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Maritimes, Gulf, Newfoundland & Labrador, Quebec Regions

Canadian Science Advisory Secretariat
Science Advisory Report 2012/036

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

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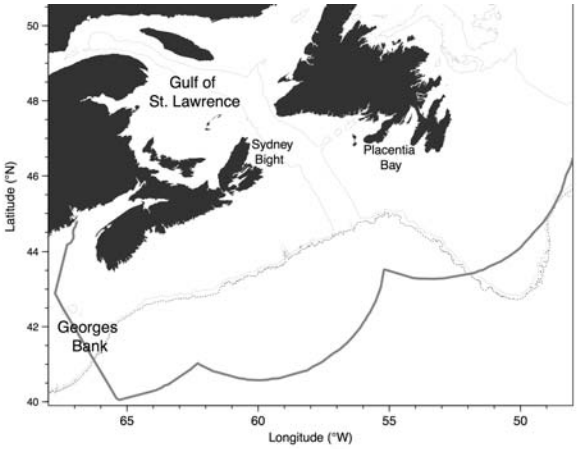

Figure 1. Areas mentioned in text. Thick grey line indicates Canadian Exclusive Economic Zone (EEZ) boundary; thin grey line indicates 1000 m isobath. See text for details.

Context

The leatherback turtle (Dermochelys coriacea) was designated as Endangered by COSEWIC in April 1981 and reassessed as Endangered in May 2001 (COSEWIC 2001). A Recovery Strategy for the Leatherback Turtle in Atlantic Canada was published in February 2007 (Atlantic Leatherback Turtle Recovery Team 2006). Critical habitat was not identified at that time, but a schedule of studies to identify critical habitat was provided. The Species at Risk Act (SARA) requires that the competent minister report on the implementation of the Recovery Strategy and progress toward meeting its objectives within five years of when it is included in the public registry. This deadline for review was established as February 2012. An Action Plan for Leatherback Turtles in Atlantic Canada is also being developed at this time, which will include a description of critical habitat, as it was not included in the Recovery Strategy. Information that could be used to identify important habitat for leatherback turtles in Atlantic Canadian waters was peer reviewed by the October 2010 National Marine Mammal Peer Review Committee (NMMPRC)(DFO 2011). Some additional information was requested and is included here.

The information generated in this zonal advisory process will be used by the Maritimes Region Species at Risk Management Division in the 5-year review of the Leatherback Turtle Recovery Strategy, in the development of the Action Plan, and in the proposal of critical habitat for designation by the Minister of Fisheries and Oceans.

This Science Advisory Report is from the February 29 to March 1, 2012 review of Leatherback sea turtle Part 1: Using Satellite Tracking Data to Define Important Habitat. Additional publications from this process will be posted as they become available on the DFO Science Advisory Schedule at www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm .

Canada

SUMMARY

- The leatherback turtle is the most widely distributed and largest of all marine turtles, and undertakes annual migrations to Atlantic Canadian waters to forage.
- Satellite telemetry data from 70 leatherbacks tracked in Atlantic Canadian waters were used to identify important habitat for the species.
- Satellite telemetry data serve as a proxy for direct sampling of important habitat, under the explicit assumption that the relative probability of leatherbacks exhibiting residency behaviour is positively correlated with foraging habitat quality. In the current context, residency denotes turtles that are likely engaged in area-restricted search while present in Atlantic Canadian waters and does not imply that turtles are present year-round.
- A state-space model was used to estimate the most probable locations for each turtle at regular time intervals, and to infer the behavioural state (resident or transient) that turtles were engaged in at each estimated location.
- The relative probability of residency (i.e., being in the resident behavioural state) associated with each turtle location was mapped to visualize the spatial distribution of the relative probability of residency for all leatherback turtles tracked in Atlantic Canadian waters. A relative probability of 0.4 or greater was selected to illustrate a strong likelihood of leatherback turtles being present and engaging in intensive prey searching or foraging behaviour.
- Three primary areas of important habitat are identified: (1) GB - waters east and southeast of Georges Bank, including the Northeast Channel near the southwestern boundary of the Canadian Exclusive Economic Zone (EEZ); (2) 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 (3) PB - waters south and east of the Burin Peninsula, Newfoundland, including parts of Placentia Bay.
- These areas are likely important for leatherback turtles because they serve as foraging habitat.
- The movements of satellite tagged turtles were widely distributed throughout Atlantic Canadian waters, with turtles sampling habitat across a broad area (most of the Atlantic Canadian EEZ). Peak use of the important habitat areas occurs in summer and autumn.
- It is expected that review of important habitat areas will be updated when new information (e.g., prey distribution, prey concentration, turtle behaviour) becomes available.

BACKGROUND

Leatherback Turtle Biology

The leatherback turtle (*Dermochelys coriacea*) is the most widely distributed and largest of all marine turtles. In the Canadian Atlantic, leatherbacks may attain curved carapace lengths of 175 cm and weights of 640 kg (James et al. 2007). Tag-recapture data confirm that leatherbacks in Atlantic Canadian waters originate from nesting beaches in the wider Caribbean; South and Central America; and Florida, USA (James et al. 2007). 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 leatherbacks from throughout the western Atlantic undertake annual migrations to Atlantic Canadian waters (Figs. 1, 2) to forage on scyphomedusae, including lion's mane jellyfish, *Cyanea capillata*, and moon jellyfish, *Aurelia aurita* (Heaslip et al. 2012).

Turtles migrate to Atlantic Canadian waters to accumulate the large fat reserves required to sustain southward migration and subsequent reproduction. In Atlantic Canadian shelf waters, leatherbacks can consume an average of 330 kg wet mass of jellyfish per day (up to 840 kg/day); this is equivalent to 3-7 times their daily metabolic requirement (Heaslip et al. 2012). This attests to the importance of habitat in Atlantic Canadian waters to leatherback turtles.

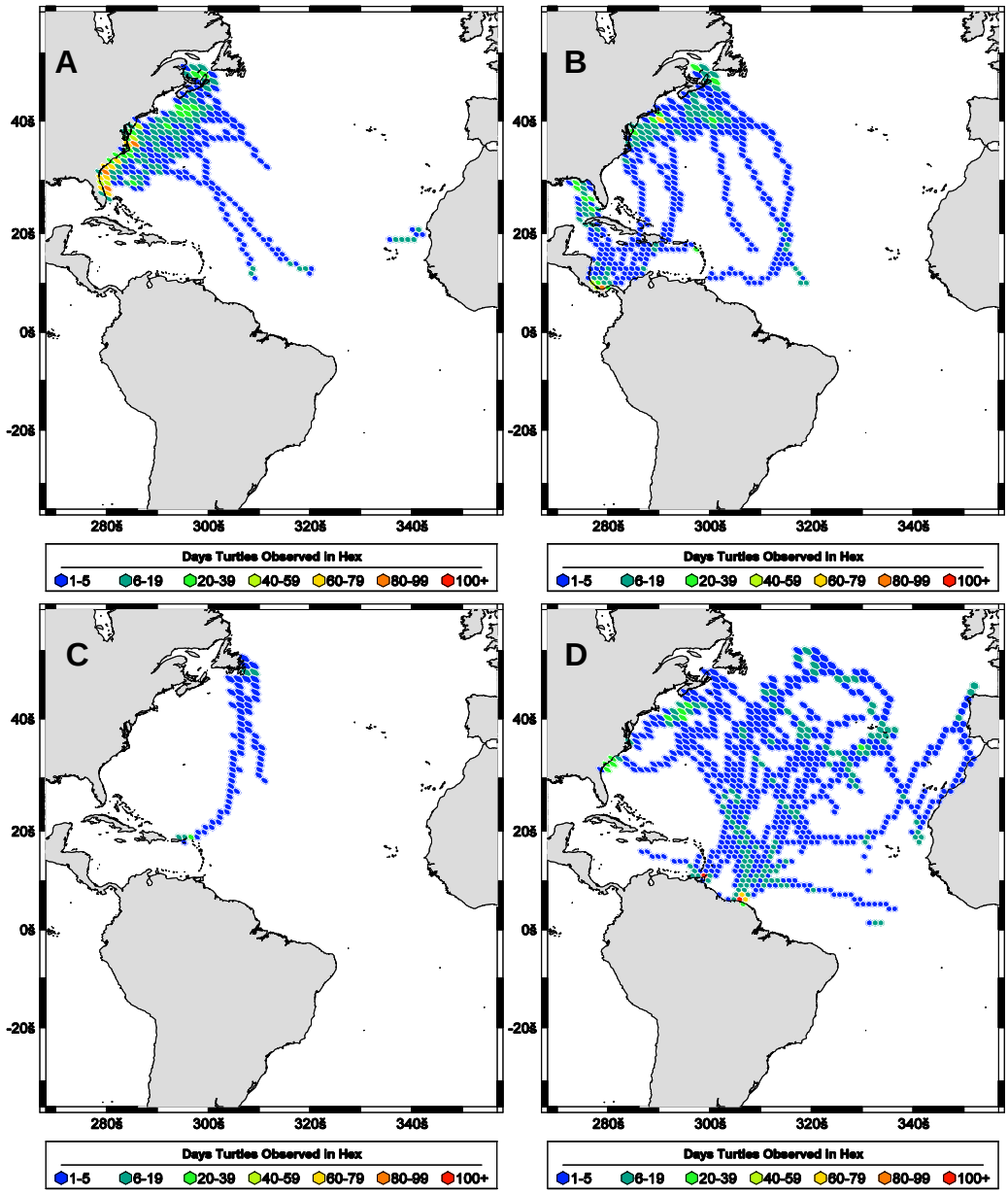

Figure 2. Movements of leatherback turtles leaving the nesting beaches as determined from satellite telemetry. (A) Florida assemblage (n=13 animals, 2687 days), (B) western Caribbean assemblage (n=13 animals, 1287 days), (C) northern Caribbean assemblage (n=3 animals, 212 days), and (D) southern Carribean/Guianas assemblage (n=65 animals, 3544 days). Note that about 25% of the animals intercepted on the foraging grounds could be identified to population by the presence of marks or from bring tracked to the beaches. When known, these animals also were depicted with the appropriate nesting assemblage: 5 (793 days) for the western Caribbean population and 6 (729 days) for the southern Caribbean/Guianas assemblage. (Reproduced with permission from Figure 15, Turtle Expert Working Group 2007.)

While foraging in continental shelf waters off Canada's Atlantic coast, leatherbacks spend approximately two thirds of their time in the top 6 m of the water column, with maximum dive depths seldom exceeding 50 m, and about 50% of day and evening hours (0900-2100) spent at the surface (James et al. 2006). Such extended surface behaviour is consistent with foraging success and associated prey handling (Heaslip et al. 2012). Dive behaviour off the shelf is characterized by deeper maximum dive depths and longer dive durations, which likely reflect changes in foraging tactics for those turtles continuing to exhibit seasonal residency (James et al. 2005b), and broader behavioural shifts accompanying the initiation of southward migration (James et al. 2006).

Tracking Leatherback Turtles with Satellite Tags

Satellite telemetry offers numerous advantages for studying leatherbacks, as it enables remote tracking over broad spatial and temporal scales, and the collection of location, environmental, and dive data. The towed varieties of satellite-linked tags often used to study the movements of pelagic fish (e.g., pop-up archival tags) geo-locate using light-level data, which results in position estimates with a high degree of uncertainty/error, often in the realm of several degrees latitude/longitude (e.g., several hundred km). By contrast, as turtles are air breathers, conventional satellite tags, which transmit directly to a polar-orbiting satellite-based system (ARGOS), can be used to study movements. ARGOS uses the Doppler shift of radio transmissions from tags to estimate location with a relatively high degree of accuracy, and also enables near-real time tracking. Location accuracy, which has been assessed in captive marine turtles, where position can be verified via Global Positioning System (GPS), and on free-ranging turtles equipped with GPS-linked satellite tags, is especially good at high latitudes, as a result of both increased ARGOS satellite coverage (more passes per day) and animal behaviour (extended surfacing times).

Since 1999, researchers affiliated with Dalhousie University, in collaboration with the Canadian Sea Turtle Network (Halifax, Nova Scotia) and commercial fishermen in Nova Scotia, have conducted at-sea field research on leatherbacks in Atlantic Canada. A key component of this work has been the study of local and long-distance movements of leatherbacks using satellite telemetry.

In this analysis, satellite telemetry data serve as a proxy for direct sampling of important habitat, under the explicit assumption that the relative probability of leatherbacks exhibiting residency behaviour is positively correlated with foraging habitat quality. It is important to recognize that while residency behaviour will be used to inform potential identification of critical habitat under SARA, the functional components of critical habitat are what require protection (e.g., gelatinous prey species).

Rationale for Assessment

The objective of this zonal science advisory process was to review information available to assist in the identification of important habitat for leatherback turtles in Atlantic Canada. Given that little is known about the biological, chemical, and physical features associated with important feeding habitat for leatherback turtles, this advisory process reviews the data on the spatial distribution and behavioural patterns inferred from satellite tracking data to identify areas consistently used by leatherback turtles, i.e., patterns in turtle behavioural data are used to infer where important habitat exists. Specifically, the objectives are to:

- review the methodology of using satellite tracking data to define important habitat (reviewed previously at the 2010 Meeting of the National Marine Mammal Peer Review Committee (NMMPRC), DFO 2011);

- review areas of high-use likely associated with intensive prey searching and foraging activity, that could be considered important feeding habitat;
- identify important habitat by month or season, and concatenate this information into a definition of important habitats;
- review a table of tagging locations, tracking durations, and where turtles from different locations were tracked during their deployment;
- provide clarity on where and when leatherback telemetry data were available spatially; and provide details, where available, on habitat characteristics in the turtle high-use areas (e.g., sea surface temperature, jellyfish densities).

ANALYSIS

Using Satellite Tracking Data to Define Important Habitat

Satellite telemetry data from 70 leatherbacks tracked in Atlantic Canadian waters were used to identify important habitat for the species. This is the single largest telemetry dataset for leatherbacks in the Atlantic. It includes 65 tags deployed on leatherbacks in Atlantic Canadian waters over an 11-year period (1999-2009). At-sea capture of leatherbacks enables more representative sampling of the population versus the traditional focus on tagging adult females on nesting beaches. The sample considered in this analysis included all sexes and size classes that use Atlantic Canadian waters (36 mature females; 18 mature males; 11 sub-adults). To augment sample size for the purpose of the present analysis, tracking data corresponding to the Canadian Atlantic Exclusive Economic Zone (EEZ) were solicited from researchers deploying tags on nesting females. Tracking data corresponding to the post-nesting migrations of 5 turtles were also included.

Early satellite tag deployments in Nova Scotia, including tracks of turtles returning to Atlantic Canadian waters after spending time at lower latitudes during the winter months, demonstrated a general pattern of movement in shelf waters from the southwest to the northeast (James et al. 2005a, 2007). To reduce potential biases associated with tagging turtles at one location and/or at only one time of year, turtles were tagged at two field sites: Halifax (approx. 44°N, 64°W, with a focus on deploying tags as early in the season as possible, i.e., July), and waters off northeastern Cape Breton Island (approx. 47°N, 60°W; mid-August through to early September deployments).

Tracking durations that capture return movements to high latitude foraging areas in the year following tagging are particularly valuable, as potential residual tagging effects are unlikely and turtles can be tracked from their first entry into Atlantic Canadian waters that season (versus tagging at an unknown time after entry into Atlantic Canadian waters). Seven return tracks to temperate shelf and slope waters within the Atlantic Canadian EEZ were included in the analyses.

After transmissions from satellite tags are received by polar-orbiting satellites, ARGOS processing centres derive a position for each tag, and assign a location quality class to each position calculated. Of the 51,172 ARGOS positions calculated for the 70 satellite tags considered here, about 40% of the ARGOS calculated positions are estimated to be within less than 1500 m of the tag's true position; a very high location accuracy. However, as these satellite tracking data do contain errors in the observed locations of tagged animals, especially those with accuracy estimations greater than 1500 m of the tags' true position, in order to make use of these data at relatively fine spatial resolutions (e.g., 0.25 degrees), the data must be

filtered, or corrected. For the present analysis, a state-space model (Jonsen et al. 2005) was used to estimate the most probable locations for each turtle at regular time intervals of 6 hours. 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 state-space model was also used to infer the behavioural state that turtles were engaged in at each estimated location. The model separates a turtle's movements (e.g., the direction and distance between consecutive pairs of locations) into two classes: (1) resident - slow, tortuous movements, which are often indicative of intensive searching and foraging activity, and (2) transient - fast, directed movements, which are indicative of transit between foraging sites or migration. In the current context, residency denotes turtles that are likely engaged in area-restricted search while present in Atlantic Canadian waters and does not imply that turtles are present year-round.

The relative probability of residency (i.e., being in the resident behavioural state) associated with each turtle location was mapped by binning the six-hourly estimated locations for all tracked turtles into 0.25 x 0.25 degree cells. For each turtle, the average probability was obtained from all locations occurring within each cell. These average probabilities were then summed, within each cell, across all turtles and divided by the maximum cell value for the entire grid to ensure that all cells had values between 0 and 1. These cell-specific relative probabilities were then mapped to visualize the spatial distribution of the relative probability of residency for all leatherback turtles tracked in Atlantic Canadian waters. A relative probability of 0.4 or greater was selected to illustrate a strong likelihood of leatherback turtles being present and engaging in intensive prey searching or foraging behaviour.

This approach treats all turtle tracks equally, regardless of track duration. Residency probabilities were also weighted by relative track duration prior to summing across all turtles, which yielded similar results to the unweighted probabilities. In order to reduce the influence of initial tagging location, the first 7 days of data were removed prior to calculating the cell-specific relative probabilities. Removal of more or less data did not have a substantial effect on the residency pattern. Residency maps were produced spanning the time period 1999 to 2009 (but excluding 2007, when no tagging data were available).

Areas of High-use Likely Associated with Intensive Prey Searching and Foraging Activity

Three primary areas of important habitat are identified: (1) GB - waters east and southeast of Georges Bank, including the Northeast Channel near the southwestern boundary of the Canadian EEZ; (2) 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 (3) PB - waters south and east of the Burin Peninsula, Newfoundland, including parts of Placentia Bay (Fig. 3). These areas are likely important for leatherback turtles because they serve as foraging habitat.

Selection of thresholds of relative probability of residency behaviour, ranging from 0.4 to 0.6, results in similar estimates of location of important habitat. Specifically, changing the threshold will not change the location of important habitat areas but likely will change the extent of these areas. Selection of a threshold of 0.6 is considered to be less cautious in that boundaries derived from this value may not encompass all important habitats. A threshold of 0.4 may incorporate more of the uncertainty inherent in the leatherback location estimates used to produce the maps of relative probability of residency behaviour.

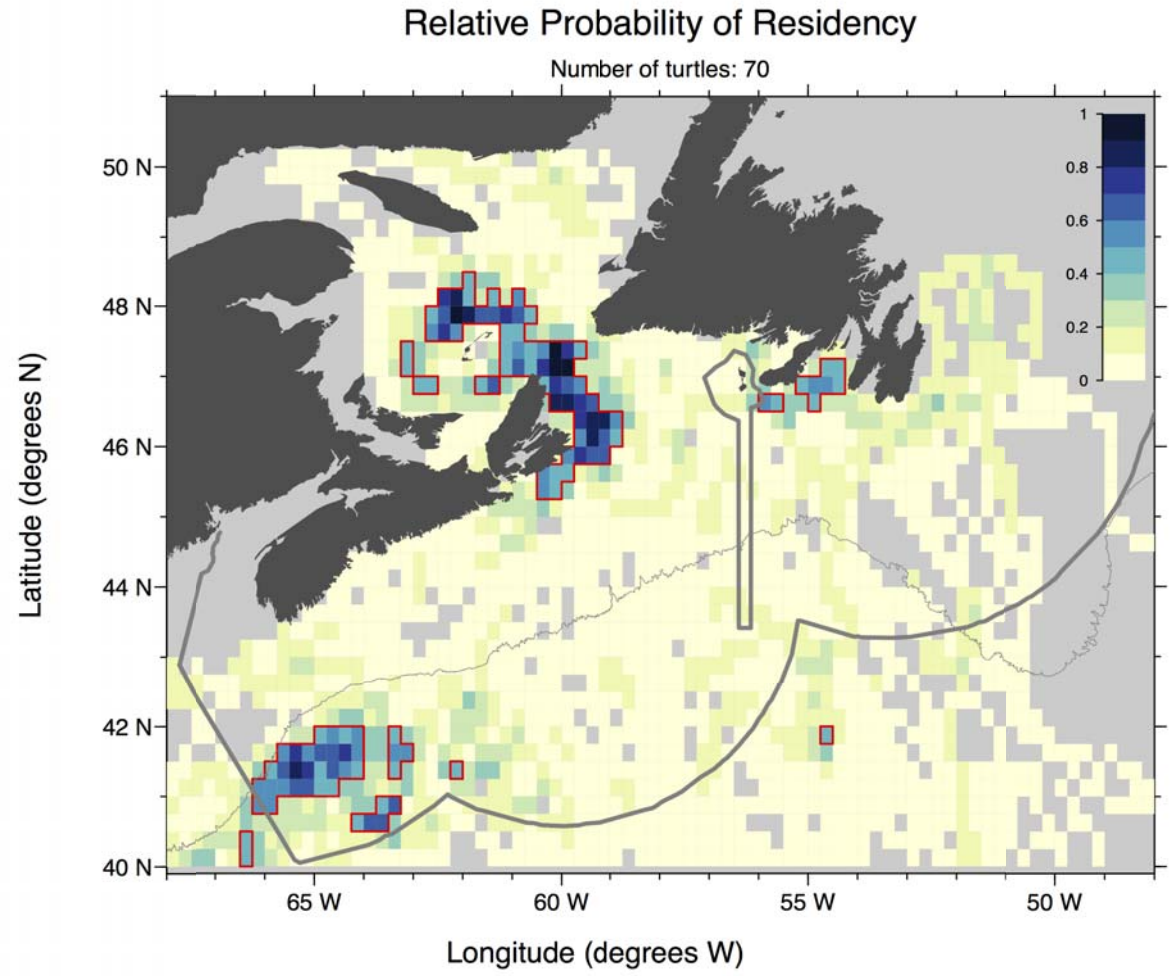

Figure 3. Relative probability of residency estimated from 70 leatherback turtles equipped with satellite tags. Note that all but those areas shaded in light grey were sampled by turtles. Red polygons denote areas where aggregated residency probabilities ≥0.4 for all satellite tracked turtles. Thick grey line indicates Atlantic Canadian EEZ boundary; thin grey line indicates 1000 m isobath. (James and Jonsen unpublished data; not to be cited outside the context of this zonal advisory process.)

Identify Seasonal Habitat

The seasonal maps of relative probability of residency indicate peak use of the important habitat areas in summer and autumn (Fig. 4). While many leatherbacks are present in Atlantic Canadian waters by July, satellite telemetry data predict relatively low density of leatherbacks in the northern part of their range, including GSL and PB, until August. There is a southward migration from GSL and PB in late September and October (Fig. 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. 2007). By November, all of the satellite tagged leatherbacks have departed high-use continental shelf habitat corresponding to GSL and PB, with turtles continuing to exhibit seasonal residency only in GB. This matches the pattern of migration timing described by Sherrill-Mix et al. (2007).

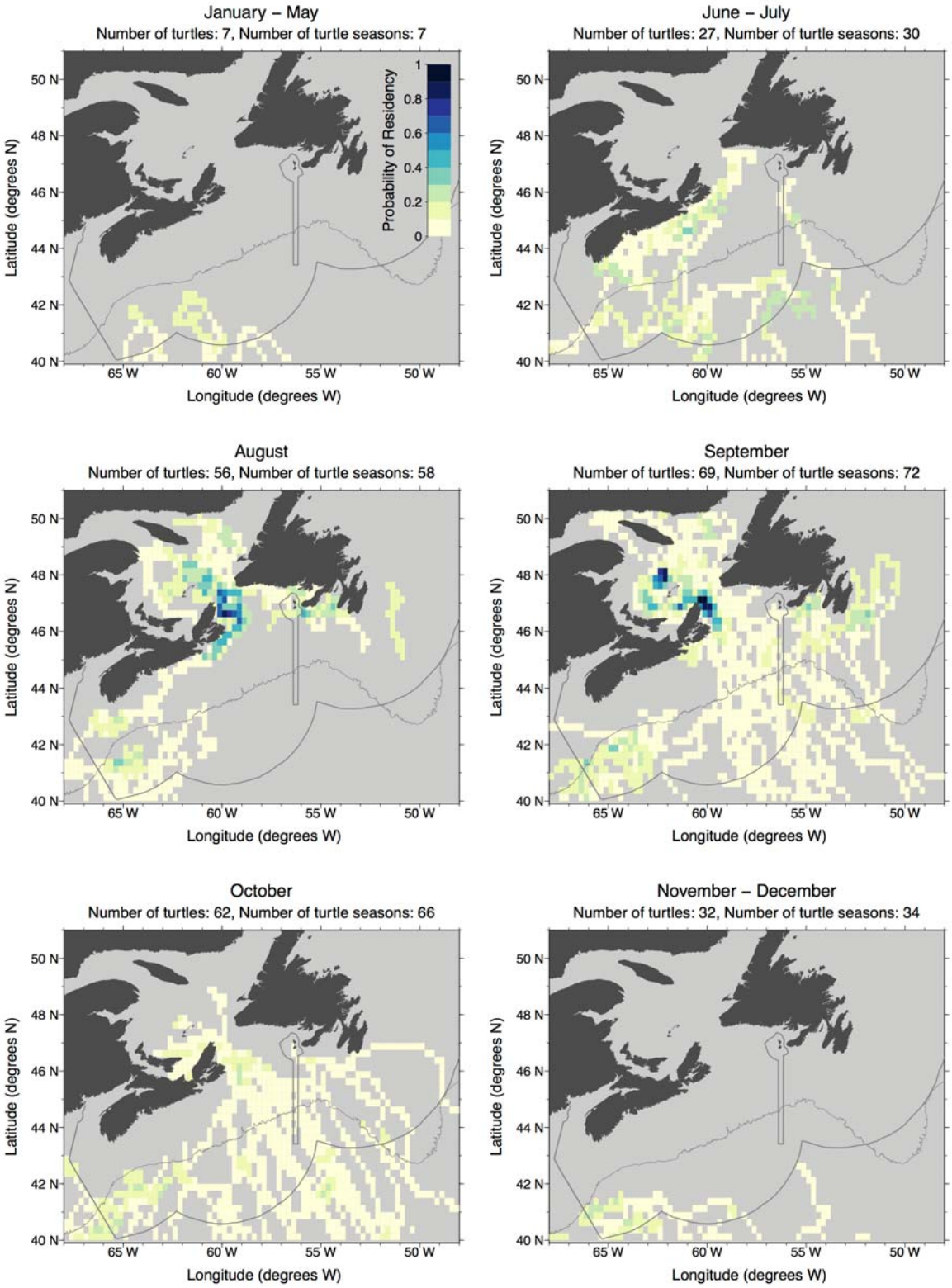

Figure 4. Standardized relative probability of residency by season estimated from 70 leatherback turtles equipped with satellite tags. Thick grey line indicates Atlantic Canadian EEZ; thin grey line indicates 1000 m isobath. (James and Jonsen unpublished data; not to be cited outside the context of this zonal advisory process.)

Tagging Locations, Tacking Durations, and where Turtles from Different Locations were Tracked During their Deployment

Table 1 lists all satellite tags used in the analyses, with accompanying information on the sex of the corresponding turtle, plus year, month, and location where the tag was deployed. The table also reports data on the number of associated tracking days in the Atlantic Canadian EEZ, the number of observed return migrations to Atlantic Canadian waters, and which areas of important habitat were sampled by each tagged turtle (see below for details).

Table 1. Defining important habitat for leatherback turtles in Atlantic Canadian waters: satellite tag deployment details for 70 turtles. "X" denotes sampling of area. (James and Jonsen unpublished data; not to be cited outside the context of this zonal advisory process.)

Tag ID	Sex[1]	Period when tag applied		Tagging Location[2]	Duration of tracking: Number of tracking days in Canadian EEZ	Number of forage seasons/partial seasons in Canadian EEZ	Canadian EEZ seasonal residency areas[3]		
		Year	Month				GB	GSL	PB
15394	M	1999	9	CBI	45.75	1		X	X
18285	F	2000	8	CBI	67.25	1		X	X
18284	M	2000	8	CBI	20	1		X	
26932	F	2000	8	CBI	23.25	1		X	X
26934	M	2000	8	CBI	72	1		X	
17709	F	2001	6	Beach	105	1	X	X	
26933A	F	2001	7	Halifax	20	1	X		
26931	JV	2001	8	Halifax	28	1	X		
18286	JV	2001	8	Halifax	94	1	X		
13426	F	2001	8	Halifax	101.25	1	X		
13430	M	2001	8	Halifax	11.25	1	X		
13425	F	2001	8	Halifax	75	1	X		
13427	F	2001	8	Halifax	61.25	2	X	X	
13428	M	2001	8	Halifax	12.25	2	X		
13429	F	2001	8	Halifax	22.25	1	X		
30511	F	2001	8	Halifax	42.75	1	X		
29874A	F	2001	9	CBI	14.25	1		X	
30510	M	2001	9	CBI	21.75	1		X	
14637A	JV	2001	9	CBI	104.5	2	X	X	
19184	F	2002	7	Beach	5	1	X		
16094	M	2002	8	CBI	24.25	1		X	
17228	JV	2002	8	CBI	60.5	1		X	
16093	JV	2002	9	CBI	13.25	1		X	
13431	JV	2002	9	CBI	10	1		X	
13432	F	2002	9	CBI	13	1		X	
16550	F	2002	9	CBI	15.25	1		X	
17362	F	2002	9	CBI	9.75	1		X	
17679	F	2002	9	CBI	38.5	1	X	X	
14637B	F	2002	9	CBI	12	1		X	
19285	F	2002	11	Beach	25	1	X		
30239	JV	2003	7	Halifax	96	2	X		
29738	F	2003	7	Halifax	61.5	1		X	
29874B	M	2003	7	Halifax	180.75	2		X	X
30719	F	2003	7	Halifax	261.5	2	X	X	
13433	JV	2003	8	Halifax	69.75	1	X		
30296	JV	2003	8	Halifax	40.75	1	X		
41567	F	2003	8	Halifax	82.5	1		X	
41564	JV	2003	8	Halifax	8.75	1	X		
41565A	M	2003	8	Halifax	71.25	1	X		
41566	F	2003	8	CBI	52.25	1		X	
41568	M	2003	8	CBI	64.75	1		X	
45721	M	2004	8	CBI	35.75	1		X	
45722	F	2004	8	CBI	18.5	1	X		
41565B	F	2004	9	CBI	38.75	1	X	X	
26933B	F	2004	9	CBI	11.5	1		X	
53186	F	2005	7	Beach	64	1			X
42570	F	2006	6	Beach	94.75	1	X		X
86993	F	2008	7	Halifax	100	1		X	
86994	M	2008	7	Halifax	95.5	1		X	
86989A	F	2008	7	Halifax	88.25	1		X	
86990	F	2008	7	Halifax	99	1		X	
86991	M	2008	7	Halifax	92.75	1		X	
86992	M	2008	7	Halifax	62.75	2	X	X	
77021	F	2008	7	Halifax	79	1		X	
77022	F	2008	7	Halifax	77.75	1	X	X	
86986A	F	2008	7	Halifax	64.25	1		X	X
86987	F	2008	7	Halifax	85.25	1		X	
86988	F	2008	7	Halifax	85.5	1		X	
94520	M	2009	7	Halifax	74.25	1		X	X
86986B	F	2009	7	Halifax	69.5	1		X	
86989B	F	2009	7	Halifax	89	1		X	X
94523	F	2009	7	Halifax	7.75	1	X		
94521	M	2009	7	Halifax	92	1		X	
72911	JV	2009	8	CBI	46.25	1		X	
72914	F	2009	8	CBI	55.75	1		X	
72915	M	2009	8	CBI	66	1		X	
72919	M	2009	8	CBI	64	1		X	
72905	F	2009	8	CBI	59.5	1		X	
72917	F	2009	8	CBI	40.75	1		X	
72918	F	2009	8	CBI	25.5	1		X	
Totals					4041.5	7>1	27	50	9

[1] Sex: M=mature male; F= mature female; JV=sub-adult sex unknown.
[2] Tagging location: Beach= NW Atlantic nesting beach; Halifax= Halifax-area field site, approx. 44°N, 64°W; CBI= Cape Breton area field site, approx. 47°N, 60°W.
[3] Canadian EEZ residency areas: GB= Georges Bank area; GSL= southern Gulf of St. Lawrence and eastern Cape Breton Island area; PB= Placentia Bay area.

Sampling: When and Where Data were Available Spatially

The movements of satellite tagged turtles were widely distributed throughout Atlantic Canadian waters, with turtles sampling habitat across a broad area (most of the Atlantic Canadian EEZ). Peak use of the important habitat areas occurs in summer and autumn. Notable areas not sampled by tagged turtles included northern portions of the Strait of Belle Isle, northeast coast of Newfoundland, Bay of Fundy, and Northumberland Strait (Figs. 3, 4). While opportunistic sightings of leatherbacks have occurred in these areas, such records are rare relative to those corresponding to the high-use areas identified via satellite telemetry. While the total spatial area sampled by satellite tagged turtles was large, turtle movements throughout most of the EEZ were consistent with transiting behaviour, with residency behaviour principally restricted to the three general areas (Fig. 2).

Fifty turtles spent some time in GSL, 27 in GB and 9 in PB (Table 1). Eighteen turtles only used GB, 35 turtles only used GSL, and 1 turtle only used PB (Table 1). While no individual turtle used all three areas of important habitat, 16 turtles used two of the three areas (GB+PB=1, GB+GSL=8, GSL+PB=7), and all turtles tracked into the Atlantic Canadian EEZ used at least one of the three areas (Table 1).

Habitat Characteristics in High-use Areas

Research on the biophysical attributes of leatherback high-use habitat in Atlantic Canadian waters, as identified through satellite telemetry, has been initiated. Insights may also be gained from results of research focused on a high-use leatherback foraging area in the temperate Pacific, corresponding to portions of the California Current Ecosystem (Benson et al. 2011). There, Benson et al. (2011) identified high seasonal primary production associated with wind-driven upwelling and coastal nutrient input from river plumes, sea surface temperature fronts, and retention areas as important oceanographic correlates of leatherback high-use habitat and area-restricted search behaviour of leatherbacks satellite tracked in this area. Similar to the findings of Benson et al. (2011) off California, the 11-year tracking dataset employed in the present analysis provides evidence for both spatial and temporal (seasonal) predictability in the availability of prey resources for leatherbacks in high-use areas off Atlantic Canada.

Sources of Uncertainty

In these analyses, satellite tracking data are used to infer leatherback behaviour based on their movements (resident versus transient). In turn, residency behaviour is being used as a proxy for habitat containing densities of jellyfish prey that support leatherback foraging. It is the jellyfish that make the habitat important for leatherback turtles. While this sequence of assumptions is considered robust, there is no direct measure of important leatherback habitat, e.g., surveys of jellyfish densities.

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

Handling: Potential short-term handling effects may be of concern. To reduce the influence of initial tagging location as well as handling effects, turtles were tagged in two different areas and the first 7 days of data were removed prior to calculating the cell-specific relative probabilities of residency.

Sample size: Seventy tags is a relatively large sample size for a satellite telemetry study. The extent to which a sample of 70 turtles over 11 years represents the population as a whole is unknown, although the quality and quantity of data associated with the present analyses are considered to be of a very high standard.

Tag locations are estimates: Satellite tracking data do contain errors in the observed locations of tagged animals. In order to make use of these data at relatively fine spatial resolutions, the data were filtered using a state-space model (Jonsen et al. 2005) 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.

Bias may be introduced through discrete expression of a continuous variable.

Habitat use early in the season may be under-represented, since tagging did not begin until July on the Scotian Shelf and, apart from nesting animals, no individuals were tagged prior to or upon entry into Atlantic Canadian waters in the late spring or early summer, and most tracking durations don't encompass a second foraging season at high latitudes. Tagging location may result in underestimation of habitat use in some areas.

CONCLUSION

Three primary areas of important habitat are identified: (1) GB - waters east and southeast of Georges Bank, including the Northeast Channel near the southwestern boundary of the Canadian EEZ; (2) 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 (3) 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.

Future considerations for delineating boundaries of leatherback turtle critical habitat in Atlantic Canadian waters:

1) Critical habitat at a minimum should be based on relative probabilities of residency behaviour including 0.4 and above.
2) Boundaries should be contiguous, such that adjacent and/or nearby cells should be grouped inside a single polygon, and exclude landmasses above high tide mark.
3) For practical reasons, boundaries composed of relatively simple, straight lines are preferable to boundaries with complex delineation.
4) In general, inclusion of a greater number of important areas is superior to identification of fewer areas, and provision of larger areas is favoured over smaller areas, in order to account for uncertainties inherent in estimation of tag reporting locations.

It is expected that review of important habitat areas will be updated when new information (e.g., prey distribution, prey concentration, turtle behaviour) becomes available.

OTHER CONSIDERATIONS

Although the Terms of Reference for this zonal advisory process specifically requested a review of areas of high-use likely associated with intensive prey searching and foraging activity that could be considered important feeding habitat, locations of high transient behaviour may also be considered important habitat. Further, the vertical component (depth) of important habitat was not considered.

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

SOURCES OF INFORMATION

This Science Advisory Report is from the February 29 to March 1, 2012, review of Leatherback Sea Turtle Part 1: Using Satellite Tracking Data to Define Important Habitat. Additional publications from this process will be posted as they become available on the DFO Science Advisory Schedule at www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

Atlantic Leatherback Turtle Recovery Team. 2006. Recovery Strategy for leatherback turtle (*Dermochelys coriacea*) in Atlantic Canada. Species at Risk Act Recovery Strategy Series. Fisheries and Oceans Canada, Ottawa.

Benson, S.R., Eguchi, T., Foley, D.G., Forney, K.A., Bailey, H., Hitipeuw, C., Samber, B.P., Tapilatu, R.F., Rei, V., Ramohia, P., Pita, J., and Dutton, P.H. 2011. Large-scale movements and high-use areas of western Pacific leatherback turtles, *Dermochelys coriacea*. Ecosphere 2: 1-27.

COSEWIC. 2001. COSEWIC assessment and update status report on the leatherback turtle *Dermochelys coriacea* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa.

DFO. 2011. Meeting of the National Marine Mammal Peer Review Committee; November 22-26, 2010. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2011/003.

Heaslip, S.G., Iverson, S.J., Bowen, W.D., and James, M.C. 2012. Jellyfish support high energy intake of leatherback sea turtles (*Dermochelys coriacea*): video evidence from animal-borne cameras. PLoS ONE 7(3): e33259. doi:10.1371/journal.pone.0033259.

James, M.C., Eckert, S.A., and Myers, R.A. 2005a. Migratory and reproductive movements of male leatherback turtles (*Dermochelys coriacea*). Marine Biology 147: 845-853.

James, M.C., Myers, R.A., and Ottensmeyer, C.A. 2005b. Behaviour of leatherback sea turtles, *Dermochelys coriacea*, during the migratory cycle. Proceedings of the Royal Society of London (B) 272: 1547-1555.

James, M.C., Sherrill-Mix, S.A., and Myers, R.A. 2007. Population characteristics and seasonal migrations of leatherback sea turtles at high latitudes. Marine Ecology Progress Series 337: 245-254.

James, M.C., Ottensmeyer, C.A., Eckert, S.A., and Myers, R.A. 2006. Changes in diel diving patterns accompany shifts between northern foraging and southward migration in leatherback turtles. Canadian Journal of Zoology 84: 754-765.

Jonsen, I.D., Mills Flemming, J., and Myers, R.A. 2005. Robust state-space modeling of animal movement data. Ecology 86: 2874-2880.

Sherrill-Mix, S.A., James, M.C., and Myers, R.A. 2008. Migration cues and timing in leatherback sea turtles. Behavioral Ecology 19: 231-236.

Turtle Expert Working Group. 2007. An assessment of leatherback turtle population in the Atlantic Ocean. NOAA Technical Memorandum NMFS-SEFSC-555. 116 p.

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