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Impact of Nondegradable Marine Debris on the Ecology and Survival Outlook of Sea Turtles

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Sea turtles of all kinds are peculiarly prone to eat plastic scraps and other buoyant debris and to tangle themselves in lines and netting discarded by fishermen, and records of such mishaps have increased markedly in recent years. Advances in our understanding of the developmental ecology of sea turtles shed new light on the impact of buoyant wastes on the juvenile stages. The initial developmental stages of all species are passed in the open sea. In the case of the loggerhead *Caretta* this period of pelagic life is likely to include 3–5 years of planktonic open-ocean travel, which may involve multiple transatlantic crossings. During this time both the young turtles and their buoyant food are drawn by advection into fronts (convergences, rips, driftlines) and the same process also brings in and aligns persistent plastics and lost fishing gear. This effect exacerbates survival problems for sea turtles that are dependent on driftlines for their food supply or shelter.

Two recent advances in our understanding of sea turtle ecology have made the survival prospects of the group seem even less favourable than when the species were first recognized as threatened and endangered (Carr, 1986a). One is the dependence of the young stages on convergences—fronts, rips, driftlines, into which they and their food are drawn by downwelling. The other is new evidence that the juvenile pelagic stage may last for a period of 3–5 years, according to the species. During this time of early development the young turtles are passive migrants in driftlines in the surface water of the open sea. Here they come into intimate contact with buoyant debris (Carr, 1984, 1986a), and there is massive evidence that entrapment, entanglement, and impaction of the alimentary canal by ingested plastics have become major threats to sea turtle survival (Balazs, 1985).

For some years a principal research goal of the sea turtle programme of the Caribbean Conservation Corporation at Tortuguero, Costa Rica has been to fill gaps in knowledge of the developmental ecology and migration of marine turtles. Until lately the earliest stages were shrouded in mystery so deep that the period was spoken of as the 'lost year' (Carr, 1984). Eventually, however, investigations showed that post-hatchlings pass their initial period of development as surface-dwelling plankton, in the borders of currents and eddies into which they are drawn by advection. This same force mobilizes and aligns buoyant pollutants; and the ecological implications of this have not been given the attention they warrant.

The fluid dynamics of advection and diffusion are well understood by physical oceanographers; and the role of currents, gyres, and rings in transporting debris is well documented (Galt, 1985); but the gathering action of downwelling in worsening the effect of pollutants on animals in driftline habitats has had little attention from marine ecologists. Neglect of this fundamental aspect of marine ecology can probably be attributed to the formidable arithmetic of advection and diffusion. But differential equations are not needed to understand that the driftlines, slicks, rips, and windrows that form along fronts, large and small, are an essential feature of the surface water of the ocean (Fig. 1). They are the hedgerows of the epipelagic environment. The importance of these zones as marine habitat is well known to pelagic fishermen and to a scattering of marine zoologists (Ashmole, 1971), but the role of downwelling in the ecologic organization of the surface waters of the ocean has been generally overlooked. With the present volume of biologically injurious flotsam in the sea, and the probability that the spread of these materials will increase, it seems appropriate to examine the ecological threat posed by persistent plastic materials in driftlines along which biologic activity is at a maximum.

Role of Convergences in the Life History of Sea Turtles

In a relatively stable driftline, such as those that form at the borders of major currents and gyres, the ecologic contribution of flotsam is threefold. For one thing, it increases diversity by providing a substrate for the pelagic larvae of sedentary animals. Bryozoa, barnacles, pelagic crabs, and many other species of invertebrates attach themselves to objects floating in the front, including trees and driftwood, weed rafts, and increasingly today, tar clots and plastic objects. Besides the passively mobilized pelagic eggs and planktonic animals, other species come in actively. The first of these are the shelterseekers, which are attracted to any solid floating object. These then become bait for predaceous fishes and sea birds. Commercial fisheries for tuna, billfish, and the other big cursorial species regularly exploit the tendency of their quarry to aggregate at fronts, where they are attracted by the schools of bait species that form there. For centuries artisanal fishermen have known that flotsam attracts fish and that it accumulates in driftlines. Sport fishermen also regularly go out to the rips to fish for cobia, dolphin, and various other species.

Hatchlings of sea turtle populations in the range of Sargasso weed usually move directly into an initial habitat in which both food and shelter are provided by the algal mats (Fig. 2). When the young turtles swim seaward, as they always do, they eventually encounter a convergence along the inner edge of either a border current or a longshore eddy. If sargassum occurs in the region, rafts will be strung out in this convergence. Because sargassum has a specialized invertebrate fauna it provides both shelter and a food supply. Off many nesting shores, however, perhaps off most, sargassum is not present. But even there, downwelling at the fronts

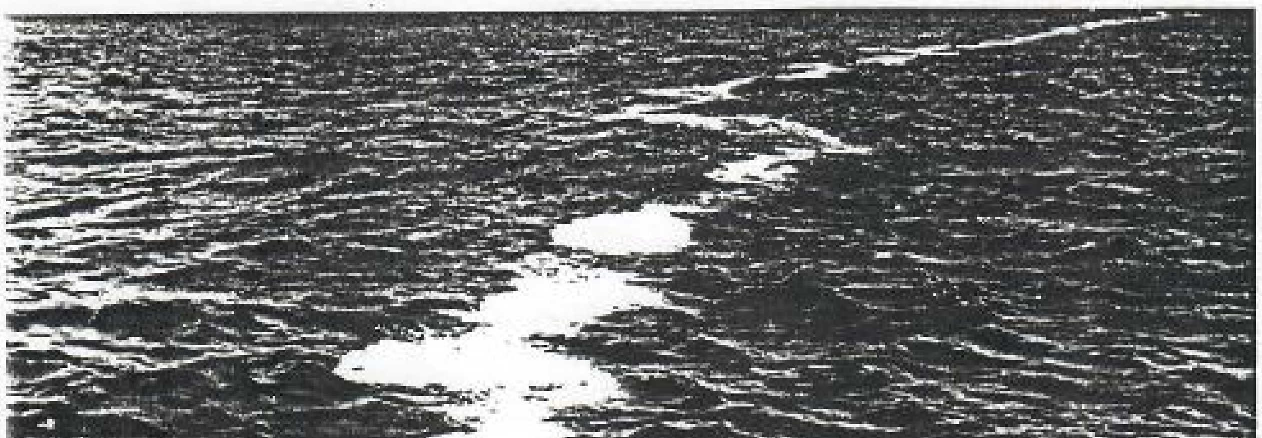

Fig. 1 Sargassum line off Tortuguero, Costa Rica, at the front between the South Equatorial Current and Southwest Caribbean Gyre. (Lynn Fowler photo.)

assembles and aligns any organisms that float or are able to control their buoyancy at a given depth, including the macroplankton that hatchlings feed on.

In most cases the pelagic stage of sea turtle development ends prior to maturity and a transition to benthic habitats occurs. Two of the eight named species, however, the leatherback and the olive ridley, appear to be mainly epipelagic foragers even after reaching maturity. When Atlantic leatherbacks leave their main nesting shore in northern South America, they follow the edge of the Gulf Stream northward along the US coast, sometimes as far as Cape Cod and beyond. The attraction is the seasonal abundance of jellyfish there.

The other species that characteristically lives in the open sea even after reaching sexual maturity is the olive ridley (*Lepidochelys olivacea*). Observations at sea, and recent tag-recoveries, indicate that olive ridleys may migrate between their sites of mass nesting in Mexico and Costa Rica, and feeding grounds as far south as Ecuador, probably foraging on macroplankton in longshore convergences along the way. Mature Atlantic green turtles (*Chelonia mydas*) and loggerheads (*Caretta caretta*) also feed along rips when jellyfish are abundant; but more characteristically they, like the hawksbill (*Eretmochelys imbricata*) and Kemp's ridley (*Lepidochelys kempi*), forage on the bottom.

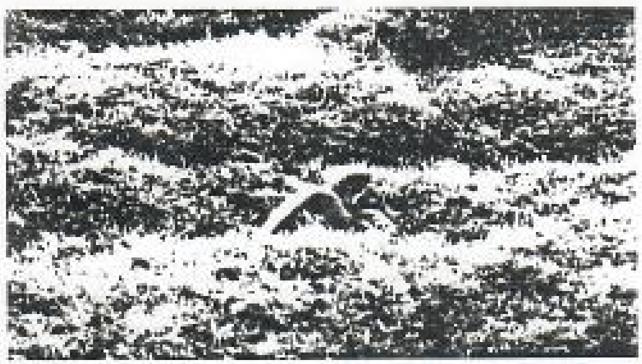

Fig. 2 Pelagic stage green turtle in massive sargassum raft off the tip of Little Bahama Bank. (Lisa Bibko photo., R/V Cape Florida Cruise.)

Recent evidence indicates that the pelagic developmental stage is much longer than was once supposed. Pacific loggerheads are not seen again for at least 4 yr after leaving the nesting shore in Natal (Hughes, 1978). It now seems clear that the development of the Atlantic loggerhead may involve a comparable period, and that during this time the young turtles may make one or more passive trans-Atlantic migrations in the Gulf Stream system (Carr, 1986a, b).

The existence of this extended epipelagic period is supported by new age-group data from the Azores. As part of an effort to trace the developmental migrations of American sea turtles, I graphed carapace-length distribution in the three developmental stages of *Caretta* that occur in American waters. In the histogram (Fig. 3) a conspicuous gap separated the smallest turtles of the benthic subadult class which is abundantly represented along the coasts of northeast Florida and Georgia, and the biggest pelagic post-hatchlings and early juveniles that occur in offshore US waters. A little later, I received a set of measurements of little loggerheads from collaborators in the Department of Oceanography, University of the Azores, and the size-range in these makes a trans-Atlantic developmental migration by West Atlantic *Caretta* seem a virtual certainty. The carapace lengths of all 82 turtles tagged range within the gap in the age-class histogram (Fig. 3). That at least some young American loggerheads go through part of their development in the East Atlantic now seems clearly indicated.

The little Azores loggerheads were taken on Princesse Alice Bank by tuna fishermen who say the turtles regularly show up there in the summer months. To bring them home within the size-range that would fill the gap in the US data, would require at least two years' additional growth. By the most direct recirculation route back to US waters in the Gulf Stream system they

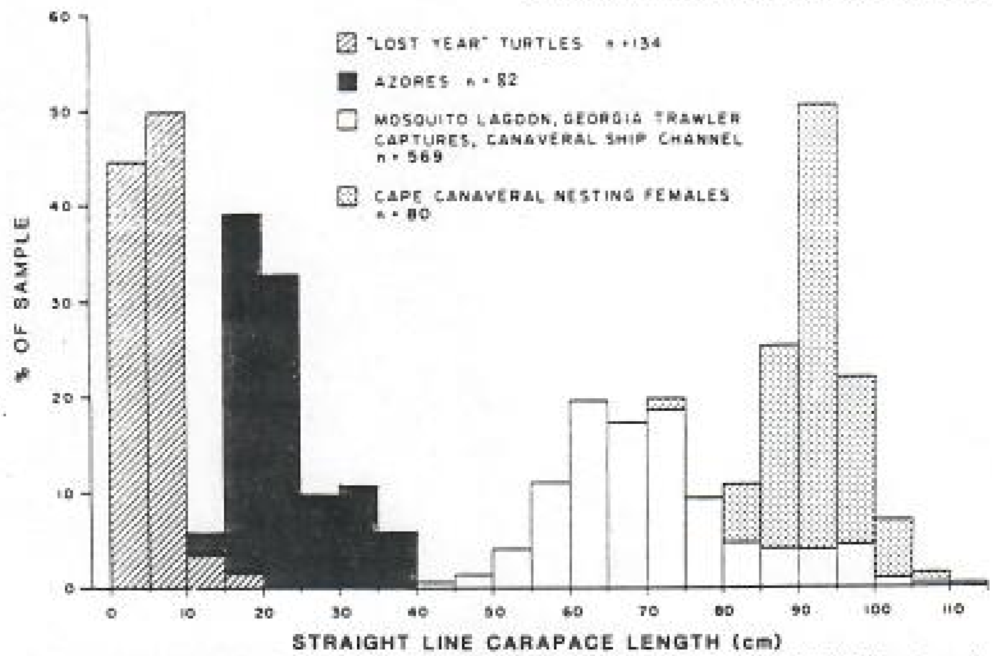

Fig. 3 Shell-length distribution in three size groups of American loggerheads (Carr, 1986b; Hilstead *et al.*, 1977; Ehrhart, 1980; Mendonca & Ehrhart, 1982; Ogren & McVea, 1982) and one East Atlantic group (unpublished data from the Department of Oceanography, University of the Azores).

would return far too soon. To consume the time for the necessary growth, either repeated crossings in the main system must be made, or time must be passed circling in rings and minor eddies along the way.

Twenty years ago the latter supposition might have been rejected on the grounds that fronts, rings, and small eddies were too few in the open sea to provide the resources for protracted transoceanic travel by an air-breathing, surface-feeding migrant. Recent observations made from the Space Shuttle shows that the ocean teems with fronts of varied origin, size and configuration (Scully-Power, 1986). A growing body of oceanographic data from the Atlantic (Kerr, 1985) indicates that small eddies, recognizable by their salinity or oxygen content, occur far more often, last longer, and travel farther through the ocean than has been realized. About 11 cold-core rings (enclosing shelf water) and about three warm-core rings (surrounding Sargasso Sea water) may occur at any given time in the North Atlantic—the former south and east of the Gulf Stream, the latter to the northward of the Gulf Stream (Kerr, 1977). Some small eddies are being traced back to distant places of origin. According to McDowell (1986), shallow eddies detected 800 km southeast of Cape Hatteras had originated 4500 km to the east toward Gibraltar. Others had come from far down to the southeast in the mid-Atlantic Gyre, or 500 km to the east in the Gulf Stream. Sometimes one of these small eddies splits and spawns two new rings that continue separate life (Lindstrom *et al.*, 1986). It is significant that these newly discovered structures occur in precisely the region where they are needed to account for the growth of the Azores migrants to the size of the West Atlantic subadults.

When the geographic distribution of size classes in other species of marine turtles is better known it seems probable that patterns of long distance developmental travel comparable to that of the Atlantic loggerhead will be revealed. This new aspect of the developmental ecology of the species increases the biological interest of the animal, but it obviously adds gravity to the problem of marine pollution.

Effects of Debris on Sea Turtles

Besides providing useful resources, the convergences may become, in a way, a trap for marine life. In addition to the food and shelter, the animals that come in find themselves in close association with lethal floating objects and toxic substances. Persistent plastics are often the most conspicuous visible flotsam in a rip, and ghost gear and tar pellets are also often present. Juvenile sea turtles are peculiarly vulnerable to the hazards of this new breed of driftline because the fronts are their essential habitat and the only source of the resources that make life possible during their period of pelagic development.

The tendency of marine animals to investigate, pry into, or eat floating debris is well known. Many years ago, Dr. E. W. Gudger published a series of short papers reporting cases in which fishes had been trapped, entangled or otherwise hurtfully involved with human artifacts of various kinds (Gudger, 1922, 1928, 1929, 1937, 1938a, b). In those days plastics were barely known. Fishing gear was made of degradable vegetable fibre, and the agents of injury to marine life were mostly rings or other objects made of perishable metal or rubber. Nevertheless, the Gudger anecdotes made it plain that fishes will eat inedible objects, or poke their heads into rings, tins and the like. It has recently become disturbingly clear that turtles, sea birds, and seals have the same hazardous tendencies.

When heavy seas wash the Florida East Coast in the fall, little loggerheads, dead or moribund, are often thrown ashore, sometimes in great numbers. The stomachs of the dead ones often contain pellets of tar and the ubiquitous plastic beads that are delivered to the sea by the millions in industrial waste water. Both the tar pellets and the beads are suggestively similar in size and shape to sargassum floats, and this likeness may account for the turtles' misguided feeding. Plastic beads are ubiquitous in surface waters of the oceans. In 1985–1986 they were particularly abundant in the West Caribbean Gyre, littering the Tortuguero nesting beach of the green turtle in Costa Rica like little hailstones. The southern arc of this gyre, which transports the Tortuguero hatchlings into their pelagic habitat, is increasingly cluttered with plastic debris of every conceivable kind, and of untraceable origin.

The special susceptibility of sea turtles to injury by ingesting such material, and by entanglement in ghost nets and nondegradable cordage, was thoroughly documented by Balazs (1985). His list of such casualties was compiled from a widely scattered literature, from extensive interviews and correspondence, and from broad personal experience. He documents 79 cases in which the guts of turtles were loaded down with synthetic scrap including fishing lines and nets, plastic bags, beads, bottles, vinyl films, and tar balls. The gut of one turtle found dead contained a sheet of heavy plastic measuring 3×4 m. Balazs also recorded 60 cases of entanglement involving monofilament line, rope, netting, cloth debris, tar, and even such strange forms of entrapment as that shown in Fig. 4. His paper leaves no doubt that persistent plastics and discarded or lost nylon fishing gear must be added to tar, liquid petroleum, and toxic chemical wastes in any assessment of the impact of pollution on marine vertebrates (Balazs, 1985). The marked tendency of leatherbacks to ingest

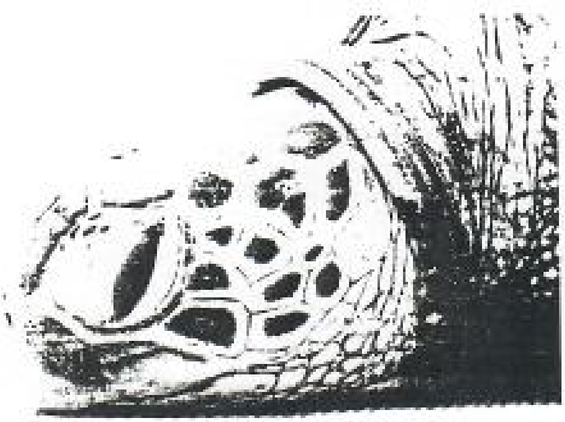

Fig. 4 Hawaiian green turtle with plastic collar. (George Balazs photo.)

sheets and bags of plastic film has been attributed to misidentification of the translucent films as jellyfish. That the species is a generally indiscriminate feeder, however, is suggested by the ingestion of a 180 m length of heavy monofilament line by a New York leatherback (Sadove, 1980).

The vulnerability of young sea turtles to these materials is particularly serious. During our early investigations of the 'lost-year' puzzle, sargassum rafts were ultimately shown to be an important habitat for the hatchlings of turtle colonies nesting in certain areas. However, there remained the problem of accounting for the existence of populations breeding where no algal rafts drift by. From the beginning it seemed clear that in temperate and tropical regions pelagic macroplankton was too thinly distributed to provide adequate food for an air breathing animal restricted to surface water and not able to filter food. After pondering oceanographic publications for a while, I realized that this drawback is removed by the processes of advection and downwelling, which align buoyant material—sargassum mats and anything else that floats—along convergences. That this has not been cried from the rooftops reflects a curious compartmentalization of the marine sciences, with biologists not taking stock of the ecologic importance of fronts, and with physical oceanographers making little effort to spread the concept. The sea turtles of the world, already suffering from over-exploitation, elimination of breeding ground, and incidental trawler catch, are now seen to face a new threat in the growing burden of nondegradable debris in the borders of currents and eddies in their epipelagic habitat.

One reason for the scant attention the driftline habitats have received in marine ecology is the fact that until lately most convergences have been conspicuous only to the oceanographers or tuna fishermen who run transects to detect sudden changes in salinity, density, oxygen, etc. To the casual observer it is only when there is flotsam in the line or a fog-wall along it that a convergence is recognized, or when an abrupt change in the colour or clarity of the water occurs, or a band of little waves glitters in the sunlight—or when fish, porpoises, sea snakes, sea birds, whales, whale sharks, or manta rays string out along the front. Today, however, the convergences are emerging into public view. When styrofoam trash gathers in one it can be seen by anybody from the deck of a ship or window of an airplane.

The accumulation of floating refuse in the ocean has been noted and deplored for several decades. For a while it was seen as mainly an aesthetic violation, a symptom of human untidiness. Today, however, nondegradable debris is clearly a progressive disruption of the ecologic organization of marine systems. With growing frequency the fronts now emerge as white lanes of styrofoam (Carr, 1986a). The most conspicuous intrusion of the invasion is in the Langmuir bands, the fields of roughly parallel jagged lanes that often string out ahead of a steady wind. But the borders of the major currents and their gyres are also often white with plastic. On our last trip across the Gulf Stream searching for little pelagic turtles, the front off Little Bahama Bank was marked by a continuous line of plastic scraps of untraceable provenance.

In their paper on ocean fronts Cromwell & Reid (1956) gave as the basic definition of a convergence, 'a band along the sea surface across which the density of the water changes abruptly'. To this I would add, '. . . and a lane along which little turtles, their food supply, and the buoyant pollutants of the seas are all brought in together'.

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