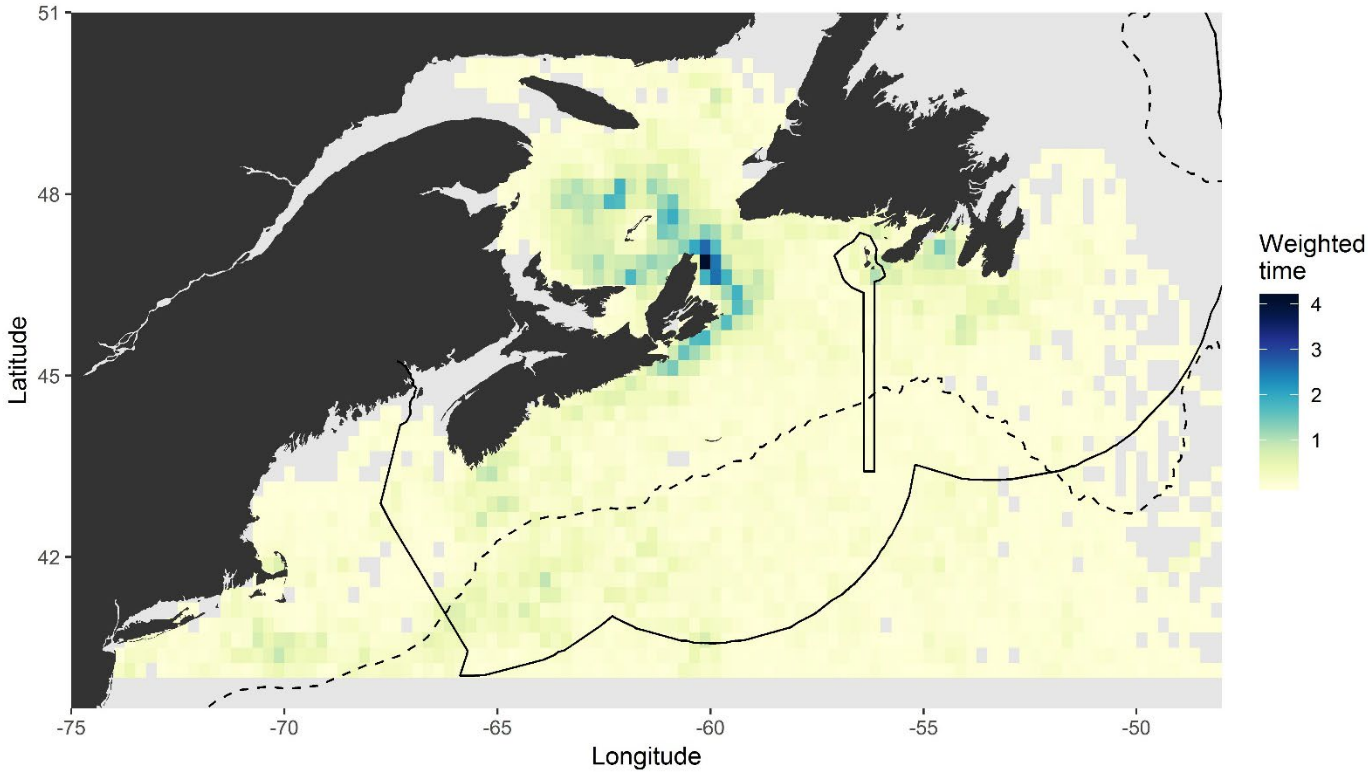

Figure 3. Leatherback Turtle spatial habitat use based on weighted location estimates from 128 turtles equipped with satellite tags. Spatial habitat use estimated from 128 Leatherback Turtles equipped with satellite tags. Note that all but those areas shaded in light grey were sampled by turtles. Thick black line indicates Atlantic Canadian EEZ boundary; dashed black line indicates 1,000 m isobaths. (Unpublished data; not to be cited outside the context of this zonal advisory process.)

Identification of Seasonal Habitat

Seasonal maps of Leatherback spatial use in Canadian waters indicate a general movement of Leatherbacks from the southwest to the northeast, as previously described (James et al. 2006b; DFO 2012), with many Leatherbacks first entering Scotian Shelf waters in early summer (June to July), moving to more northerly foraging areas by late summer and autumn, and initiating southward migration in September or October (Figure 4). Leatherbacks are abundant in Atlantic Canadian waters, and the Scotian Shelf in particular, in late June and July. This is consistent with many Leatherbacks arriving along the coast of Nova Scotia from offshore waters at that time. This pattern is corroborated by sightings reported by the general public and dedicated Leatherback field research activities (James et al. 2006b) and also the return movements of turtles satellite-tagged in Canadian waters the previous year (James et al. 2005c). However, satellite telemetry data predict relatively low density of Leatherbacks in the northern part of their range, including GSL, until August, and peak density in PB during September. There is a southward migration from GSL and PB in late September and October (Figure 4). This is consistent with previous studies of the timing of southward migration from Atlantic Canada continental shelf foraging areas, which reveal most turtles departing by mid-October (James et al. 2007; Sherrill-Mix et al. 2008). However, regular use of offshore area GB may persist late into the fall. These results corroborate the pattern of southward migration timing described by Sherrill-Mix et al. (2008), where departure date was negatively correlated with higher latitude, which may allow turtles departing more northerly foraging areas to compensate for greater travel distances to southern nesting and wintering grounds.

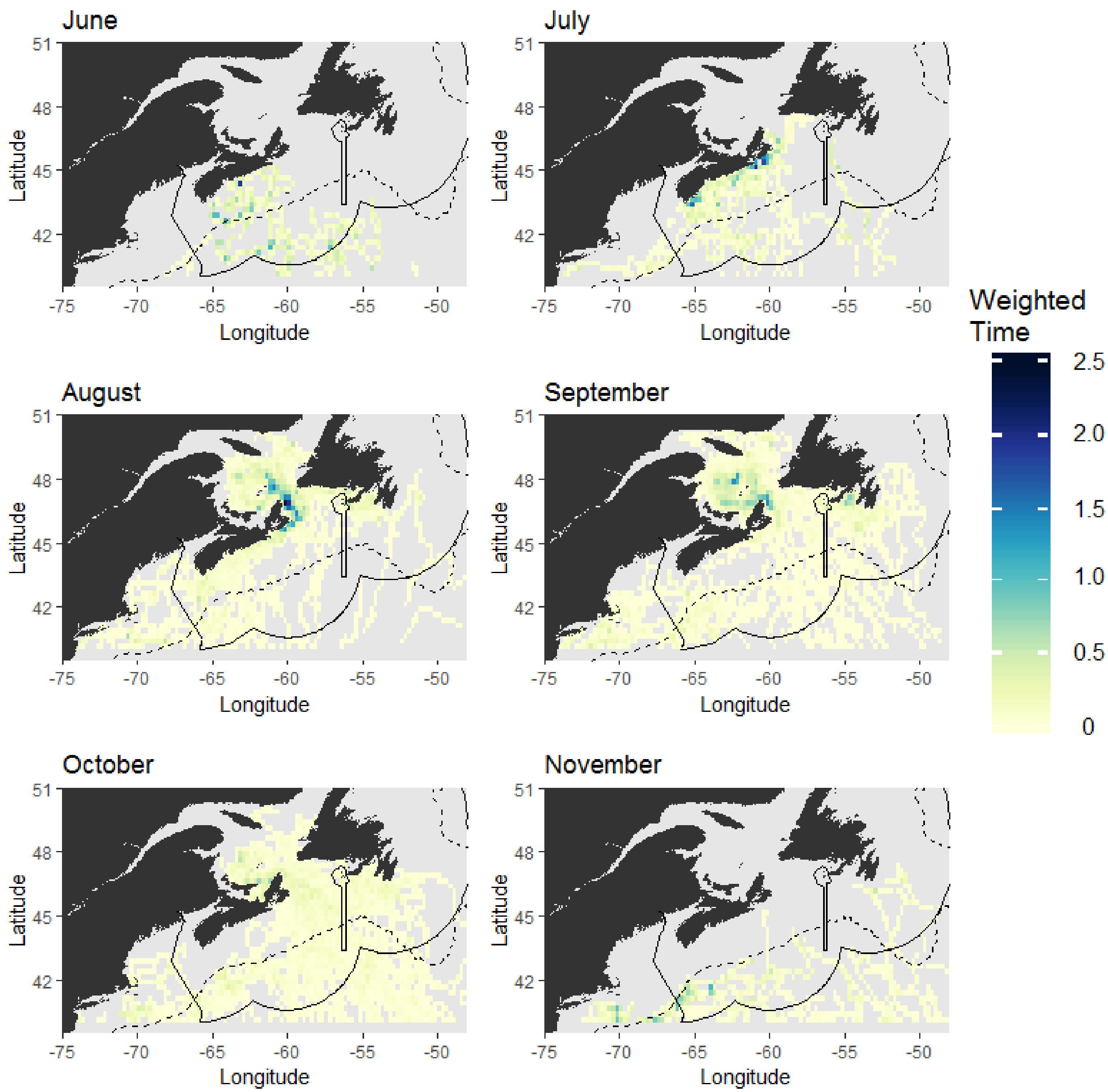

Figure 4. Monthly spatial use of 128 Leatherback Turtles equipped with satellite tags. Thick black line indicates Atlantic Canadian EEZ; dashed black line indicates 1,000 m isobath. (Unpublished data; not to be cited outside the context of this zonal advisory process.)

Spatial Availability of Data

The movements of satellite tagged turtles were widely distributed throughout Atlantic Canadian waters (most of the Atlantic Canadian EEZ). Peak use of important habitat areas occurred in summer and autumn. Notable areas not sampled by tagged Leatherbacks included northern portions of the Strait of Belle Isle, northeast coast of Newfoundland, Bay of Fundy, and Northumberland Strait (Figure 4). While sightings of Leatherbacks have occurred in these areas (Goff and Lien 1988; James et al. 2006b, Hamelin et al. 2016; Mosnier et al. 2018), such records are rare relative to those corresponding to the high-use areas identified via satellite telemetry.

Habitat Characteristics in High-use Areas

Insights into Leatherback-habitat associations may also be gained from results of research focused on environmental correlates of Leatherback distributions from satellite telemetry studies (e.g., Benson et al. 2011; Bailey et al. 2012; Dodge et al. 2014, Chambault et al. 2017; Aleksa et al. 2018) and aerial surveys (e.g., Shoop and Kenney, 1992; Eguchi et al. 2018; Mosnier et al. 2018). Collectively, these studies point to high seasonal primary production, upwelling, retention areas, and oceanographic frontal systems, as common oceanographic correlates of foraging habitat for Leatherbacks. The physiological ecology of this species is influenced by thermal regime (Bostrom et al. 2010; Casey et al. 2014; Wallace et al. 2018), thus sea surface temperature also shapes Leatherback distributions (McMahon and Hays 2006; Witt et al. 2007).

Sources of Uncertainty

In the present analysis, satellite tracking data were used to calculate the relative amount of time Leatherbacks spend in different areas, with the explicit assumption that time in area is positively correlated with resource acquisition (i.e., foraging behaviour). Quantification of foraging behaviour from fine-scale, short-term studies in one of the high use areas identified here (GSL) confirms the primary functional role of this habitat to seasonally-resident Leatherbacks (Heaslip et al. 2012; Wallace et al. 2015, 2018), as does stomach biotelemetry research spanning many weeks (Casey et al. 2014). The metrics of spatial use employed here are, therefore, a proxy for foraging habitat; direct measurements of prey (jellyfish) densities that support Leatherback foraging are not available at this time.

There are a number of uncertainties common to tagging and telemetry studies:

- Tagging location bias: To reduce the influence of initial tagging location, Leatherbacks were tagged in multiple areas, including at-sea field sites and several western Atlantic nesting beaches, and the first 7 days of tracking data were removed prior to calculating the cell-specific relative probabilities of residency. While post-nesting tracks from 23 Leatherbacks were included, and Leatherbacks regularly move between inshore and offshore foraging habitat at high latitudes, the majority of northern satellite-tag deployments occurred in continental shelf waters; therefore, it is possible that offshore habitat use is underrepresented in the sample.
- Tagging effects: To reduce the potential for tagging effects, since 2008, direct satellite tag attachment methods have been employed on live-captured and nesting turtles. Direct attachment is currently considered to be the most humane and benign satellite tag attachment method for Leatherbacks and is now standard practice in associated research (Hamelin and James 2018). Nonetheless, as an additional precaution to help ensure reliability of the results, the first 7 days of tracking data were removed.

- Sample size: The present sample size of 128 Leatherbacks represents the single largest telemetry dataset for northwest Atlantic Leatherbacks and includes both at-sea tag deployments and nesting beach deployments. The extent to which a sample this size over 19 years reflects the Canadian foraging population as a whole is unknown. However, the similarity of the present results to those from an earlier analysis in 2012 (DFO 2012; n=70 turtles, data spanning 11 years) suggest the present sample may be representative of the population.
- Tag locations are estimates: ARGOS locations represent estimates of true locations, each with an associated error ellipse. To address this issue, data were filtered using a state-space model (Jonsen et al. 2019) to estimate the most probable locations for each turtle at regular time intervals. This approach accounts for the errors in the observed locations and provides a set of estimated locations at regular time intervals that are comparable across individual tracking datasets.
- The present analysis indicates the existence of persistent seasonal high-use areas for Leatherbacks in Atlantic Canada. While outside the scope of the present advisory process, higher resolution analyses of telemetry data, and other associated data (e.g., environmental variables), would be required to explore potential variation in Leatherback spatial use patterns in response to changing habitat conditions and/or to identify finer scale seasonal distribution patterns (e.g., more localized movement corridors).

Conclusions

The present results, incorporating data from 128 Leatherback Turtles collected over 19 years, are similar to those of an earlier analysis (DFO 2012) based on a much smaller sample size (n=70) and shorter data collection period (11 years). Both analyses point to the existence of persistent high-use areas in Canadian waters, with peak use during summer and autumn (July through October). Complementary research provides direct evidence for Leatherback foraging in these areas.

Two primary areas of important habitat are identified: (1) GSL – the southeastern Gulf of St. Lawrence and waters off eastern Cape Breton Island, including Sydney Bight, the Cabot Strait, portions of the Magdalen Shallows and adjacent portions of the Laurentian Channel; and (2) PB – waters south and east of the Burin Peninsula, Newfoundland, including parts of Placentia Bay. Peak occupancy of these important habitat areas occurs in summer and autumn. The present sample provides evidence for a potential third, more diffuse area of important habitat, corresponding to offshore waters east and southeast of Georges Bank, which is frequented by Leatherbacks early and late in the foraging season.

Further considerations for delineating boundaries of Leatherback Turtle critical habitat in Atlantic Canadian waters:

1. Application of threshold values to circumscribe potential high-use areas based on output of models inferring behavioural state switching from error-prone location estimates (e.g., SSSM applied to ARGOS data) require careful consideration, and, whenever possible, high resolution movement data (e.g., GPS) should be used to ground-truth model assumptions.
2. Boundaries should be contiguous, such that adjacent and/or nearby cells should be grouped inside a single polygon, and landmasses above high tide mark should be excluded.

The present analysis focuses on the use of biotelemetry data to identify high use areas for Leatherback Turtles. These same data have been combined with surveys of stranded jellyfish to explore the overlap in the spatiotemporal distribution of Leatherbacks and their prey, with results highlighting the role of prey fields in shaping turtle movements (Nordstrom et al. 2019). Continued long-term monitoring of Leatherbacks and jellyfish in Atlantic Canada will be important for both evaluating and predicting the distribution and abundance of this endangered sea turtle population over time.

It is expected that review of important habitat areas will be updated when sufficient new information (e.g., prey distribution, prey concentration, turtle behaviour) becomes available. This might include analysis of Leatherback Turtle data recorded during systematic aerial surveys for marine megafauna.

Other Considerations

This Science Response contains unpublished data that should not be cited outside the context of this zonal advisory process.

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