Leatherback Sea Turtles (*Dermochelys coriacea*) in Irish waters

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Leatherback Sea Turtles (*Dermochelys coriacea*) in Irish waters

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1. LEATHERBACK MORPHOLOGY AND PHYSIOLOGY

Leatherback turtles (*Dermochelys coriacea*, Vandelli 1761) are the only surviving species of an evolutionary lineage (Fm. Dermochelyidae) that diverged from other sea turtles 100-150 million years ago (Dutton *et al.* 1999). Today they are characterised by a low genetic diversity that suggests they may have radiated from a narrow refugium, possibly during the recent Pleistocene glaciation (Dutton *et al.* 1999). They are the largest extant sea turtle (Fig. 1) and have many unique anatomical and physiological adaptations. These include the absence of a hard shell, possession of an extensive layer of peripheral blubber (Davenport *et al.* 1990), proportionally larger fore flippers than other species of sea turtle (Joyce & Gauthier 2004), and a rete-like arrangement of blood vessels at the proximal end of each fore flipper (counter-current heat exchangers) (Greer *et al.* 1973; Davenport *et al.* 1990)(Fig. 2).

Importantly, the insulating properties of its peripheral tissues combined with their large body size help leatherbacks retain the heat generated from muscular activity. In turn, this retention of heat, allows leatherbacks to maintain an elevated core body temperature (or regional endothermy) above that of the surrounding sea temperature (as much as 8 °C) (Paladino *et al.* 1990; James & Mrosovsky 2004). This temperature model described as 'gigantothermy' by Spotila *et al.* (1997) permits leatherbacks to forage into cooler temperate waters that are largely inaccessible to other sea turtles. However, often described as 'warm blooded' (inferring a high metabolism like mammals and birds), leatherbacks have a typical reptilian ectothermic metabolic rate (i.e. low) (Wallace *et al.* 2005; Bradshaw *et al.* 2007). The combination of regional endothermy and a low metabolism enables leatherbacks to survive on the nutritionally poor diet of gelatinous zooplankton (Doyle *et al.* 2007).

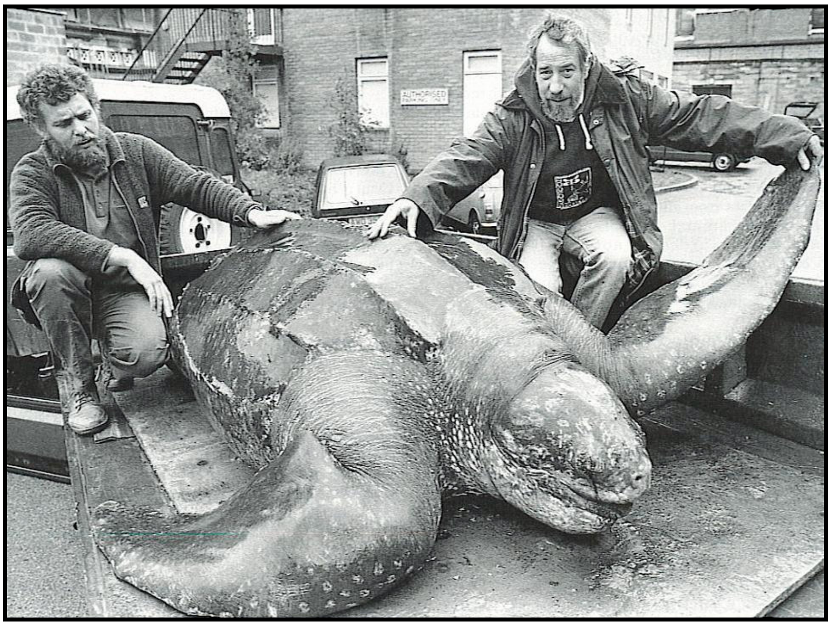

Figure 1: The Harlech leatherback stranded in Wales in 1989, and weighed 916kg. © Western Mail & Echo, Wales.

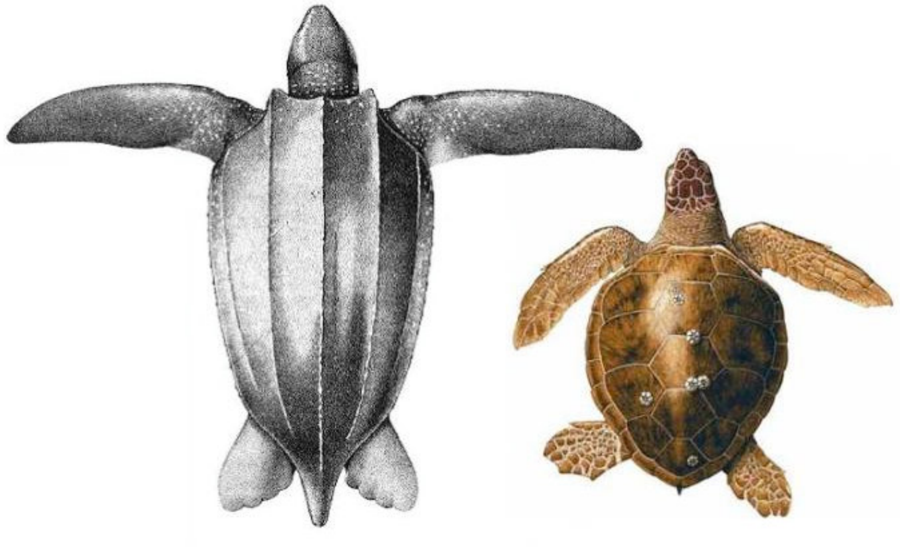

Figure 2: Leatherback (left) and loggerhead (right) turtles. Note absence of hard shell, scutes and scales on leatherback. Also, note 7 longitudinal ridges on leatherback and its proportionally larger front flippers than other sea turtles. Picture adapted from adapted from Penrose (2003).

2. REPRODUCTION AND POPULATION ESTIMATES OF FEMALES

As reptiles, leatherbacks are reproductively confined to warm tropical regions because of thermal constraints on egg incubation (Pritchard 1997; Dutton *et al.* 1999). This constraint has a marked bearing on their migratory behaviour, as mature females most return to these sandy tropical/subtropical beaches once every 2-3 years to reproduce (Rivalan *et al.* 2005). It is possible that male leatherbacks may return to nesting areas every year to mate (James *et al.* 2005a). During reproductive years when a female returns to her natal nesting beach, she may lay 6 to 7 consecutive clutches per season (Boulon *et al.* 1996; Girondot & Fretey 1996; Miller 1997), laying some 500 eggs in total (Miller 1997) (Fig. 3). This occurs over a period of 7-9 weeks, depending on the number of clutches deposited and timing between consecutive nesting events (Miller 1997). During consecutive nesting events females return to the water and normally remain over the continental shelf, yet sometimes perform extended movements and may even nest in neighbouring countries (Georges *et al.* 2007).

In the Atlantic, the largest nesting populations of leatherbacks are located in French Guiana and Suriname along the northern coastline of South America, in the southern Caribbean islands of Trinidad and Tobago, and in Gabon on the coast of West Central Africa (Rivalan *et al.* 2005; Eckert 2006; Georges *et al.* 2007) (Fig. 4). Many smaller populations of leatherbacks are located throughout the wider Caribbean and southern states of the USA. It is estimated that the current Atlantic population lies somewhere between 26,000 and 43,000 female leatherbacks (Spotila *et al.* 1996; Dutton *et al.* 1999), with very little known about the male population as they do not come ashore at any stage. The peak nesting periods (range in parenthesis) are: June (March-mid August), for Guiana, end of May (March-July), for Trinidad January/February (November-April), for Gabon (Girondot *et al.* 2002; James *et al.* 2005a).

Figure 3: Female leatherback on Yalimapo nesting beach in French Guiana, South America. The majority of females nest at night when it is dark. This female is almost finished and retuned to the sea soon after the photo was taken (early morning). Females use their extremely dexterous hind limbs to dig a nest before laying approximately ~80 eggs. The whole nesting process takes between 1- 2 hours. © Tom Doyle.

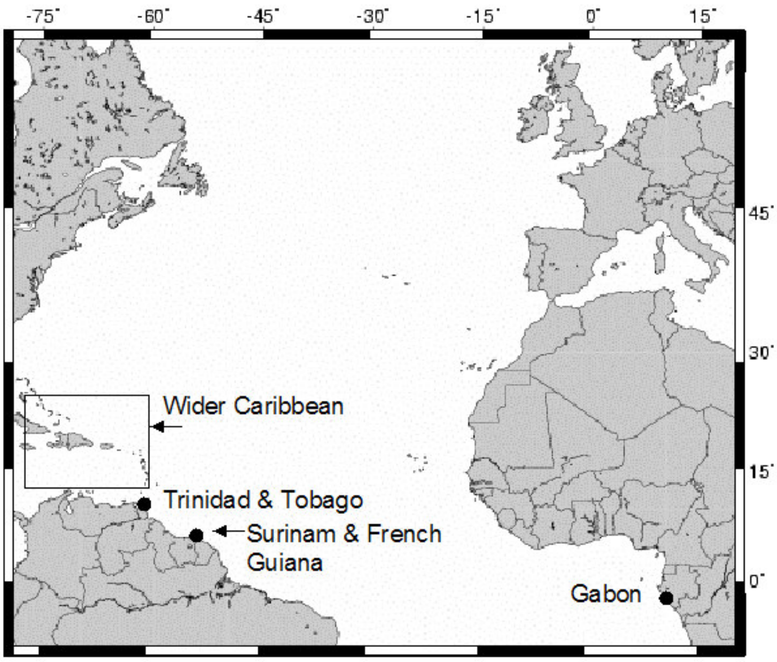

Figure 4: Distribution of the main nesting beaches in the Atlantic.

3. HATCHLINGS, JUVENILES AND ADULTS IN TEMPERATE WATERS

Eggs hatch after 6-13 weeks of incubation and hatchlings head immediately for the sea (Miller 1997). Upon entering the sea, hatchlings swim continuously offshore for at least six days (Musick & Limpus 1997). Thereafter, their fate is one of the least understood aspects of sea turtle life history (Musick & Limpus 1997; Eckert 2002). Sightings of hatchlings and their subsequent juvenile phase are very rare, and as yet, no method has been devised to follow their movements at sea.

Eckert (2002) compiled a database of leatherback sightings having a SCCL [standard curvilinear carapace length] <145 cm (Fig. 5) and found that juveniles with SCCL <100 cm are only sighted within waters warmer than 26 °C. Eckert (2002) suggested that juvenile leatherbacks (from hatchling to approximately 100 cm SCCL) are thermally constrained to warm, tropical and subtropical waters; however, at approximately 100 cm SCCL there may be an onset of regional endothermy that enables them to penetrate much cooler temperate waters. Indeed, in the northern Atlantic, sub-adult to mature adults are regularly sighted each summer along the Canadian seaboard, Western Europe and even as far north as northern Norway (Brongersma 1969; Duron 1978; King 1983; Carriol & Vader 2002; James *et al.* 2005b; King & Berrow in press). At such latitudes they have been observed to consume great quantities of jellyfish (up to 200 kg d-1 (Duron 1978)) with turtles regularly seen in areas where jellyfish are abundant at the surface (Duron 1978; James & Herman 2001) (Fig 6).

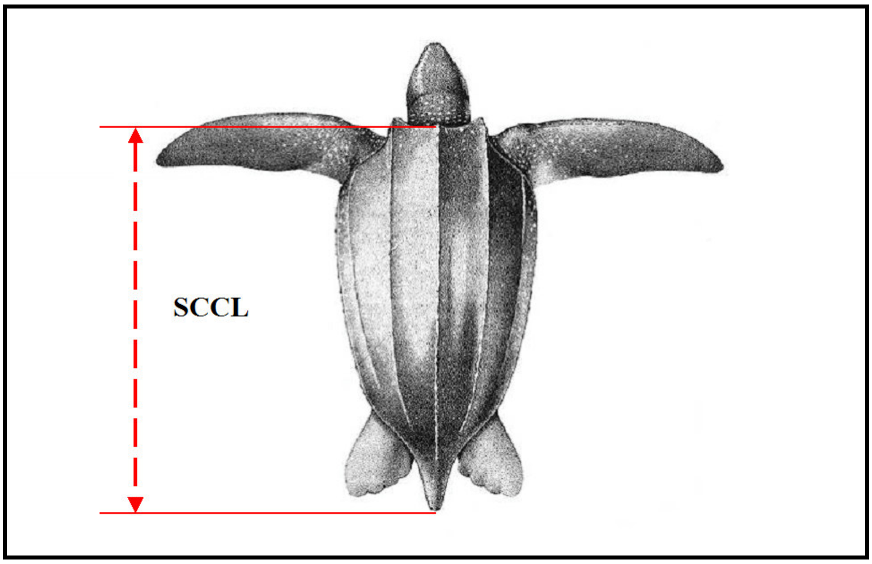

Figure 5: The Standard Curvilinear Carapace Length (SCCL), or the measurement of the curved length of the central ridge. This is the most important morphometric measurement taken and is the international standard measurement used for comparison. Adapted from Penrose (2003).

Figure 6: In temperate latitudes leatherbacks are regularly seen in areas where jellyfish are abundant at the surface. This photo was taken off west Cork where blooms of *Chrysaora hysoscella* are a regular occurrence. Note white patch (pineal eye) on forehead. @ Ian Slevin.

4. BIOTELEMETRY STUDIES AND MIGRATION

Prior to satellite telemetry, our understanding of leatherback turtle movements was based on incidental sightings (including strandings), by-catch data and recovery of flipper tags (Pritchard 1976). However, with satellite tags it is now possible to follow leatherbacks (and other apex marine predators) across entire oceans, sometimes for periods greater than a year (Luschi *et al.* 2003; Ferraroli *et al.* 2004; Hays *et al.* 2004; James *et al.* 2005c; Eckert 2006). Indeed, recent research in the Atlantic has shown that, after nesting, the majority of females head north towards cooler temperate waters (Ferraroli *et al.* 2004; Hays *et al.* 2004) (Fig. 7). This northerly movement has been attributed to individuals moving from a nesting area where food is scarce, to distant temperate waters where food is more abundant (Hays *et al.* 2004).

Pioneering studies off the coast of Nova Scotia, Canada, have documented the first round-trip seasonal migrations of leatherback turtles (Fig. 8), with individuals foraging off the coast of east Canada during the summer / autumn months before (James *et al.* 2005c). These individuals then migrate south and over-winter in waters adjacent to nesting beaches or the pelagic waters east of the Caribbean (James *et al.* 2005b; James *et al.* 2005c). Importantly all turtles tagged in Canadian waters that migrated south and then retuned the following summer, did so to within several hundred kilometres of where they occurred the previous year (James *et al.* 2005c).

However, to fully understand the migratory behaviour of leatherbacks it is important to understand the term migration. Migration is considered to be a habitual 'to and fro' movement between two areas i.e. foraging to mating grounds (Dingle 1996). These to and fro movements normally involve breeding at one end of the migratory pathway and refuging at the other end. This refuging is associated with animals escaping the seasonal harshness of the breeding area (Dingle 1996). Typical examples include songbirds migrating from Europe to Africa and back again, and whales migrating from the tropics to temperate / polar waters and back again (Dingle 1996).

However, leatherbacks have an atypical migration as they rarely breed every year. Instead, after departing a nesting beach female leatherbacks generally shuttle between temperate foraging grounds and less productive tropical over-wintering grounds for a number of years, before returning to their natal nesting ground. This atypical migration is associated with the low energy density (Doyle *et al.* 2007) and northerly distribution of their gelatinous zooplankton prey i.e. their food is of such poor quality and located large distances from their breeding grounds that they require two or more years to build up enough fat deposits to fuel reproduction and associated migrations back to the tropics.

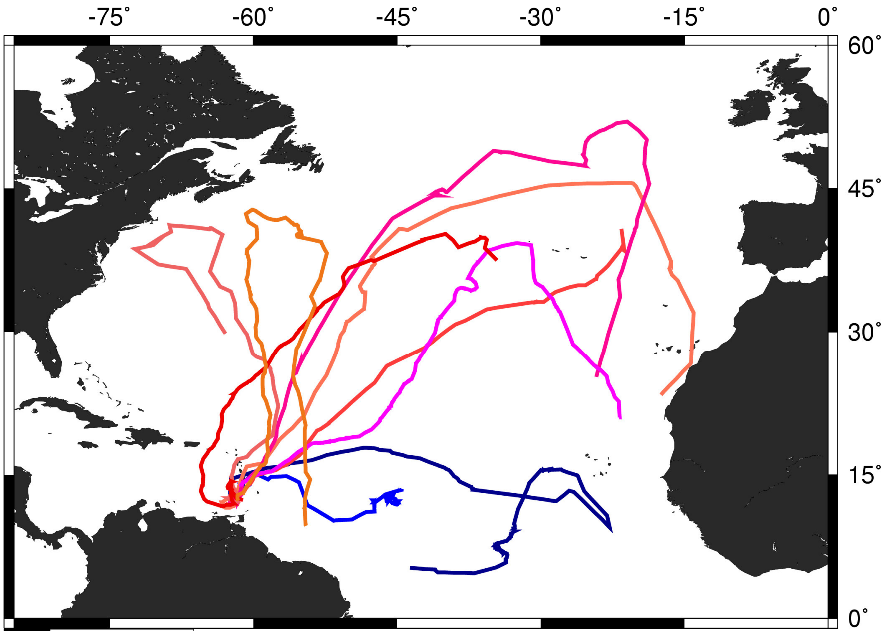

Figure 7: Movements of nine leatherback turtles tracked after nesting in the Caribbean. Figure reproduced from Hays *et al.* (2006). Average duration (time since deployment and last transmission) of tracks is ~ 1 year.

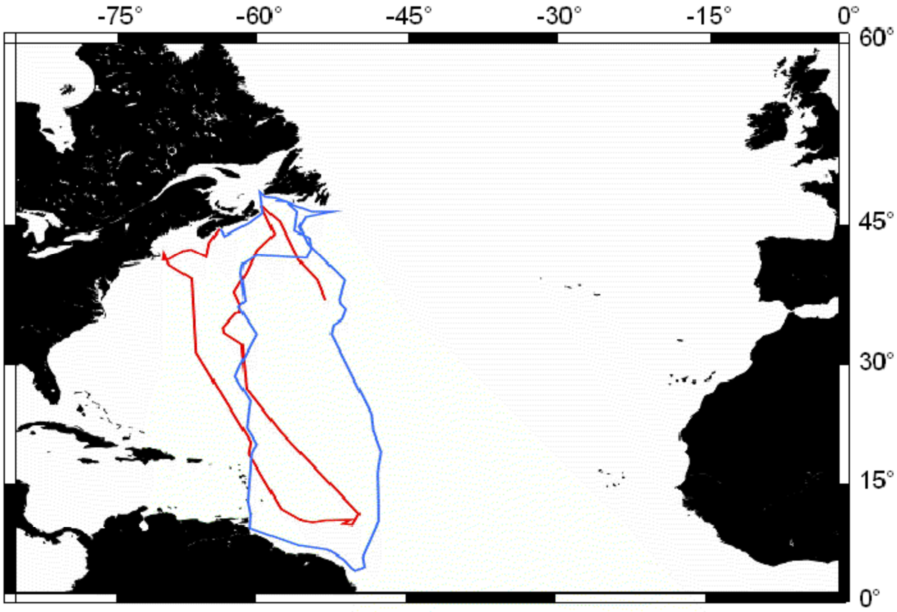

Figure 8: Round trip migrations of leatherbacks satellite tagged in Nova Scotia, Canada. Note that after departing Canadian waters turtles head south and over-winter in waters adjacent to nesting beaches (blue track) or pelagic waters east of the Caribbean (red). Adapted from (James *et al*. 2005b; James *et al*. 2005c)

5. DIET

Leatherbacks feed on gelatinous zooplankton (Brongersma 1969; Duron 1978; Den Hartog & Van Nierop 1984; Davenport & Balazs 1991; James & Herman 2001), which is an encompassing term for animals that share the convergent features of transparency, fragility, and a planktonic existence (Haddock 2004). Examples include the familiar jellyfish of the Phylum Cnidaria, but other members of this phylum are also eaten by leatherbacks such as the large Leptomedusae *Aequorea* (spp.), the chondrophore *Velella velella*, and many different siphonophores e.g. *Apolemia uvaria* and *Physalia physalis* (Portuguese Man O'War) (Den Hartog 1980).

Other gelatinous organisms that leatherbacks are known to feed on include the pelagic tunicates of the Phylum Chordata. Pelagic tunicates, as their name suggests, are the pelagic relatives of the familiar bottom living sea squirts. Examples include the salps, and the spectacular pyrosomes (or fiery bodies) that can illuminate the deck of a ship at night using their luminescence (Fig. 9).

Observations of leatherbacks actually feeding on gelatinous zooplankton are very rare and are limited to descriptions of feeding behaviour on surface-dwelling and coastally-distributed species (e.g. jellyfish). For example, Duron (1978) made repeated observations of leatherbacks feeding on large *Rhizostoma pulmo* jellyfish (Fig. 10) in the Bay of Biscay, France, and wrote that 'the turtles must be able to eat in one feeding hour a number of jellyfish, in the region of ten'. Amazingly, this sentence derived from observations made three decades ago remains the best estimate that we have of prey ingestion rates for leatherback turtles, emphasising just how little we know about the behaviour of the species away from their nesting beaches.

Figure 9: The pelagic tunicate *Pyrosoma atlanticum*, © www.medslugs.de/E/Photographers/Peter_Wirtz.htm#photos

Figure 10: The barrel jellyfish *Rhizostoma octopus*. Individuals can weigh up to 30 kg (© Chris Wilson)

Figure 11: The Lion's Mane jellyfish *Cyanea capillata* can be twice as nutritious as other Irish jellyfish (© Patricia Byrne)

6. GLOBAL CONSERVATION CONCERNS

Leatherback turtles are listed in Appendix I of the Convention on the International Trade in Endangered Species of Flora and Fauna (CITES) 1975, Appendix II of the Bern Convention 1979, Appendices I and II of the Bonn Convention 1979, and Appendix IV of the Habitats Directive. They are also protected under the Irish Wildlife Acts (1976 & 2000). However, it is not yet clear what impact, if any, these forms of protections are having on the conservation status of the leatherback.

The situation in the Pacific appears grave with as few as 2,300 adult females leatherbacks remaining (Crowder 2000; Spotila *et al.* 2000). This alarming decline may be largely attributed to loss or alteration of nesting beaches, egg poaching, and the negative interaction of leatherback turtles with pelagic long-line fisheries. Indeed, a recent study Lewison *et al.* (2004) suggested that the annual bycatch probability of leatherbacks in the Pacific is 0.63, which roughly equates to a single turtle being caught and released once every two years. Note, the probability of mortality per take was 0.08-0.27. Clearly the well-documented decline of Pacific leatherbacks raises serious concerns for the Atlantic population where bycatch rates are thought to be even higher (Lewison *et al.* 2004; Carranza *et al.* 2006).

There has been no observed decline of nesting populations in the Atlantic to date, and even in some cases there has been a dramatic increase that is probably due to an aggressive program of beach protection and egg relocation (Dutton *et al.* 2005). Nevertheless, the international nature of this problem means that the species' survival will depend on cross border collaborations focused not only on the tropical nesting beaches, but also on the more temperate feeding grounds that lay thousands of kilometres away (Crowder 2000; Hays *et al.* 2004; Lewison *et al.* 2004; James *et al.* 2005c; Hays *et al.* 2006).

7. POTENTIAL THREATS AND RISKS IN IRISH WATERS

7.1 Fixed fisheries

A small but significant threat to leatherbacks in Irish coastal waters is from fixed fisheries (i.e. fishing gear that is anchored to the bottom, or rests on the bottom) (James *et al.* 2005c; King & Berrow in press). Examples of fixed gear include the pot fisheries for lobster (*Homarus gammarus*), crawfish / spiny lobster (*Palinurus elephas*), spider crab (*Maja squinado*), brown / edible crab (*Cancer pagurus*) and shrimp species (Fig. 12). Another type of fixed gear is the gill net fishery for hake (*Merluccius merluccius*), monkfish (*Squatina squatina*) and turbot (*Psetta maxima*), although in reality many of these fisheries are mixed (i.e. they target several species) (Fig. 13). However, in terms of their potential threat to leatherbacks, it is not the actual pots or nets that pose a risk, but the ropes used to secure and mark their positions (i.e. buoy ropes and their loose ends (slack) (Figs. 14-15).

Leatherbacks that become entangled in fixed gear have a high risk of mortality, because turtles entangled at depth or at the surface during low tide will almost certainly drown (James *et al.* 2005c; King & Berrow in press). However, considering the amount of fixed fisheries in our coastal waters the number of leatherbacks caught per unit effort is very small. For example, there are currently 10,000 pots fished for spider crabs in the Maherees area alone, which is equivalent to 250-500 lines or 500-1000 buoy ropes (Fahy 2001). Yet during the years 2005/6 (when a central reporting mechanism was very prevalent i.e. INTERREG Irish Sea Leatherback Turtle Project was well established and very much in the public eye) only six leatherbacks are known to have become entangled in Irish waters (3 per year). Notably, four of these were released alive. So if we take a conservative estimate of 5000 buoy ropes around the Irish coastline, this is equivalent to 0.0006 (i.e. 3/5000) turtles caught per buoy rope. However, as James *et al.* (2005c) suggested for Atlantic Canada, leatherback-fixed gear interactions may be under reported.

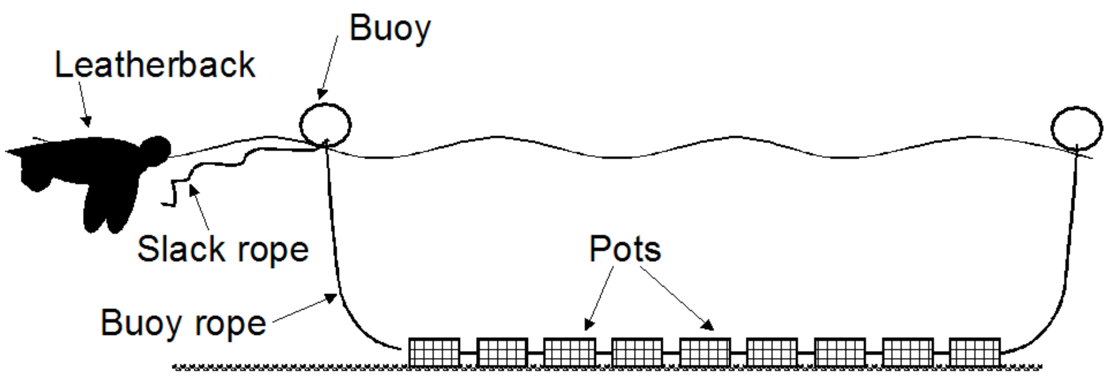

Figure 12: Schematic of leatherback interaction with pot fishery. Leatherbacks become entangled in the buoy rope or their loose ends.

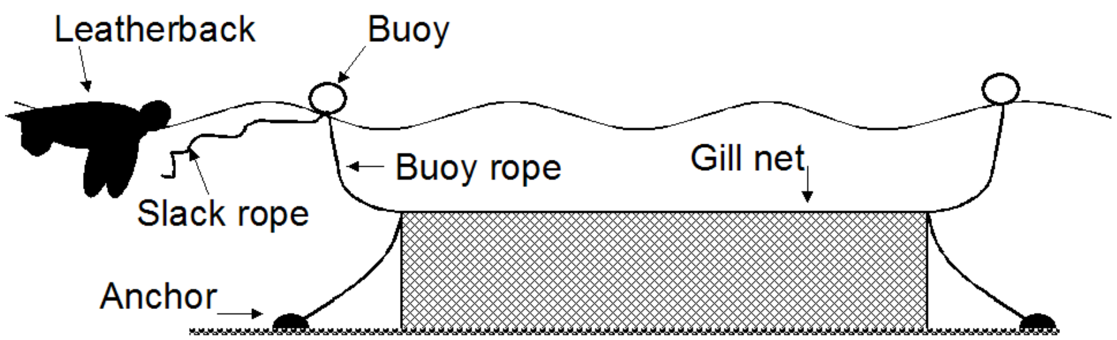

Figure 13: Schematic of leatherback interaction with gill net fishery. Leatherbacks become entangled in the buoy rope or their loose ends.

Figure 14: Leatherback sea turtle entangled in a buoy rope (unknown fishery) off the Fastnet Rock, Cork, 5th August 2006. Animal was successfully released alive. © Oliver Buckley

Figure 15: Close up of buoy rope entanglement. Note how buoy rope is tightly wound around turtle's neck. Also note the chafed skin as a result. © Oliver Buckley.

7.2 Salmon drift net fishery

The recently banned salmon drift net fishing industry probably had one of the highest encounter rates of leatherback turtles in Irish waters. King & Berrow (in press) stated that of 868 records of leatherbacks turtles recorded in Irish waters, the 'real number of actual captures, especially in surface drift nets was much higher', 'as in many cases, turtles caught in nets and released alive were recorded as sightings'. Importantly, there was a very low mortality (if any) of bycaught individuals as most turtles were very loosely entangled and could come to the surface to breathe. Indeed, during attempts in 2005 to satellite tag leatherback turtles off Smerwick Harbour (Dingle), the author witnessed two individuals entangled in salmon drift nets. One escaped almost immediately as the author arrived at the scene, and the second was very easily released after several attempts failed to attach a satellite tag to its carapace. In 2006 the author witnessed another leatherback turtle entangled in a salmon drift net off Dingle. Again this turtle was very loosely entangled in the net.

The low mortality rate associated with salmon drift nets may be attributed to several factors. When a salmon net is set, certain parts of the net become very taut because of the local currents and tides pulling on it. A turtle that swims into this vertical wall of netting just bounces off it. However, there is a very strong possibility that a turtle will become fouled when sections of the net become slack and fold back on itself. Again, it is important to stress that these nets are so light that a turtle has no problem coming to the surface to breathe. Importantly, each fisherman keeps a close eye on his nets for salmon, by periodically moving from one end of the net to the other. In this way any bycaught turtle does not go undetected for any length of time and is quickly removed and sent on its way.

7.3 Marine pollution

Marine pollution in the form of plastic bags and debris offers a real threat to leatherback turtles in Irish waters as turtles seemingly cannot discriminate between indigestible plastic debris and their jellyfish food. In July 2007, Mr Luke Harman (of University College Cork) and the author carried out a necropsy on a female leatherback found dead off Ballycotton Harbour (Fig. 16). In the small intestine they found a large piece of plastic debris (20 cm by 20 cm) and several small pieces of fishing net (Fig. 17). It is not clear whether this plastic caused the death of this turtle but its presence highlights the fact that marine pollution is a serious threat to turtles in Irish waters.

Figure 16: Largest leatherback ever measured in Irish waters (SCCL = 168 cm). This female was found floating off Ballycotton on 24th July 2007 by Peter Manning. Luke Harman and author carried out a necropsy in the Ballycotton Lifeboat Station assisted by lifeboat cox Ian Sheridan and crew member Olan Walsh. © Tom Doyle

Figure 17: Plastic bag and small bits of fishing net found in small intestine. © Tom Doyle

7.4 Other fisheries operating outside the Irish box

It is uncertain what impact other fisheries in Irish waters may have on leatherbacks. A trial to make pelagic pair trawls for albacore tuna a viable option to replace the banned tuna drift-net fisheries, recorded two leatherback turtles as by-catch with both specimens returned to the sea alive (BIM 2000). However, as the tuna catches are very sporadic and the diesel costs (to run the boats) very high, there are only 2 – 3 pairs of vessels fishing each year, and only for ~1 month during the summer. As such this fishery may have a relatively minor impact leatherback mortality.

Globally, one of the biggest threats to leatherbacks are the interactions with pelagic longline fisheries for tunas (*Thunnus* spp), swordfish (*Xiphias gladius*) and blue shark (*Prionace glauca*) (Lewison *et al.* 2004; Carranza *et al.* 2006). These fisheries generally use a monofilament polyamide longline, that can be up to 80 kilometres long, with ~ 1300 hooks baited with squid or/and mackerel per set, at a depth of 40-80 m (Carranza *et al.* 2006). There are no Irish or European vessels fishing this way and as such no longlining within Ireland's Exclusive Fisheries Zone (i.e. 200 nautical miles from shore). However, outside of this area Japanese long-liners fish for blue-fin tuna from August to November. Their fishing effort is sporadic (largely depending on where the fish are) and at times they concentrate their effort as far south as the Azores. Very little data exists in terms of the number of leatherbacks caught but considering the numbers individuals by-caught in other long-lining vessels (e.g. Carranza *et al.* (2006) documented 10 individual leatherbacks caught in one set off the coast of Guinea, West Africa), the number may be substantial. Further monitoring or obtainment of bycatch data of these vessels is required.

8. LEATHERBACKS IN THE NORTHEAST ATLANTIC

The entire North Atlantic can be considered priority habitat for leatherback sea turtles. However, within this broad geographical region certain areas have been identified as high-use areas or important habitats. For example, James *et al.* (2005c) identified the waters off Nova Scotia, Canada, as critical habitat for leatherback sea turtles, and Eckert (2006) documented four high-use areas in the north Atlantic where individuals (or many individuals) resided for long periods.

One of these high-use areas (the Iberian Peninsula and the Bay of Biscay area) is within the northeast Atlantic (NEA). More recently the first tracking results for turtles tagged off Ireland lend support to the suggestion that the Bay of Biscay region within the northeast Atlantic is a high-use area that plays a central role in the feeding ecology and trajectory of body condition for some individuals (Doyle *et al.* in review)(Fig 18). This study also demonstrated the first protracted 'summer' residence of a leatherback in the northeast Atlantic that was previously asserted from turtle sightings and strandings data (Brongersma 1972; Duron 1978; Duguy *et al.* 1980; Den Hartog & Van Nierop 1984; Pierpoint & Penrose 1999; Houghton *et al.* 2006b; Witt *et al.* 2007a; King & Berrow in press). Furthermore, analysis of these first European tracks also demonstrated the individual differences in space utilisation by leatherback turtles in the NEA. For example, Houghton *et al.* (2006b) revealed that distinct coastal 'jellyfish hotspots' in the Irish Sea provide important foraging habitat for leatherbacks in coastal waters, whereas satellite tracking revealed foraging behaviour in more open-water habitats associated with mesoscale features such as those found in the Bay of Biscay region (Doyle *et al.* in review).

An alternative approach to determine the importance of the NEA as a foraging ground for leatherback sea turtles was carried out by Witt *et al.* (2007a). They used the CPR (Continuous Plankton Recorder) Data to map the gelatinous zooplankton distribution in the NEA. They identified the European continental shelf-break and the Rockall Bank as probable foraging grounds for leatherback turtles based on the abundance of gelatinous zooplankton in these areas (Witt *et al.* 2007a). However, given the extraordinary diving capabilities of leatherback turtles, a full assessment of habitat utilisation within the NEA can only be made in three dimensions. For example, leatherbacks are capable of diving to depths > 1000 m (Hays *et al.* 2004) although long-term studies have shown the species to normally restrict dives to epipelagic waters (Hays *et al.* 2004). Overlying this general trend of epipelagic diving, leatherbacks at the northern range limit also tend to perform shallower dives and for shorter periods (Eckert 2006; Hays *et al.* 2006) which may reflect the continuous near surface distribution of gelatinous prey at such latitudes (Hays *et al.* 2006).

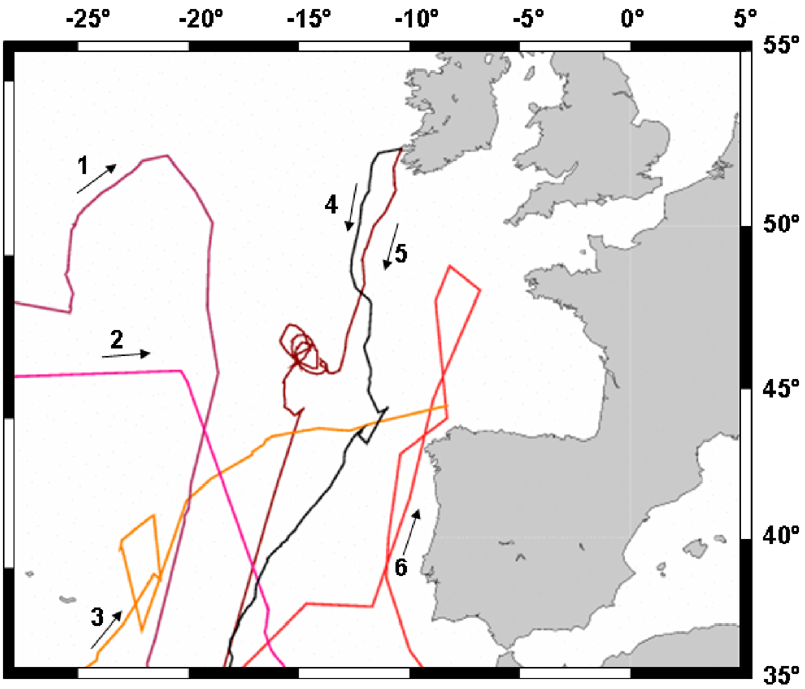

Figure 18: All known leatherback tracks with the northeast Atlantic (published & pending). 1-3: Female turtles satellite tracked from Grenada, Caribbean (see (Hays *et al.* 2006) (data to construct tracks courtesy of Prof. Graeme Hays of University of Wales Swansea). 4-5: Two turtles satellite tracked from Dingle, Ireland (4 = female; 5 = male). 6: Female turtle satellite tracked from Trinidad & Tobago (adapted from Eckert 2006). Arrows indicate direction of travel.

9. LEATHERBACKS IN IRISH WATERS

9.1 Sightings and strandings data provide unique insights

In their recent review of marine turtle records in Irish waters, King & Berrow (in press) documented 868 sightings/strandings of leatherback turtles. This dataset represents the second largest leatherback sightings/strandings dataset in Europe, after France (N =1176, see Witt *et al.* 2007a). As such, a considerable responsibility of ensuring their protection within European waters may lie with Ireland. However, caution must be stressed when attempting to elucidate any patterns from this dataset, as there are many inherent biases. For example, most turtles were sighted within 12 nautical miles (~ 22 km) of the coastline, with a strong bias towards three counties: Cork (N = 378), Kerry (N = 113), and Donegal (N = 109) (King & Berrow in press).

The coastal bias probably reflects the 'distribution of observers rather than turtles' (King & Berrow in press), as it very probable that large numbers of leatherbacks occur further offshore (James *et al.* 2005c; Eckert 2006; Hays *et al.* 2006; Witt *et al.* 2007a; Doyle *et al.* in review). Furthermore, the observer effort varies greatly between counties i.e. 60 % (N = 229) of leatherback sightings in county Cork came from a single observatory (i.e. Cape Clear Observatory) that has an almost constant 'sea watch'. No other county has comparable observer effort.

Another important consideration is that 'many of the leathery turtle records reported were observed by fishermen and most [of these] were of turtles entangled in fishing gear' (King & Berrow in press). Subsequently, the large numbers observed in counties Cork, Kerry and Donegal may reflect the large fishing effort in these areas. A fourth bias may stem from the actual sourcing of records, i.e. the vast majority of leatherback records were actively sought by Gabriel King who approached fishing communities around Ireland. Indeed, many peaks in sightings reported are evident: 1984-1985, 1990, 1993, most of which can be attributed to an increase in recording effort by King rather than actual peaks in the abundance of turtles in Irish coastal waters.

Nevertheless, the high number of leatherback sightings reported by King & Berrow (in press) and others, documents the importance of Irish neritic waters for foraging and transient individuals, from which some general statements can be drawn. Essentially, sightings of leatherbacks can occur anywhere in Irish coastal waters, but are more likely to occur in higher numbers off the south and west coasts of Ireland because of their facing aspects (Witt *et al.* 2007a). Underlying this general pattern (and accounting for various biases e.g. fishing effort, coastal population, and boating activity) there is a greater probability of occurrence in areas where jellyfish regularly occur in high concentrations e.g. off Sauce Creek (Brandon Head) (pers ob) and Rosslare Harbour (see Houghton *et al.* 2006b) for the importance of jellyfish hotspots). In terms of Irish oceanic waters, a recent study has suggested that the European continental shelf edge (particularly the Rockall Area and Porcupine Bank and Porcupine Bight) may potentially support appreciable densities of foraging leatherbacks because of the high abundance of gelatinous zooplankton located there (Witt *et al.* 2007a).

9.2 Satellite tracking leatherbacks from Ireland

Elucidating migratory pathways is a key component of any conservation strategy. This is particularly true for widely roaming marine species such as leatherback sea turtles that may utilise entire oceans. Unfortunately, limited information exists regarding the movements of individual leatherbacks to and from the seas off Europe's northwesterly fringe. The reasons are twofold: 1) individuals that are satellite tagged on their tropical nesting grounds (note: females only) generally do not have enough time to travel to European waters before decreasing food availability/light levels/sea temperatures drives them south again. And, 2) tracking individuals from Europe requires capture and attachment of satellite transmitter at sea, which is difficult to perform (James *et al.* 2005a; Doyle *et al.* in review). However, pioneering studies in Nova Scotia, Canada, have shown that this is possible (James *et al.*

2005a; James *et al.* 2005c). In 2003 the INTERREG Irish Sea Leatherback Turtle Project was established as a collaborative venture between the Swansea University and University College Cork. A key objective of this project was to satellite tag leatherbacks in Irish waters in a similar vein to the Nova Scotia study.

During the INTERREG Irish Sea Leatherback Project one turtle was successfully tagged in 2005 (referred to as T1). Building on from the success of this project, a National Parks and Wildlife Service / Marine Institute funded initiative provided the necessary funds to tag another turtle in 2006 (T2). Both turtles were fitted with satellite tags (Satellite Relay Data Loggers [SRDLs] manufactured by the Sea Mammal Research Unit, St Andrews) close to Dingle (Daingean Uí Chúis) (52.24 °N, 10.30 °W) on the west coast of Ireland. Both turtles became entangled in fishing gear prior to tag attachment. The tag was attached to T1 using a harness system (Fig. 19), whereas for T2 the tag was attached directly to the carapace (Fig. 20). Both tags were attached under license from the National Parks and Wildlife Service of the Department of the Environment, Heritage and Local Government. Importantly, only with the help of the local salmon fishing community of Chorca Dhuibhne (especially Pádraig Franck O'Súilleabháin) and Dingle Oceanworld Aquarium, was it possible to tag these turtles.

T1 quickly left the west coast of Ireland (01/09/05) and immediately headed southwards for approximately 20 days. Off the northwest coast of Spain, T1's movement changed from directed motion to an erratic motion for a period of approximately three weeks before heading south again (Fig. 21). On 10/11/05, 350 km northeast of Tenerife, regular transmissions ceased. Thereafter, analysis of the intermittent locations revealed that T1 passed 160 km west of Mauritania, reaching her furthest point south on the 03/03/06, 400 km south-south-west of the Cape Verde Islands (Fig. 21). Although limited locations were received, T1 spent approximately 3 months in West African waters. From her furthest point south, she swam along a very directed path towards Canada, at which point we received a final Argos location on the 07/07/06, 1300 km southeast of Newfoundland (see Doyle *et al.* in review, for more details).

Figure 19: Illustration of harness attachment method. a-c) Author and Dr Jonathan Houghton of Swansea University placing harness on T1 in Dingle Oceanworld Aquarium. d) T1 being released in Cuas Harbour, Dingle (animal was removed from aquarium and placed upon a trailer to facilitate release into sea).

Figure 20: Illustration of direct attachment method. a-c) Top, side, and bottom view of SRDL/Baseplate attached to a vertical pole (60 mm diameter, and representing central keel of turtle) to demonstrate direct attachment method prior to deployment. Note cable ties run through baseplate and around the pole, with two at the anterior end and one at the posterior end. When cable ties are fully tightened the rubber tubing tightens around the pole (or keel) preventing any side-to-side movement of SRDL/Baseplate. Length of SRDL/Baseplate is 27 cm and weight (out of water) is 1 kg. d) Drilling 6.5 mm hole into right side of central keel of a leatherback turtle. Note drilling angle and that a similar hole was drilled into the central keel from the left side, with the two holes meeting in the middle. Cable ties are first fed through one hole in the baseplate, then through a hole in the keel,

before looping the cable tie back into the baseplate where it is fastened (see Fig. 20 a - e) Frame shot from video of Turtle T2 swimming at night after release. SRDL/Baseplate attached closer to the anterior end of carapace. Adapted from Doyle *et al.* (in review).

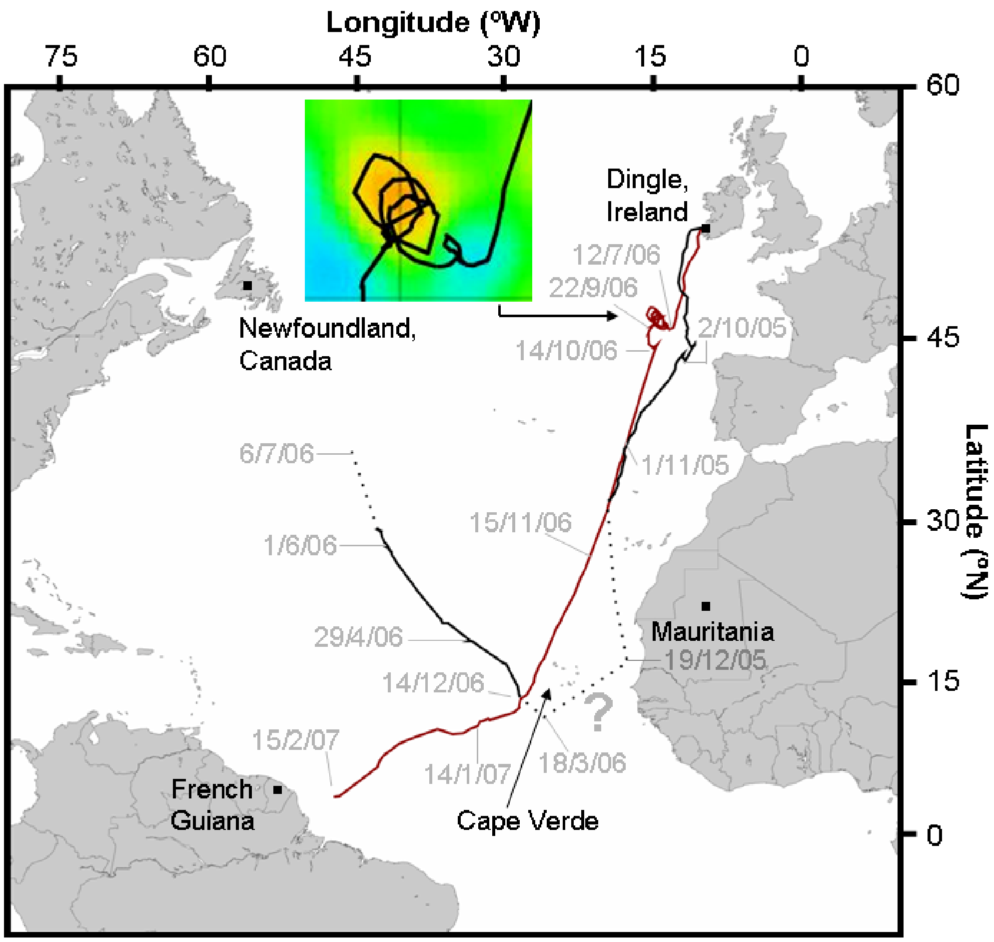

Figure 21: The complete track of T1 leatherback (female, SCCL = 153 cm, tagged 01/09/05) (black track with dotted sections) & T2 (male, SCCL = 166 cm, tagged 29/06/06) (red track). Dotted section denotes section of female track where locations were intermittently received. T1 spent 3-month period between waters west of Mauritania and Cape Verde. T2 resided for 66 days in a cyclonic mesoscale feature (yellow area), with the turtle looping around in the same direction (clockwise) three times (see inset). Male turtle preformed deepest dive ever recorded by a reptile (1280 m) just south west of Cape Verde. Adapted from Doyle *et al.* (in review).

T2 quickly left the area where he was tagged, and travelled south (Fig. 21). Just over 11 days after release the turtle was west of the Bay of Biscay, 700 km from the release point. T2 then remained in the same general area for the next 66 days, making large loops in a clockwise motion. Analyses of altimetry imagery confirmed that T2 was in a cyclonic feature that rotated clockwise (Fig. 21). T2 completed 3 circum-rotations around this mesoscale feature taking approximately 20 days for the turtle to travel once around the feature. On the 14/10/06, T2 swam south-southwest covering approximately 3200 km in an almost perfect linear direction before reaching Cape Verde on 04/12/06. After Cape Verde, T2 travelled southwest towards the coast of South America and was only 700 km from Yalimapo Beach (a major nesting beach) in French Guiana when transmission ceased (see Doyle *et al.* in review) for more details).

Although only a sample size of two, when compared with previously published data (Ferraroli *et al.* 2004; Hays *et al.* 2004; James *et al.* 2005b; James *et al.* 2005c; Eckert 2006) these tracks highlight the large variation in performance (e.g. distance travelled and route taken) (Dingle 1996) among the North Atlantic leatherback population. For example, a leatherback foraging off Ireland will have travelled ~twice the distance as a leatherback foraging off Nova Scotia. So although leatherbacks are characterised by a low genetic diversity (Dutton *et al.* 1999), there is clearly a large phenotypic expression of those genes, with turtles from the same nesting beach capable of foraging in widely different parts of the North Atlantic. This differential migration (Dingle 1996) has important implications for conservation of this species, as preserving phenotypic diversity is paramount to species survival.

In terms of collecting data with Irish waters, unfortunately neither turtle remained in the immediate vicinity for any length of time. However, from a regional conservation point of view, knowledge of turtle movements to and from Ireland may be critical in helping to define important areas where conservation measures need to be implemented. Therefore one of the most important findings from these tagging studies has been the documentation of southerly movements towards the nesting beaches and over wintering areas. Indeed, the movements and long term residency of T1 off West Africa suggests that this area may be a very important area where leatherbacks over winter during their sabbatical years (i.e. when not returning to their nesting beaches).

In terms of identifying the origin of turtles that occur in Irish waters, the track of T2 has certainly suggested that the major nesting beaches of French Guiana and Suriname are a likely candidate. Unfortunately, T2's track ended just short of this rookery (Figure 21); however, his time of arrival would have coincided with the onset of the breeding season (James *et al.* 2005a). In other words he was arriving just as the females where beginning to arrive. Indeed, James *et al.* (2005a) found that male leatherbacks from Nova Scotia travel south and arrive at nesting grounds before females do. Whether T2 was doing likewise we will never know but his track certainly shows that male turtles foraging off the coast of Ireland during the summer months are capable of doing so.

9.3 Aerial surveys provide 1st relative abundance estimates

During 2003-2005 (June-October), (Houghton *et al.* 2006b) carried out aerial surveys throughout the Irish and Celtic Seas to determine the abundance (order of magnitude) of leatherback sea turtles and their jellyfish prey. During the surveys, four live and one dead leatherback turtle were observed from the air with two of the live animals found within 1 km of *Rhizostoma octopus* aggregations. These sightings equate to 0.25 leatherbacks per 1000 km of track flown (or 0.06 leatherbacks per 100 km^2) (Doyle *et al.* in review).

When compared with comparable estimates from coastal foraging grounds in the northwest Atlantic, this value of 0.25 provides some useful insights on the density of leatherbacks in Irish waters (and indeed, in the North Atlantic). For example, Shoop & Kenney (1992) found 6.85 leatherbacks per 1000 km of track flown over continental shelf waters of Nova Scotia to Cape Hatteras (NWA); Murphy *et al.* (2006) found 40.00 leatherbacks per 1000 km of track, in nearshore waters off South Carolina (NWA); and Brown and Tobin (1999) (from James 1999) found 5.11 leatherbacks per 1000 km of track, Nova Scotia (NWA). Considering these values, the density of leatherbacks foraging in Irish (and UK) coastal waters is probably less than that of coastal foraging areas in the NWA.

This large difference in density estimates may be largely attributable to simple geography / location i.e. the NEA is much further away from the major nesting centres in the tropics than the NWA (James *et al.* 2006). Therefore, turtle migrations to Irish waters may incur a higher energetic cost (Doyle *et al.* in review) and subsequently be heavily selected against unless there are some favourable advantages. For example, if there was a greater abundance of gelatinous zooplankton in the NEA than the NWA, any extra energy expenditure incurred when migrating to the NEA may be recouped upon arrival.

However, at present there are insufficient data available regarding the profitability of the different foraging grounds.

9.4 Abundance of leatherbacks in Irish waters

Providing an actual estimate of the number of leatherbacks foraging within Irish waters is difficult as their numbers may be extremely low (Houghton *et al.* 2006a; Houghton *et al.* 2006b). There will also be an inherent variability in leatherback numbers between years as a result of long-term population cycles (Rivalan *et al.* 2006), differential residency of turtles (Doyle *et al.* in review) and variations in prey abundance. Furthermore, an important consideration to bear in mind is climate change and its associated effects on species 'bioclimatic envelopes' i.e. species distributions and abundances are largely determined by their physiological tolerances (Genner *et al.* 2004).

For leatherback sea turtles, McMahon & Hays (2006) have shown that their northerly distribution limit can be encapsulated by the position of the 15°C isotherm (i.e. leatherback occurrence in Irish and UK waters is primarily driven by water temperature). Importantly, the position of the 15°C isotherm has moved northwards by 330 km over the past 20 years (McMahon & Hays 2006), suggesting that the leatherback bioclimatic envelope has expanded. As the position of the 15°C isotherm will vary between years, the suitability of Irish waters for foraging leatherbacks will vary, with good and bad years in terms of abundance. Considering recent warming trends there may be an overriding trend towards an increase in leatherback abundance (Kintisch 2006).

Using leatherback sightings as an index of abundance can be informative, however, variability in the reporting mechanisms, their consistency and effort, can mask any real trends (King & Berrow in press). Determining if two sightings were of the same animal or two different animals can also add confusion to this index. Therefore, the aerial survey estimates provided by (Doyle *et al.* in review) may represent the most realistic estimate of leatherback activity in Irish waters to date. However, their value may be an underestimate of actual leatherback abundance, as their surveys primarily focused on the Irish Sea where leatherbacks may not be as numerous as other areas (Witt *et al.* 2007a; King & Berrow in press) and submerged animals would not have been spotted (Houghton *et al.* 2006b).

With the above caveats in mind, and using the abundance estimate provided by Doyle *et al.* (in review), the number of leatherbacks in Irish territorial waters (12 nautical miles from coastal baseline) during a summer day is probably around 25 (i.e. [39,000 x 0.06]/100)[1]. If you extend this calculation to include Ireland's designated marine limits (652,000 km^2, which includes Ireland's continental shelf waters) (Bartlett 2004), the number of leatherbacks during a summer day may be as many as 400. However, there will be much variation around this estimate considering population estimates for other species that occur in low densities (i.e. many beaked whales have CV (coefficient of variation) values of 0.80 and upwards, which means that any estimate will have huge errors associated with it). If we apply the same CV value of 0.80 to our estimate of 400 animals this will give a range between 80 and 720 leatherbacks during a summer day.

In terms of the actual number of leatherbacks that pass through or use Irish waters each year, there is great uncertainty. How long individual turtles remain resident in Irish waters and how much time they spend at the surface are important criteria for estimating population abundance, yet these data are scarce (Doyle *et al.* in review). However, considering that individuals may spend periods of two months or more in coastal/shelf waters and other areas (James *et al.* 2005c; Eckert 2006; Doyle *et al.* in review), and that turtles spend as much as 41 % of their time at the surface (James *et al.* 2005b) the number of leatherbacks passing through or residing in Irish waters each year (using our aerial survey estimate) is probably at most in the very the low thousands, which may be equivalent to 2-5 % of the

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[1] Area of Irish Territorial waters (km^2) x density estimate of leatherbacks (from Doyle et al in review)/100

Atlantic population. Future aerial surveys and more dedicated observations from ships of opportunity in-conjunction with concerted coastal observatories may improve these estimates. We are still far from determining the actual numbers of leatherbacks that visit Irish waters in any one-year, particularly outside coastal waters.

10. SUMMARY & RECOMMENDATIONS

Leatherback sea turtles are a part of our natural heritage, and have probably been visiting Irish waters for millennia. Considering recent trends of warming seas, leatherbacks are likely to increase in abundance and occupancy in Irish waters (Kintisch 2006; McMahon & Hays 2006) with a probable concomitant increase in interactions with fisheries (particularly fixed fisheries). In order for Ireland to comply with the Habitats Directive (Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora), it must ensure the favourable conservation status of all Annex IV species (which includes leatherbacks). Before this can happen, a better understanding of leatherback numbers, distribution patterns and feeding ecology is required.

Dedicated observers on ships of opportunity (ShOps) in conjunction with targeted aerial surveys and concerted 'coastal observatories' may provide an important tool for assessing leatherback abundance, distribution and seasonality. This combination of methodologies will allow for a more robust assessment of leatherback abundance, data that is vital for ensuring favourable conservation status. Furthermore, in line with current policies and government agendas (i.e. Marine Institutes Sea Change) leatherback abundance estimates may provide a very useful indicator of climate change.

Increased monitoring of sightings and strandings is paramount as such data is necessary to provide information on the seasonality, abundance and behaviour of leatherbacks in Irish waters (Houghton *et al.* 2006b; Witt *et al.* 2007b). Also, stranded individuals provide a unique opportunity to examine questions regarding the demographics of leatherbacks in Irish waters, but before this can happen it is critical that suitable necropsies are carried out. For example, correct identification of sex, collection of morphometric data (wet weight, SCCL etc), collection of femur and scleral ossicles samples for skeletochronology, and DNA samples to identify natal nesting beaches. Perhaps more importantly, recorded strandings provides a minimum number of leatherback mortalities in Irish waters. If this number exceeds a defined threshold it may indicate that the favourable conservation status of leatherback sea turtles in Irish waters is at threat.

Further tracking of individuals using satellite telemetry will help address key questions regarding site fidelity to the northeast Atlantic (return migrations), foraging behaviour, residence times, surface behaviour, and behavioural plasticity of the species. As telemetry studies are unquestionably one of the best methods for acquiring vital life-history data on large on cryptic species that do not lend themselves to observation, it is important to assess potential new methods for tagging leatherbacks in Irish waters following the recent ban of salmon driftnet fisheries. For example, targeted use of decommissioned salmon boats (as research platforms) off the coast of Dingle may provide a unique opportunity to tag more turtles and gather weight measurements of live animals (whilst precluding salmon i.e. the drift nets can be deployed with a much larger mesh size that will catch turtles but not salmon). Such deployments would build on the success of the INTERREG Irish Sea Leatherback Turtle Project and will continue to place Ireland firmly at the centre of international efforts to conserve this endangered species.

As we are still left with limited information regarding the foraging ecology of leatherbacks (especially prey ingestion rates), much more data are needed on the distribution and abundance gelatinous zooplankton species (e.g. salps, siphonophores and jellyfish). This is particularly true for oceanic waters that may have higher numbers of leatherbacks. However, even such basic data as depth distribution of jellyfish in the coastal waters may provide important data for examining foraging behaviour. With evidence suggesting that jellyfish are increasing globally possibly as a result of climate change, turtles may benefit too, as they will have greater access to their jellyfish food (Kintisch 2006).

Finally, assessing trends of nesting populations in the tropics may be the best method of assigning conservation status to leatherbacks as any decrease or increase in the number of females nesting is more easily observed than population changes at sea. The current National Parks & Wildlife Service funded work in Gabon (see: www.mayumbanationalpark.com) is an excellent example of how the Irish Government is meeting its responsibility of ensuring the future survival of this species.

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