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LETTER

Identification of high-use habitat and threats to leatherback sea turtles in northern waters: new directions for conservation

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Abstract

Incidental capture in fisheries threatens many marine vertebrates, however, conservation cannot be effective without identifying major sources of mortality. For the critically endangered leatherback turtle (*Dermochelys coriacea*), a reliance on fisheries observer data and an absence of behavioural data sets corresponding to a large and diverse sample of animals have focused conservation efforts on a very limited part of the species marine habitat. Using the largest satellite telemetry data set for Atlantic leatherbacks, morphometrics from foraging animals and entanglement records, we show annual return migrations to key feeding areas by males, females and juveniles, and demonstrate the importance of northern latitudes to leatherbacks. We show that leatherbacks are vulnerable to entanglement in northern coastal and shelf waters, where turtle–fishery interactions represent a greater threat to this species than previously recognized. Unless conservation efforts expand to coastal and shelf areas, present efforts alone will not be sufficient to save the species.

Keywords

Conservation, *Dermochelys coriacea*, endangered, fisheries, hotspots, leatherback turtle, migration, north-west Atlantic, satellite telemetry, shelf waters.

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INTRODUCTION

A poor understanding of the distribution and movements of many marine vertebrates has impeded conservation of these species (Block *et al.* 2001). Such basic biological information is critical to identifying and evaluating potential sources of anthropogenic mortality and designing effective conservation plans. Movement data have had important implications for predicting how threats may impact upon populations and meta-populations of bluefin tuna (Block *et al.* 2001), wandering albatross (Inchausti & Weimerskirch 2002), South American fur seals (Thompson *et al.* 2003) and Florida panthers (Maehr *et al.* 2002). Incidental capture in fisheries has been implicated in the decline of many species (Tuck *et al.* 2001; Baum *et al.* 2003; Lewison *et al.* 2004), but because most analyses focus on observer data from only a fraction of fisheries with potential impacts, the importance of interactions occurring in other parts of a species' range often remains virtually unknown. This is the case with the leatherback turtle (*Dermochelys coriacea* Vandelli 1761).

The leatherback is the largest of the turtles and is found in all of the world's oceans, specializing on a diet of gelatinous plankton (Bleakney 1965). Following a sharp global population decline over the past two decades (Spotila *et al.* 1996, 2000), the species is now critically endangered (IUCN 2004) and may be facing imminent extinction in the Pacific (Spotila *et al.* 2000). While nesting female turtles and their eggs have received increasing levels of protection in some locations, conservation of this cosmopolitan reptile has been hampered by insufficient knowledge of its biology at sea. Most available information comes from instrument deployments on nesting females (Eckert *et al.* 1989; Ferraroli *et al.* 2004; Hays *et al.* 2004) and records of turtles incidentally captured in pelagic longline fisheries (Witzell 1999; Lewison *et al.* 2004). Recent studies have highlighted the broad oceanic movements of leatherbacks in the Atlantic (Ferraroli *et al.* 2004; Hays *et al.* 2004), but relatively small sample sizes have, until now, precluded the identification of high-use areas (hotspots) where conservation efforts may be most effective. While it is known that this species is highly migratory (Ferraroli *et al.* 2004; Hays *et al.*

2004), virtually nothing is known about its behaviour and biology in northern areas.

Here we investigate the biology of leatherbacks at northern latitudes and identify potential threats to turtles in these areas by considering information from three distinct data sets: satellite telemetry data from turtles tagged in Canadian waters, detailed morphometrics from northern foraging animals and entanglement records from shelf waters of Atlantic Canada. Insights from this synthesis highlight the importance of gathering long-term data from a large sample and thoroughly identifying key habitat when developing and implementing effective measures to ensure species survival.

METHODS

Satellite tag deployments

We deployed five different models of platform transmitting terminals from three manufacturers: Telonics (Mesa, AZ, USA) ST-10 ($n = 1$), Sirtrack (Havelock North, New Zealand) Kiwisat ($n = 17$), Wildlife Computers (Redmond, WA, USA) SPOT3 ($n = 5$); SSC3 ($n = 13$); and SDRT-16 ($n = 2$) in two different areas: waters off mainland Nova Scotia (44° N 64° W, $n = 20$ tags) and waters off Cape Breton Island (47° N 60° W, $n = 18$ tags). We captured foraging turtles at the surface using a breakaway hoop net operated from a bowsprit attached to a 10.5 m commercial fishing boat equipped with a stern ramp. Each captured animal was guided up the ramp onto a raised platform, where metal tags were applied to the rear flippers, an AVID$^{\mathrm{TM}}$ (Calgary, Canada) microchip was injected into the shoulder muscle and morphometrics were recorded. We attached the satellite transmitters to the carapace using a custom-fitted harness made of nylon webbing and polyvinyl tubing, which incorporated corrodible links to ensure release (modified after Eckert 2002).

Spatial use analysis

We included all Argos-derived positions classified as 1, 2 or 3 (categorized by Argos to lie within 350–1000 m, 150–350 m, or 150 m, respectively, of the tag's true position) in the spatial use analysis. Of 5459 rates of travel calculated between Argos positions classed 1–3 ($n = 22$ turtles), only 57 (1.0%) were 201 5 km h^{-1}, all corresponding to movements shortly after tagging or the onset of southward migration. Therefore, we filtered all other Argos positions (location classes A, B and O) based on a maximum rate of travel of 5 km h^{-1}. Positions of location quality Z and those that clearly fell outside each turtle's track were omitted. We calculated median daily locations for each turtle based on the filtered locations and then tallied the median locations for all turtles in hexagonal area bins.

Morphometric analysis

We obtained weight and corresponding curved carapace length (CCL) from live turtles and those recovered dead from fishing gear in Canadian waters ($n = 13$). These included nine turtles measured by one of us (MCJ), two previously published records (Bleakney 1965; Threlfall 1978), corroborated by original field notes, and two of Bleakney's unpublished records. We compared these measurements with data for 102 nesting turtles from St Croix, US Virgin Islands (Boulon *et al.* 1996). Differences in weight between southern nesting and northern foraging turtles (CCL > 140 cm: individuals presumed to be adults) were analysed using constant slope ANCOVA after log transformation.

Entanglement records

From 1997 to 2003, we collected voluntarily reported georeferenced records of leatherbacks entangled in fixed gear in Atlantic Canada.

RESULTS

We equipped 38 leatherback turtles with satellite tags at sea off Nova Scotia, Canada, during the summers of 1999–2003, and collected observations for 8288 tracking days, with a mean tag transmission life of 218 days. Eleven turtles were tracked for longer than 1 year. While all previous tracking studies have been limited to post-nesting movements of mature females tagged in specific nesting colonies, our sample of the first animals tagged in northern waters encompassed individuals from multiple disparate nesting sites both in their post-nesting and in their inter-nesting years and included the first mature males ($n = 11$) and juveniles (CCL < 140 cm, $n = 6$) to be tracked via satellite.

Turtles concentrated their movements in waters off eastern Canada and the north-eastern United States before assuming southward migrations, spending up to 4 months post-tagging in northern waters (Fig. 1). While migration start date varied from 12 August to 15 December, most turtles left during October. Twenty-five of the tags transmitted long enough to show southern destinations (eight males, 12 females, five juveniles). While 11 turtles (44%) migrated to waters adjacent nesting beaches, including those along the north-east coast of South America and the Antilles ($n = 10$) and off Panama and Costa Rica ($n = 1$), other turtles migrated to pelagic waters between 5° and 23° N ($n = 12$), or to shelf waters off the south-eastern United States ($n = 2$).

All turtles that departed southern waters assumed northward migrations ($n = 19$, six males, seven females, six juveniles), most leaving in February and March ($n = 11$).

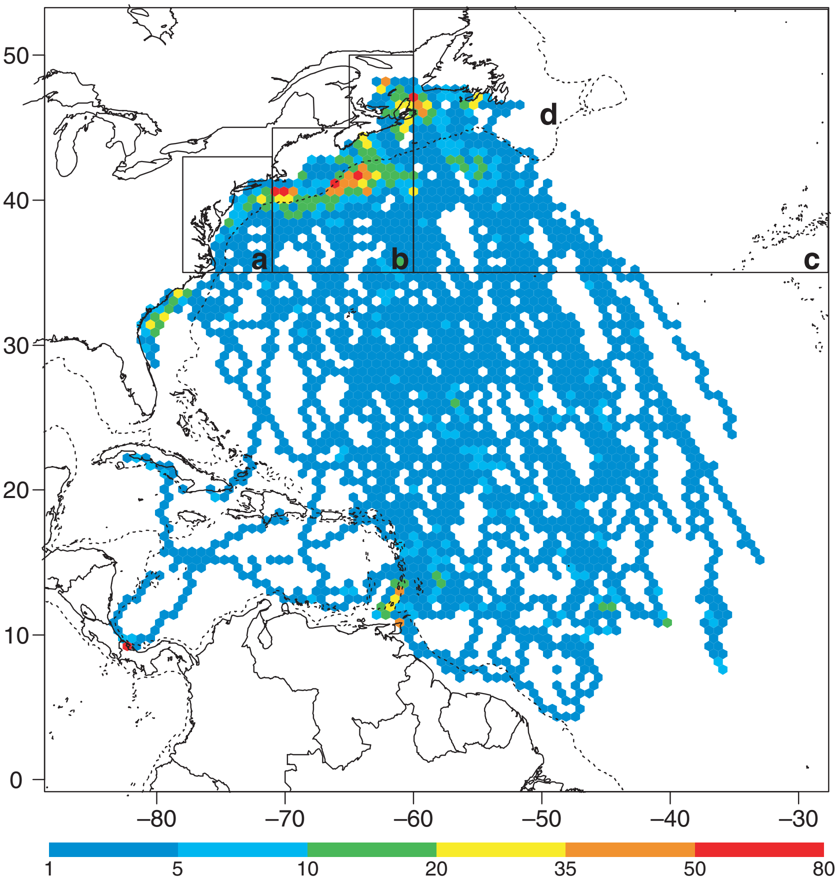

Figure 1 Spatial use by 38 leatherback turtles equipped with Argos satellite tags in waters off Nova Scotia, Canada. Colour denotes the number of days turtle(s) were observed in each hexagon (width: 0.719° longitude, largest height: 0.709° latitude). US pelagic longline reporting areas: (a) Mid-Atlantic Bight, (b) Northeast Coastal and (c) Northeast Distant. Area (c) extends eastward to −20° longitude and northward to 55° latitude, and was closed to US pelagic longline vessels to protect marine turtles. Area (d), Grand Banks. Dashed line: 1000 m depth contour.

Twelve tags (32%) transmitted long enough to show a return to the north-west Atlantic, north of 38° N, with turtles typically arriving during June of the year after tagging (range: March 25 to August 16). Moreover, turtles usually returned to within several hundred kilometres of where they occurred the previous year (Fig. 2). Four tags transmitted long enough to show a second southward trek the following autumn, a phenomenon which has not been previously demonstrated.

In eastern Canada, leatherbacks (measured alive or recovered from fishing gear) weighed 33% more (95% confidence interval = 26–40%, $n = 13$, six males, seven females) than turtles of the same carapace length nesting at St Croix, US Virgin Islands (Boulon *et al.* 1996) (Fig. 3). The effect of sex was not statistically significant. Turtles nesting at St Croix were of comparable size (range = 259–506 kg, $n = 102$; Boulon *et al.* 1996) to other western Atlantic nesting populations, including Tortuguero, Costa Rica (mean = 346.8 kg, SD = 55.4, range = 250–435 kg, $n = 22$; Leslie *et al.* 1996), and French Guiana (mean = 339.3 kg, SD = 41.3, range = 250–415 kg, $n = 15$; Girondot & Fretey 1996).

From 1997 to 2003, we collected 83 records of leatherbacks interacting with fixed gear in shelf waters off eastern Canada. Of these records, 95% were of turtles entangled in buoy lines by one or both front flippers; 18% of all turtles were reported dead. Five free-swimming turtles were observed trailing attached ropes. As most interactions were voluntarily reported ($n = 78$), these records surely represent only a small fraction of the total number of leatherback-fixed gear interactions occurring in Atlantic Canada.

DISCUSSION

The extensive tracks of leatherbacks presented here identify previously unrecognized high-use areas in continental shelf and slope waters (Fig. 1), where, in contrast to pelagic zones, threats to leatherbacks have received little attention. The extended time periods during which leatherbacks use these northern areas place special emphasis on the need to protect turtles there.

Our sample shows that, upon departing northern habitats, leatherbacks do not migrate southward along common paths, but utilize broad expanses of ocean (Fig. 1). A similar pattern has been shown for leatherback turtles migrating northward after nesting (Ferraroli *et al.* 2004; Hays *et al.* 2004). Moreover, individual turtles in our study did not utilize consistent routes to and from northern areas (Fig. 2),

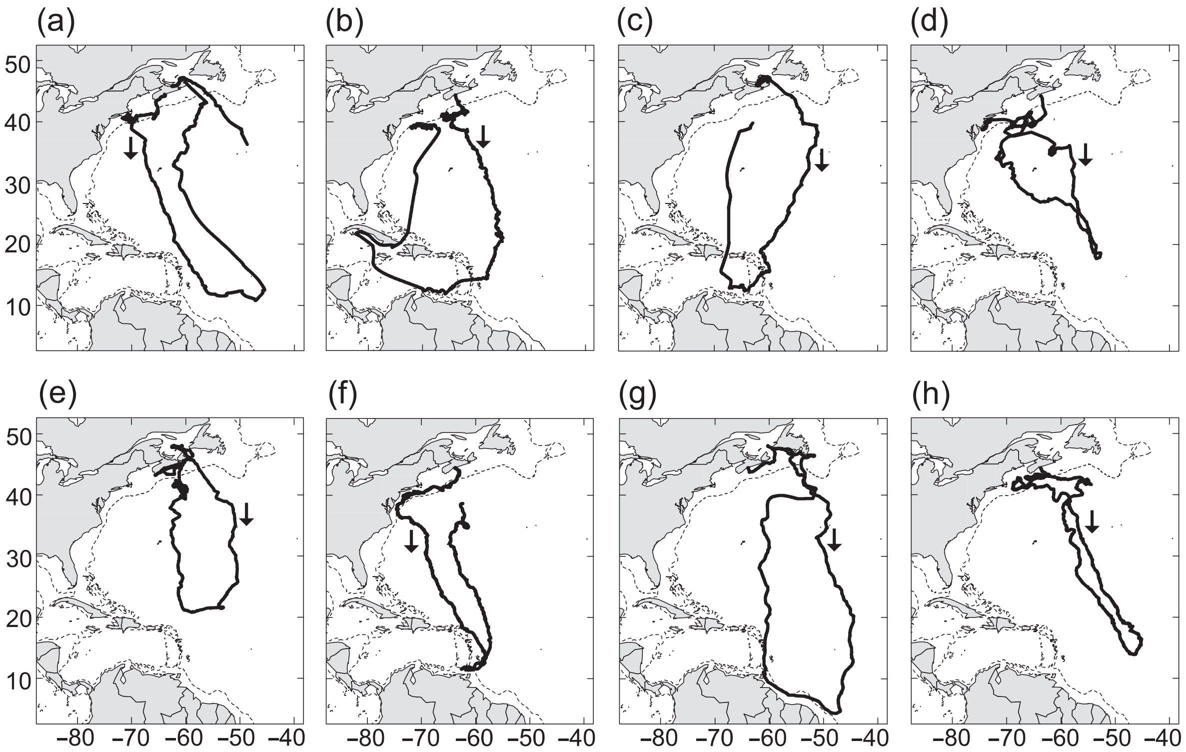

Figure 2 Return movements of eight satellite-tagged leatherbacks to northern latitudes of the northwest Atlantic. (a, e) Mature females; (f, g) mature males; (b, c, d, h) juveniles. Arrows show direction of movement. All turtles completed return migrations to temperate waters within 1 year of tagging. Dashed line: 1000 m depth contour.

but exhibited foraging site fidelity to shelf and slope waters off Canada and the north-eastern United States.

These are the first tracks to confirm annual round-trip migration in leatherbacks, a phenomenon we observed in juveniles, males and females in their inter-nesting years. A flipper tag recovery has shown that a one-way post-nesting migration to northern waters may take as few as 4 months (Girondot & Fretey 1996). Therefore, return migrations may also be possible for females during their nesting years. While most males appeared to seek coastal areas in tropical waters, females in their inter-nesting years and juveniles more commonly completed the southern part of the migratory loop in pelagic waters. Transatlantic movements have been documented for turtles departing Caribbean and South American nesting beaches (Ferraroli *et al.* 2004; Hays *et al.* 2004), however, all turtles tagged in Canadian waters remained in the western Atlantic while tags were transmitting. This pattern suggests that turtles occurring in Canadian waters may principally originate from western, rather than eastern Atlantic nesting beaches.

Considerable energetic costs must accompany the round-trip migrations of *c.* 10 000 km undertaken by the leatherbacks in this study. While weights of the same individuals over the migration cycle are not available, we have presented the first comparison of weights in northern and southern areas. Nesting female leatherbacks at St Croix lose an average of 2.0 kg per nesting (Eckert *et al.* 1989). Given the average number of nests for females of this population (Boulon *et al.* 1996), this amounts to 10.5 kg over the nesting season, an amount far less than the typical weight difference between the nesting females and the northern animals presented here. This comparison underscores the significance of temperate feeding areas for this species.

Pelagic longline fishing has led to serious declines in many large pelagic species, including sharks (Baum & Myers 2004) and loggerhead turtles (*Caretta caretta* Linnaeus 1758) (Lewison *et al.* 2004). The global decline of leatherbacks has also been largely attributed to incidental capture in fisheries (Spotila *et al.* 1996, 2000; Eckert & Sarti 1997; Lewison *et al.* 2004), with pelagic longlines proposed as a key threat (Spotila *et al.* 2000; Lewison *et al.* 2004). Recent leatherback conservation efforts in the North Atlantic have focused on reducing interactions with pelagic longlines (Witzell 1999; Lewison *et al.* 2004), including a closure affecting US vessels in the Northeast Distant (NED) reporting area (U.S. Federal Register 2001; Fig. 1). Surprisingly, none of the turtles we tagged moved into the small region within the NED (south and east of the Grand Banks) where pelagic

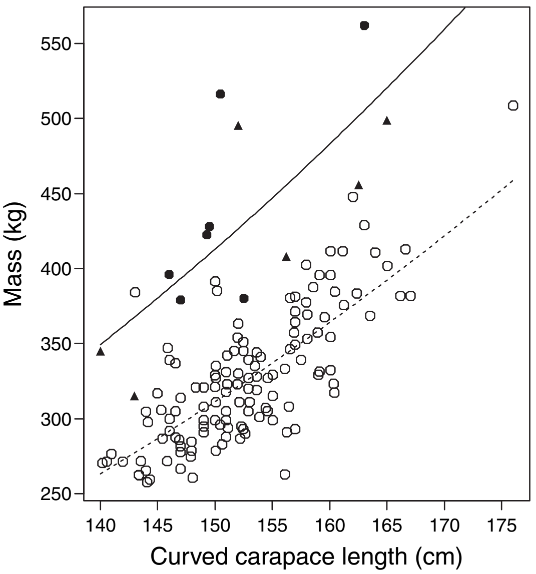

Figure 3 Mass vs. curved carapace length for leatherback turtles weighed on nesting beaches at St Croix, US Virgin Islands ($n = 102$, open symbols, dashed line) (Boulon *et al.* 1996), and those weighed during their foraging period in Canadian waters ($n = 13$, closed symbols, solid line). Circles: females, triangles: males. Lines fit by constant slope analysis of covariance after log transformation. The effect of sex was not statistically significant.

longline effort is focused (Baum *et al.* 2003; Fig. 1). The leatherbacks found interacting with those fisheries may constitute a different set of individuals. While area closures can be effective, they may not advance species conservation if fishing effort is simply displaced (Baum *et al.* 2003). In this case, closing the NED would likely increase interactions in other areas where pelagic longlining occurs, if effort were redirected there. Of particular concern are the north-east coastal and mid-Atlantic Bight US reporting areas where many turtles in our sample spend substantial amounts of time (Fig. 1), and where longlining effort is already high (Baum *et al.* 2003). However, in pelagic waters, modifying fishing practices rather than implementing area closures may be ultimately more effective in conserving leatherbacks.

While turtle–fishery interactions in pelagic waters have been a major focus of recent conservation measures and controversy, threats to leatherbacks in shelf waters have been largely ignored. This persistent focus on pelagic fisheries is, in part, likely because of the inherent bias and geographical limitations of the source of the majority of data available on leatherbacks: observer data from the pelagic longline fleets, which clearly indicate a high level of turtle–fishery interactions. However, leatherbacks caught in pelagic longlines are normally entangled or hooked externally on this mobile gear (Garrison 2003) and are usually capable of swimming to the surface to breathe (Witzell & Cramer 1995). Therefore, for leatherback turtles, entanglement in pelagic longlines does not necessarily lead to mortality. In fact, observer data reveals that very few turtles are discovered dead on pelagic longlines, although post-release mortality remains unknown. Of 323 leatherbacks observed interacting with US pelagic longline gear in 2001 and 2002, only one (0.3%) was found dead (Garrison 2003). In contrast, as our data suggest, fishing gear anchored to the bottom (fixed gear) in shelf waters may lead to higher mortality per interaction because turtles entangled at depth or at the surface at low tide will almost certainly drown. As fixed gear fisheries receive relatively little observer coverage, the magnitude of the threat they pose to leatherbacks has not been adequately recognized nor addressed.

As in Canadian waters, leatherbacks are regularly entangled in fixed gear in US waters off New York through Maine (Dwyer *et al.* 2003). Given that individual turtles in this study spend extended periods in both Canadian and US waters (Fig. 1), leatherbacks are at risk of entanglement in both areas. Emerging data from coastal waters in the Caribbean and South America show that leatherbacks are also at risk of entanglement there, with large numbers of turtles regularly interacting with artisanal drift gillnet fisheries off the nesting beaches (Chevalier 2001; Lee Lum 2003). In fact, an estimated 3000 leatherback interactions with artisanal gillnet fishing gear occurred off Trinidad in 2000, with reported mortality rates of 28–34% (Lee Lum 2003). Turtles that forage in northern waters of the western Atlantic are among those at risk in these southern coastal areas (Fig. 1), emphasizing that recovery of these animals will require multinational collaboration.

We are, as yet, unable to evaluate the relative severity of threats posed to leatherbacks by different fisheries and other sources of anthropogenic mortality. An analysis of this magnitude will first require detailed information on rates of capture and post-capture mortality resulting from interactions with fishing gear across the species entire range. Further data on turtle behaviour and movements, independent from fisheries, is also required. Only by synthesizing data from multiple sources will we be able to account for the biases in each and develop effective recovery strategies.

The combination of multiple independent data sets presented here offers new insight into the biology of leatherback turtles and demands that if we are to succeed in conserving these unique reptiles, we must look more broadly to identify where, when and how they are at risk. Protecting turtles in high-use areas may offer the best potential for their recovery, particularly if activities in those areas result in high mortality. In addition, closure of only some areas to pelagic longline fisheries will be of limited conservation value if fishing effort is redirected. By studying the biology and movements of a large sample of turtles of varying sex and size, we have identified key foraging areas in northern waters which fall outside those zones which have traditionally received the most management attention, yet which hold a substantial and largely undocumented threat.

We propose that an important component in the drastic declines of leatherbacks in the Atlantic and the Pacific may have been the underreported yet potentially widespread interactions of turtles with fishing gear in coastal and shelf waters. The impact of leatherback interactions with coastal and shelf fisheries in both temperate and tropical waters may be particularly important, as it is the mature and large subadult turtles, which may offer the greatest potential for population recovery, that aggregate to feed and breed in these areas. As leatherback numbers have reached critically low levels in the Pacific (Spotila *et al.* 2000), new hope for their recovery may come from studies in the Atlantic, where populations are still large enough to analyse trends. We urge rapid reduction of incidental capture in coastal and shelf fisheries to assist in the recovery of the leatherback worldwide.

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