Carr (1986)

Rips, FADS, and Little Loggerheads

Years of research have told us much about the behavioral ecology of sea turtles, but mysteries remain

Archie Carr

Back in 1954, when I spoke before another AIBS audience at the University of Florida, the title of my talk was "The Passing of the Fleet." The fleet was the reproductive flotilla of the Caribbean green turtle; the passing was the degradation it had suffered. One of my aims was to share the excitement I was feeling over things recently learned about the natural history of *Chelonia* —especially its long-range breeding migrations and its evident talent for high-seas path finding. Another was to tell of its 400 years of troubles at human hands and the outlook for its survival in the future.

Those were days when in all the world there was only a handful of sea turtle people, and almost nothing had been learned about the migrations and reproductive ecology of any sea turtle species. Today, hundreds of able investigators are working with this group, and more has been learned than I could possibly inventory here.

But many fundamental questions remain unanswered. A nagging one is whether a female coming ashore to nest is returning to her birthplace. One might say, sure, it has to be that way, because once she has started nesting, a green turtle nearly always comes back to nest near the place where she nested before. Those that come up on our research beach at Tortuguero, on the Caribbean coast of Costa Rica, never go anywhere else to breed. Among the 28,000 females we have tagged there, we have recorded thousands of return visits, but none has ever been seen on another nesting beach anywhere in the world. For anecdotal support of that statistic, there is old number 3438, a female we first saw on the beach in 1965. During the next 17 years she returned 26 times, from feeding grounds at least 300 miles away and very likely farther. The average distance between her nest sites on Tortuguero Beach was a few hundred meters, and some of the nests were almost on top of one another.

Fronts, or driftlines, at sea play a vital role in the "lost years" of Atlantic and Pacific sea turtle species

Despite that kind of site fidelity, the question remains: Was she herself hatched out there one day 50 or 100 years ago? Our ignorance of the answer hides a lot of behavioral ecology. It is an obstacle to the conservation of the declining populations of marine turtles everywhere. The hold-up in finding the answer is the lack of a tag which, if put on a 20-gram infant, will be there when the infant returns as a 100-kilogram adult. Recent evidence that *Chelonia* takes up to 50 years to reach breeding age does nothing to relieve the difficulty.

The second intractable problem is to learn how, during the global reproductive migrations that the populations of some species make, the migrants are guided in their open-ocean cruising. How does a female on her maiden trip to a nesting beach return to the place where she was born? Having once nested on a given shore, how do her later returns—from pastures up to a thousand miles away—take her back to the same nesting place? The guidance mechanism is wholly unknown. To me, that seems a major flaw in biological science.

The third question will be the theme of this discussion: Where do little sea turtles go, and how do they live after they leave the nesting beach? In recent years that problem has received a lot of attention, and a little new light has been shed on the "mystery of the lost year," as we used to call it. We know enough now, for example, to stop speaking of a "lost year," except maybe metaphorically. Young sea turtles leaving their natal beach no longer head into total limbo—and the time they remain out of sight is a lot longer than a year. It is now clear that the developing young are not seen because they are pelagic, passing the absent time as planktonic migrants in the borders of currents in the open ocean.

Back in 1954, one of the few things

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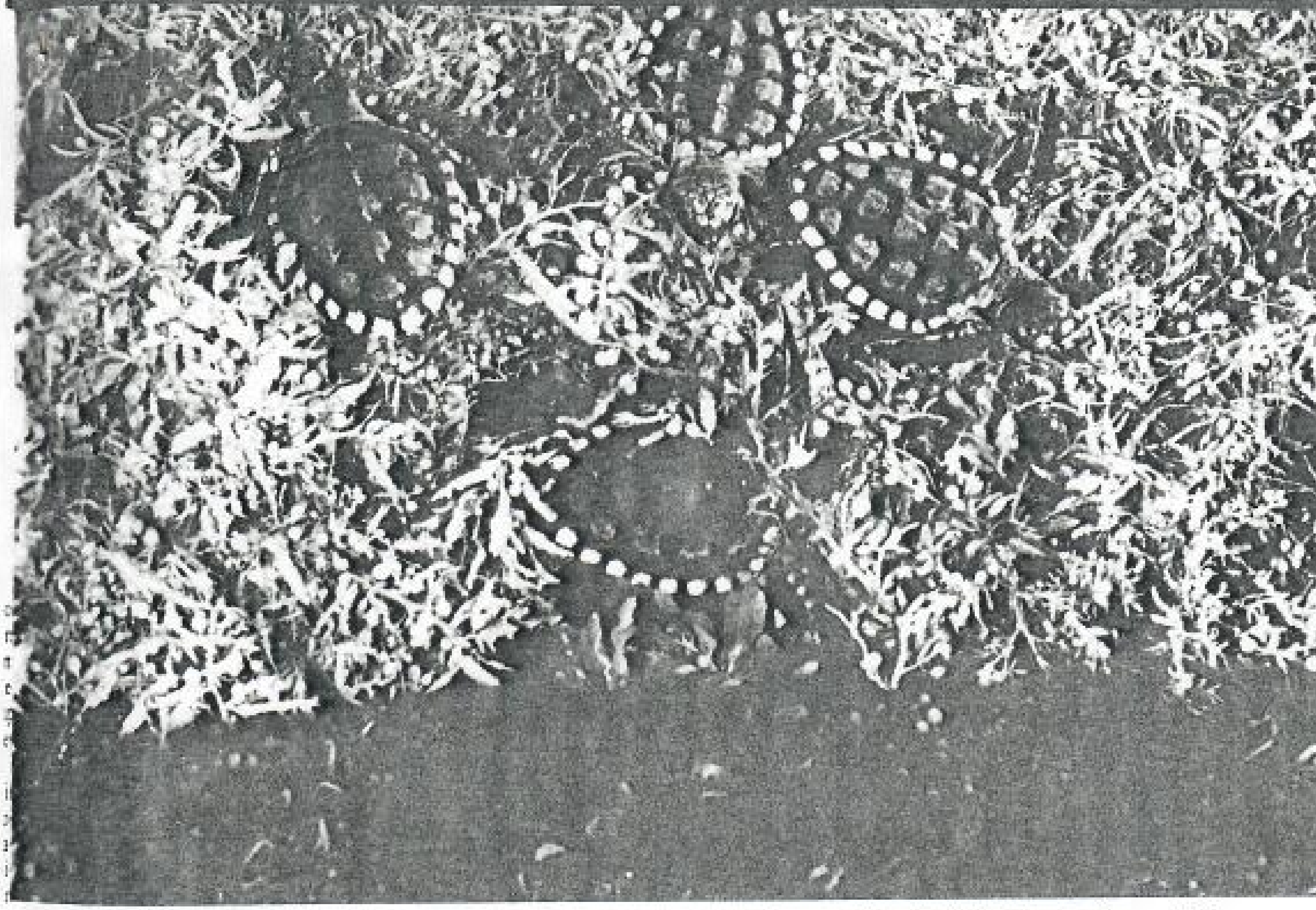

Loggerhead turtles (*Caretta caretta*) in sargassum after experimental release nearby to test their affinity for the alge. Photo: Archie Carr.

known about little sea turtles was that when they left the nest they were able to travel straight to the water, whether or not they could see it from their nest site. Once they had passed through the surf, they would not be seen again in the waters of the continental shelf until they reached sizes between those of a saucer and a dinner plate. It had also been observed, by everybody who had kept newly hatched turtles in a tank, that they tended to swim furiously against the walls, often for two or three days. This frantic travel urge—initial swim frenzy, we called it—was fueled by a residual store of yolk that made a conspicuous swelling on the hatchling's belly. All this seemed to prove that they were destined to swim away somewhere, and to continue traveling for days. Since we knew they were not hidden along any known shore, the only reasonable conclusion was that they were out of sight because they were out in the open ocean.

But if so, we used to wonder, what did they find to eat out there? Once they left the fertile water of the continental shelf, they would find the sea too thinly set with the edible, easily caught prey required to support the growth of a planktonic, air-breathing vertebrate that lacks the equipment to strain dispersed plankton and has a foraging range restricted to the upper few meters of the sea.

Down at Tortuguero, a million green turtle hatchlings or more go each year into habitat so sparse in plankton that you would think a little turtle would wear itself out running down a day's rations. There could be no Tortuguero green turtle rookery, we used to say, if its hatchlings had to depend on the open Caribbean as feeding ground—and yet out there was surely where they were. We had seen them disappear into the blue, and had even followed them on out for miles, still swimming straight away from the land long after it was out of sight under their horizon.

It was a puzzle; and it was the same at the loggerhead rookeries up on the Atlantic Coast of peninsular Florida. More loggerheads nest there than anywhere else in America, maybe in the world. If their young, too, were pelagic plankton—and they surely were because none were ever seen in the coastal lagoons or creeks of their home shores—what did they feed on when they left the shelf?

It was the thinking back and forth between the Florida loggerheads and the Costa Rican green turtles that finally suggested sargassum rafts as the lost-year refuge. Off both Tortuguero and the Atlantic coast of Florida, rafts of sargassum weed drift by, often strung out in long lines at the borders of the offshore currents. In the restocking effort of Operation Green Turtle of the Caribbean Conservation Corporation, we used to make deliveries by sea plane of hatchling green turtles out of Tortuguero. Between Panama and the Nicaraguan cape, we sometimes flew for 100 miles or more along lines of big brown algal mats in the edge of the North Equatorial Current. These were usually lined up northwest-southeast, and out of our plane's bubble window, they were easily seen from altitudes of several thousand feet. We had no clear idea why the rafts were arranged as they were, but it was the same off the coast of Florida. The walls of the Gulf Stream there were also often marked by weedlines. Fishermen recognized these as a good place to catch dolphins. That meant that forage fish were out there, too, and also the smaller creatures the forage fish preyed on.

So finally, we seemed to have found a theory to work with. Hatchling sea turtles just swam out until they found a sargassum mat, crawled into it, and went wherever the current took them. It was well known that sargassum rafts harbored a diverse, specialized fauna, including many kinds of little fishes, crustaceans, worms, molluscs, tunicates, and coelenterates, that seemed suitable forage for little turtles. Besides that advantage and the concealment the rafts offered, there was the fundamentally important tendency of the mats to be aligned off high-energy beaches and thus to enhance the probability that the seaward course of little turtles leaving a nesting shore would intercept them.

From nearly every standpoint it was an attractive notion. It made sense of the hatchling's innate drive to swim continuously and of the retained yolk to support protracted travel. Later on, the idea was further reinforced when we learned that hatchlings hold a course normal to the shoreline and travel directly seaward for many miles.

So the sargassum raft hypothesis held promise. And when I started talking about it with people at the Florida marinas and with swordfishermen on the Salerno longline boats, it turned out that many of them knew that little turtles lived in the "berry grass driftlines." Virtually every habitual weedline fisherman between Cape Canaveral and Cape Florida had seen hatchlings in sargassum or in the stomachs of fish caught near sargassum. It wasn't long before the accumulated word-of-mouth reports, combined with a growing frequency of published records, left little doubt that hatchlings go into sargassum rafts. But did they stay there? Soon answers to this question began to come in, too.

One day during a radio-tracking cruise on the RV *Alpha Helix*, we found posthatchling green turtles in the weedline off Colon, Panama, 100 miles downcurrent in the Southwest Caribbean Gyre from their probable home at Tortuguero. At that point, I approached the World Wildlife Fund with a proposal to investigate the sargassum refuge theory by direct searching and interviews with ocean-oriented people around the West Atlantic and Caribbean coasts. A small grant was awarded, and we quickly spent it. More funds came from the National Marine Fisheries Service (NMFS), and we spent those too. The search cruises were almost fruitless, but a great deal was learned by just interviewing saltwater people, especially the swordfish fishermen.

Like dolphins and many other kinds of fish, swordfish often aggregate where sargassum piles up along stable weedlines. The billfish longliners who set their 20-mile-long tackle beside sargassum lines at the northern tip of little Bahama Bank consistently spoke of seeing well-grown young turtles, "up to the size of your hand," in the heavy sargassum off Matanilla Reef. Juvenile loggerheads, hawksbills, and green turtles showing some growth sometimes also washed up on East Coast beaches in November storms. These often came bundled in masses of sargassum weed, and in the stomachs of the dead ones examined, bits of the animals that live in sargassum or the leaves or floats of the plant itself were consistently found. It was becoming clear that the storm waifs had lived in the sargassum before it was blown in from the weedline bordering the longshore current. And it was not just the autumn storms that brought them. They sometimes arrived in February and March as well, and since no North American sea turtles hatch at that season, these advanced waifs, like the ones in the Bahama Bank sargassum, must have resided in the rafts for months and have then been brought to the coast by currents from someplace far away or after circling in nearby gyres.

Then, with the weed raft theory beginning to seem promising, two flaws emerged. One was our not knowing what happened to hatchlings when their sargassum refuge went to pieces in bad weather, as the mats often do. The other, more fundamental weakness was that some sea turtle populations breed along shores where no masses of brown algae ever drift by. Where and how did the young of these populations pass their pelagic stage?

The effort to reconcile these incongruities cost me a lot of struggling with the arcane prose of physical oceanography—a form of communication that is fiendishly hard for an outsider to read. In the end, however, I came to realize that the fundamental factor in the pelagic stage of sea turtle development is not a sargassum raft, but the gathering of resources that takes place at a front, a convergence where different bodies of water come together. Apparently, horizontal friction or collision there generates sinking, or downwelling, and this mobilizes and aligns anything bouyant in the vicinity. This may not be intuitively evident, but it happens, and knowing it does make other observations easier to understand. For one thing, it is what builds up most of the big sargassum rafts and what reassembles them after storms have wrecked them. Some mat growth is obviously by vegetative proliferation. But the big rafts and lanes of rafts have not grown into those forms and sizes; they have been built by downwelling. And since the same process draws in all other floating objects within reach, it creates conditions that explain the survival of little sea turtles where there is no sargassum weed. Wherever fronts occur, the debris and food resources of the surface waters will be assembled, trophic levels will multiply, overt colonization will take place, and life in the open sea will be feasible for an epipelagic, planktonic, air-breathing little animal that forages on smaller animals.

The importance of rips and driftlines (*siome* the Japanese call them) as feeding habitat for billfish and seabirds is widely known (e.g., Ashmole and Ashmole 1967). The diversity and prevalence of the fronts that make them, however, and their profound involvement in the ecology of the open ocean have received surprisingly little attention from marine ecologists.

Convergences range in magnitude from trivial disruptions to the shears and collisions of the big geostrophic currents and midocean gyres. To a casual observer, they may be conspicuous only when flotsam is present. Anybody who has done a lot of looking down at the sea from an airplane at moderate altitude may have noticed areas of the sea surface striated with ragged, roughly parallel lines of floating stuff. These are known as Langmuir bands. They are produced, I am told, when wind blows steadily at seven knots or more. This somehow sets up a series of evenly spaced counterrotating vortices, the axes of which run—not across-wind, as you would expect—but in the direction the wind blows. Along the line where each pair of these opposing eddies collide, the water sinks, and anything afloat is drawn in.

Langmuir circulation is probably fundamentally important in reassembling sargassum rafts after heavy weather and also in lining them up in a way that makes them more easily located by the random travel of a dislodged and totally dependent inhabitant—such as a sargassum fish or a little turtle. (It is not a cheering thought that these days Dr. Langmuir's bands are made more conspicuous in the seas of the world by the abundance of styrofoam scraps and plastic bags and other human garbage that they hold.)

The most helpful explanation I have seen of the gathering action of a front is a recent paper by Donald Olson and Richard Backus (1985) of Woods Hole. They described the remarkable concentrating of a little cold-water fish, *Benthosema glaciale,* in the edge of a warm-core Gulf Stream ring. When the Gulf Stream gets up around Cape Hatteras, it often goes into paroxysms of meandering, and from time to time its bends get so narrow at the bases that they break off and move away, spinning with the old Gulf Stream momentum and moving slowly southwestward. The rings range from a few hundred to a few thousand meters across, and they sometimes last for months, keeping their integrity because their density differs from that of the surrounding cold slope water. The ones that pinch off to the north surround warm water from the Sargasso Sea. They are an important ecological influence in the shelf water and may be the vehicles by which warm-water species, including little sea turtles, sometimes turn up in Boston Harbor.

Over two months, Olson and Backus observed a fivefold increase in the concentration of benthosemas in the edge of the ring, and they provide an analytical model to account for this. I was stimulated by their idea that if an animal or plant, by either overt swimming or buoyancy control, is able to keep to a particular depth and is drawn into a front by downwelling, it will hold its position there, and its numbers are bound to build up despite the vertical movement. How deep the gathering force of a convergence extends is not clear to me, but the point is that the advection effect is by no means restricted to pulling in stuff floating on the surface.

So in one way, the sargassum rafts were a red herring that distracted attention from a factor of more fundamental importance—not just for young turtles, but for most other inhabitants of the surface water of the sea. Where the weed rafts are present, they are a blessing, but the frontal sinking that builds them is indispensable in the ecological organization of the upper waters of the ocean.

One of the most graphic accounts in William Beebe's writings about the natural world is his description of a big current rip in his book, *The Arcturus Adventure* (1926). The rip was an extraordinarily well-developed convergence, encountered 200 miles southeast of Cocos Island when the *Arcturus* was cruising down to the Galapagos Islands. For two days the ship moved along in the rip, part of the time with engines dead, held in by the convergence, drifting with a teeming band of life. "Here was a concentration of organisms greater than any I have ever seen," Beebe wrote. "We had to give up trawling with the silk nets . . . the amount of floating animals was so great that the bags would fill immediately with a weight that strained them to the utmost."

The following are notes from the *Arcturus* log for 1 April 1925:

> An extraordinary sight greeted us at dawn. As far as the eye could see, there stretched a clearly marked line of foam, zigzagging to the horizon in a NE and SW direction. On the north side of the line the water showed dark and rough, while to the south it was lighter and smoother. . . . This line, which wound across the sea like a river meandering . . . marked the meeting of two great currents, and within its narrow limits there swam or drifted or flew an amazing quantity of life. Boobies, petrels, phalaropes, gulls, tropic-birds and frigate birds dived for the abundant food. . . . A school of five or six hundred dolphins leaped and played across the line . . . myriad flying fish flickered everywhere . . . patches of the sea were colored . . . purple by millions of tiny salps, and every drop held a copepod . . . turtles drifted past and . . . a sea snake was scooped up. We put over small boats and rowed about, catching pelagic anemones, *Porpita, Glaucus, Halobates,* balls of mollusc eggs, *Ianthinas,* and hosts of crustaceans.

And that is only a ship's log talking. In his book, Beebe described the rip in still more colorful terms.

I was young when I read *The Arcturus Adventure,* and the description made a deep impression on my mind. But because I came away not knowing what held the seething band of life together, I was left unaware of a major organizing process in marine systems. If Beebe had discussed the rip with a physical oceanographer and worked out a layman's explanation of its dynamics and put that in *The Arcturus Adventure,* the pelagic environment as a place for animal life would be better understood than it is today. Beebe identified the cause of the rip as the coming together of "two warm, westwardly flowing streams of water," but he attributed the jubilee there to "a wall of water against which all the floating jetsam for miles . . . was drifted and held." This made no sense to me, and I judge to a lot of other readers, too, because *The Arcturus Adventure* was widely read. The wall idea did nothing to advance a laymen's comprehension of a widespread phenomenon without which the surface waters of the seas would be dismally unproductive.

It would be hard to overestimate the ecological importance of convergences. If there were none there would probably be no sea turtles—certainly none of the kind we know, with the racial custom of sending their young away on developmental migrations as pelagic plankton. It has taken me a long time to realize this, and one reason has been that until lately, most of the nontechnical literature that I read has stressed the ecologic importance of *upwelling*, to the virtual exclusion of downwelling. Obviously, without upwellings phosphates and nitrates would stay locked away below the photic zone, and the ocean would be far less productive. But upwellings do not assemble organisms; neither do organisms crowd in to feed on anything that wells up. What comes up is just the stuff of primary production, and even this is not concentrated locally because the vertical movement is brought about by the *divergence* of water regimes, and the nutrients that come up are soon washed away from their place of origin. Maybe a few spry diatoms multiply at upwellings. Olson and Backus (1985) pointed out that depth keepers are able to resist vertical displacement either upward or downward. But food chains lack the time to develop there, and sardines or tuna or seabirds do not congregate to forage at a zone of divergence. They gather when the water has spread to other places where convergence and sinking occur, where resources are concentrated, and where higher trophic levels can develop.

Figure 1. Loggerheads of the Indian River–Mosquito Lagoon size class in Lew Ehrhart's laboratory for tagging and release.

Once the effects and ubiquity of fronts are realized, it is not hard to see how sargassum animals regain their refuge after storms have demolished a driftline or raft and how young sea turtles find food in pelagic habitats devoid of drifting algae. But as soon as it became clear that the turtles were pelagic, other questions arose. For instance, most benthic animals of the continental shelf—invertebrates and inshore fishes—also have pelagic larvae, but they produce them by the millions, swamping with their numbers the factors opposing survival. This makes you wonder how sea turtles get by with the few hundred eggs per season a female lays. And those that do survive: where, and by what guidance process are they eventually restored to the breeding populations they came from? Do they return when the current they are riding just happens to dump dinner-plate-sized turtles into inshore habitat appropriate for their age group? or when, at a given ecological signal and stage of development, a map sense, homing urge, and navigational ability appear, and the animal, no longer a planktont, actively seeks out and rejoins its population by oriented travel?

It occurred to me lately that a way to approach these questions would be to take stock of what we know of the developmental ecology of the Atlantic loggerhead, *Caretta caretta* along the eastern coast of peninsular Florida. The biggest nesting grounds in the Atlantic are located there, and tagging has been in progress for many years. Besides the mature turtles that nest in great numbers on East Coast beaches, colonies of subadult loggerheads are being tagged by Lew Ehrhart in the Indian River and Mosquito Lagoon (Figure 1). For the past five years, NMFS research trawlers have also been tagging this age group in the missile submarine channel at Port Canaveral where, for no known reason, it aggregates in great numbers. These two subadult colonies are by far the largest assemblages of immature loggerheads ever recorded anywhere in the western Atlantic range of the species. When shrimp trawlers off the Georgia and Florida coasts catch loggerheads incidentally in their nets, the animals are mainly from this size group.

Thus, *Caretta* occurs in Florida in four distinct stages: sexually mature breeders and foragers, new hatchlings, pelagic lost-year juveniles brought back weeks or months after hatching by gyres and storm waves, and the nearly mature aggregations in Canaveral Channel and the Indian River lagoons. When size range in these different age classes is graphed, there is a conspicuous gap between the biggest American pelagic juveniles and the smallest of the subadults in the lagoons and channel.

As far as I have learned, this missing size class occurs nowhere in US waters. Very recently, however, its place in the bar diagram has been filled by measurements of an itinerant seasonal colony of little loggerheads that occurs regularly on the other side of the Atlantic, at a place on the Mid-Atlantic Ridge that is swept by the main axis of the Gulf Stream system.

The occurrence of little sea turtles—ridleys and green turtles as well as loggerheads—in European waters is nothing new. For a long time, zoologists have taken note of them and wondered where they came from and what their ultimate fate would be. They have usually been viewed as terminal expatriates, out of the geographic range of their species and with no prospects of rejoining it. In his book, *European Sea Turtles*, Brongersma (1972) compiled the East Atlantic records and also sightings made at sea. Like others who have pondered the matter, he concluded that the European arrivals probably came from America, but he, too, was dubious about their future.

The reason the lost waif idea arose was that most of the attention given European sea turtles has been on more northerly shores—the United Kingdom, Holland, France, and Scan-

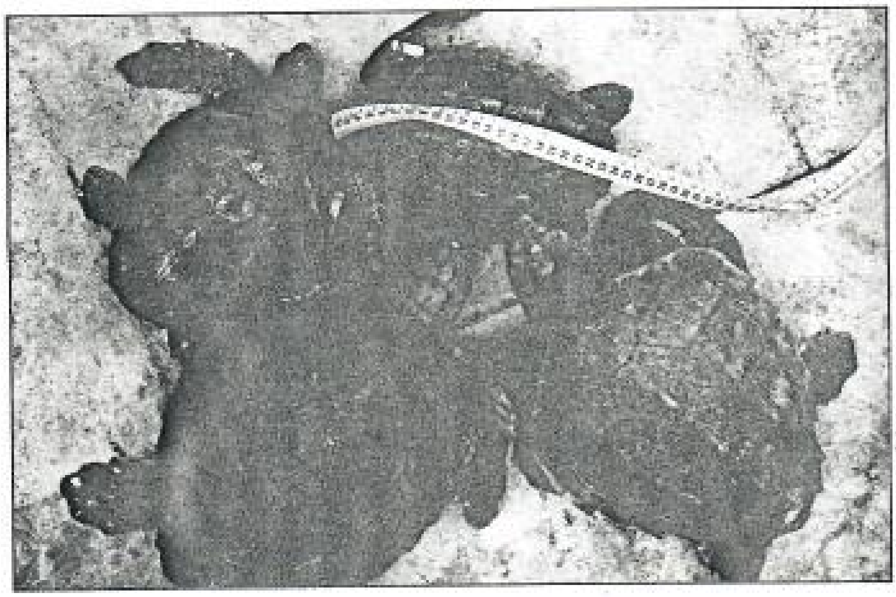

Figure 2. Young loggerheads of the Azores size class, tagged on Princesse Alice Bank. Photo: Helen Martins.

danavia—and in those regions, a sea turtle obviously faces a dim future. The Gulf Stream splits as it approaches Europe and continues past England as the North Atlantic Drift; the water temperature, once around 25° C, chills down to near zero. There thus seems no way that the northern arrivals, already feeble if not dead on shore, could ever get back to wherever they came from. Because the British turtles were those most often heralded by scientists and the popular press, the idea that they had little chance of survival arose, and little serious attention was paid to the possibility that some East Atlantic turtles might be involved in a regular transatlantic migration.

All this time, a lot more little loggerheads have been drifting into Spanish and Portuguese waters, but Iberians get less worked up over natural history than the English do, and not much has been said or written about the strandings there. Now, however, it seems probable that at least one seasonal European colony, which turns up regularly in the Azores, is not made up of waifs but of American loggerheads on a regular passive developmental migration in the global current system.

The data that brought this out were sent by Helen Martins, an oceanographer at the University of the Azores and a collaborator in our tagging program. Two years ago Martins wrote me that the tuna boats fishing on Princesse Alice Bank were catching little loggerheads with dip nets and taking them home to eat. They eat them less often now. Instead, Martins buys all they bring in, puts tags on them, and lets them go again (Figure 2). She recently sent me the measurements of her first 40. They neatly fill the gap in the West Atlantic series, fill it with data from healthy two- or three-year-old turtles taken in a pelagic habitat that is downcurrent from Cape Canaveral, out of reach of the cold North Atlantic Drift and in the full flow of the Gulf Stream, enroute to West Africa, South America, and Cape Canaveral (Figure 3).

As to what brings about the eventual departure of the Princesse Alice migrants, nothing is known beyond the fishermen's statement that they are there only in summer. Unless they have already acquired a homing urge and a guidance sense, they must just move away in the flow of the Gulf Stream system; there are downcurrent records of the size group to support the view. Long ago, Richard Backus wrote me that during a cruise of the RV *Yamacraw*, about 40 little loggerheads, 15 or 20 of them in one group, were sighted along a course from the Azores to Gibraltar. Beyond Gibraltar the main current veers southwestward as the Canaries Current and moves past Madeira, the Canary Islands, the Cape Verde Islands, and across the equatorial Atlantic to America (Figure 4). That at least some of the young Azores loggerheads leave by that drift bottle route seems confirmed by the records for the islands off West Africa.

While the juveniles are on the Azores bank they are still clearly in their pelagic mode, feeding exclusively at or near the surface. Where the tuna boats catch them, the water is too deep for bottom feeding. The

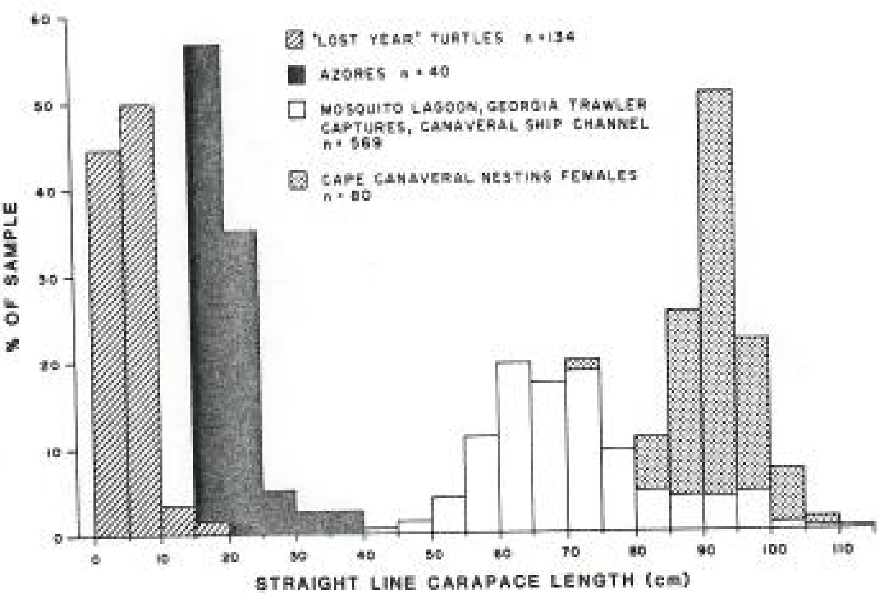

Figure 3. Shell-length distribution in three size groups of American loggerheads and one East Atlantic group.

Figure 4. Major currents of the North Atlantic Ocean.

presence of the tuna indicates that convergences are concentrating food resources in the surface water. Evidence that the Azores migrants continue their surface feeding after moving southwestward in the Canaries Current is indicated by van Nierop and den Hartog (1984), who examined the stomach contents of preserved specimens from the downcurrent islands off Africa. They found abundant nematocysts, indicating that a number of different coelenterates were the predominant items in a diet that included pelagic tunicates, pelagic snails, gooseneck barnacles, and other high-seas organisms.

But meantime, it is frustrating not to know where the Azores migrants are spending the years it takes them to grow from the sizes of saucers and dinner plates to the heft of the Florida subadults, which average 43 kg in weight and 65 cm in shell length. Nobody knows what the growth rate of turtles surface-feeding on pelagic forage would be. But if they traveled at an average speed of half a knot, in the axes of the Canaries and North Equatorial Currents, through the Antilles and directly up to Florida's eastern coast, the journey would take no longer than about 280 days. If they prolonged the trip by staying in the current through the Yucatan Channel and into the Gulf of Mexico, moved into the Loop Current, out through the Florida Straits and up the coast to Canaveral, they would get home in about 470 days, which is still several years too soon (Figure 5).

So the question is, where do they kill the time it takes them to grow from the Azores size class to the Canaveral and Indian River sizes? There is a bare possibility that they stop over in some hidden place in the shore waters of northern Africa or northern South America, but for various reasons this seems virtually out of the question. A more probable answer is that they while away the time in the gyres and eddies of the main Gulf Stream system. At an average speed of half a knot, one circuit of the mid-ocean North Atlantic Gyre would take only around 440 days, but maybe the migrants swirl on in it indefinitely or prolong their stay by detours in minor eddies within the Sargasso Sea.

At least we now know there are plenty of fronts and convergences to assemble the food the travelers require. And we know that little eels are all out there. Perhaps the itinerant loggerheads are out there too, possibly even eating little eels.

In any case, the lost year of the Atlantic loggerhead is more like four or five years—and this bears directly on the even longer absence of the young of sea turtles from nests out on the Pacific Coast. Some of the biggest breeding colonies on Earth are those of the olive ridley in the East Pacific. It nests *arribada* style, with up to fifty thousand females or more crowding ashore together on a few short beaches from Mexico down to Costa Rica. Along the same shores the big leatherback comes in to nest—not tightly aggregated like the ridley but in tremendous numbers. Nobody ever sees the young of either of these species until they come back almost fully mature.

It is the same old lost-year mystery, only even more mysterious. When you stand on a Pacific beach and watch a swarm of newly hatched ridleys scurry down to the swash and into the big Pacific surf, get through it somehow, and then reappear beyond the breakers as a scattering of little black heads that soon move seaward out of sight, it is strange to think they will not be seen again until they come back fully grown. It is the same with the leatherbacks; these two cases have always seemed the epitome of the mystery. Now, the new evidence that a transatlantic developmental stage may be standard procedure in the life cycle of Atlantic *Caretta* makes the lost Pacific ridleys and leatherbacks a little easier to live with. Out there, just as in Florida and Tortuguero, there are north-south currents to pick up hatchlings and carry them into the big east-west system that travels a quarter of the way across the globe. All along the way there are shears and driftlines where other creatures are likewise housed and fed. So even without sargassum rafts to lodge in, life is possible in the Pacific, even for planktonic wanderers that eat mainly micronekton and breathe only air.

In the places where mats of drifting algae are lacking, their role is to an extent duplicated by other kinds of flotsam gathered in by the front. One ecologically influential kind of flotsam, which turns up even out in the mid-Pacific, is drifting timber. If a dead tree washes out to sea from a river in Colombia or New Guinea and gets into a major current, it will promptly be colonized by barnacles, wood-boring molluscs, and teredo worms; their work makes it habitable by many other species that have not totally lost nostalgia for solid ancestral habitats. Besides the animals that lodge in or on the log, many kinds of small fishes and the young stages of others arrive from who-knows-where and school beneath the log; graduated sizes of predators come in after them—and after one another.

The tendency of open-sea animals to seek shelter under floating debris, though not well understood, is a fundamental behavioral factor in epipelagic ecology. It is common knowledge that to catch a cobia you cast over to a channel marker; if it is swordfish or dolphin you are after, the place to fish is along the lanes of heavy sargassum. I once watched a half-beak repeatedly hurdling a floating two-by-four 20 miles at sea, and near the same place, three little moonfishes huddled under a drifting coconut.

Some kinds of fish are attracted by anything solid at the surface of the liquid ocean, and not long ago, commercial fishermen and fishery agencies came to realize the potential of this trait for exploitation by the tuna industry. During four months in 1963 (Hunter and Mitchell 1967), two biologists of the National Marine Fisheries Service collected data on the association of fishes with logs in driftlines off the Pacific coast of Central America. Although it was not so stated, I judge this was not just a venture in pure natural history but mission-oriented research of possible use to the tuna industry. Some of the logs observed were anchored; others drifted naturally. The sampling was done with small purse seines. Altogether 32 different species of fish were collected. At logs that had been newly set out, divers recorded recruitment rates and found that after about four days, there were always too many fish to count. Sea snakes gathered around the logs, evidently attracted by the schools of little fish; a sign of the growing organization was a parasite cleaning bond, with three cleaner fishes "nipping at the neck and legs of a green turtle."

The people who probably know the most about Pacific tuna and billfish are the Japanese. They gained their lore in avid pursuit of the big cursorial species, which they catch with poles and lines, longlines, and purse seines. They do much of their fishing out in the vast spread of the open Pacific. Needless to say, it is simple-minded to drop a hook or set a purse seine just any old place out there. You go where the fish are, and the Japanese tuna fishermen know how to find them. Regions of upwelling are propitious; fronts and driftlines narrow the search, and wherever chunks of big flotsam are held in the rip, schools of tuna are almost always present.

When a floating log is pulled into a front, the line of heightened biological activity is focused at a point; diversity and abundance rise dramatically around it; and even the big, wide-ranging species gather there. The idea of anchoring artificial floating objects such as rafts of palm fronds or bamboo poles has come independently into the minds of widely separated oceanic people, and today, the log-fishing technique with both natural trees and elaborate human-made versions is spreading fast.

A few years ago the Inter-American Tropical Tuna Commission (IATTC) was threatening to exclude the US fleet from the rich tuna grounds off Central America. This was when the

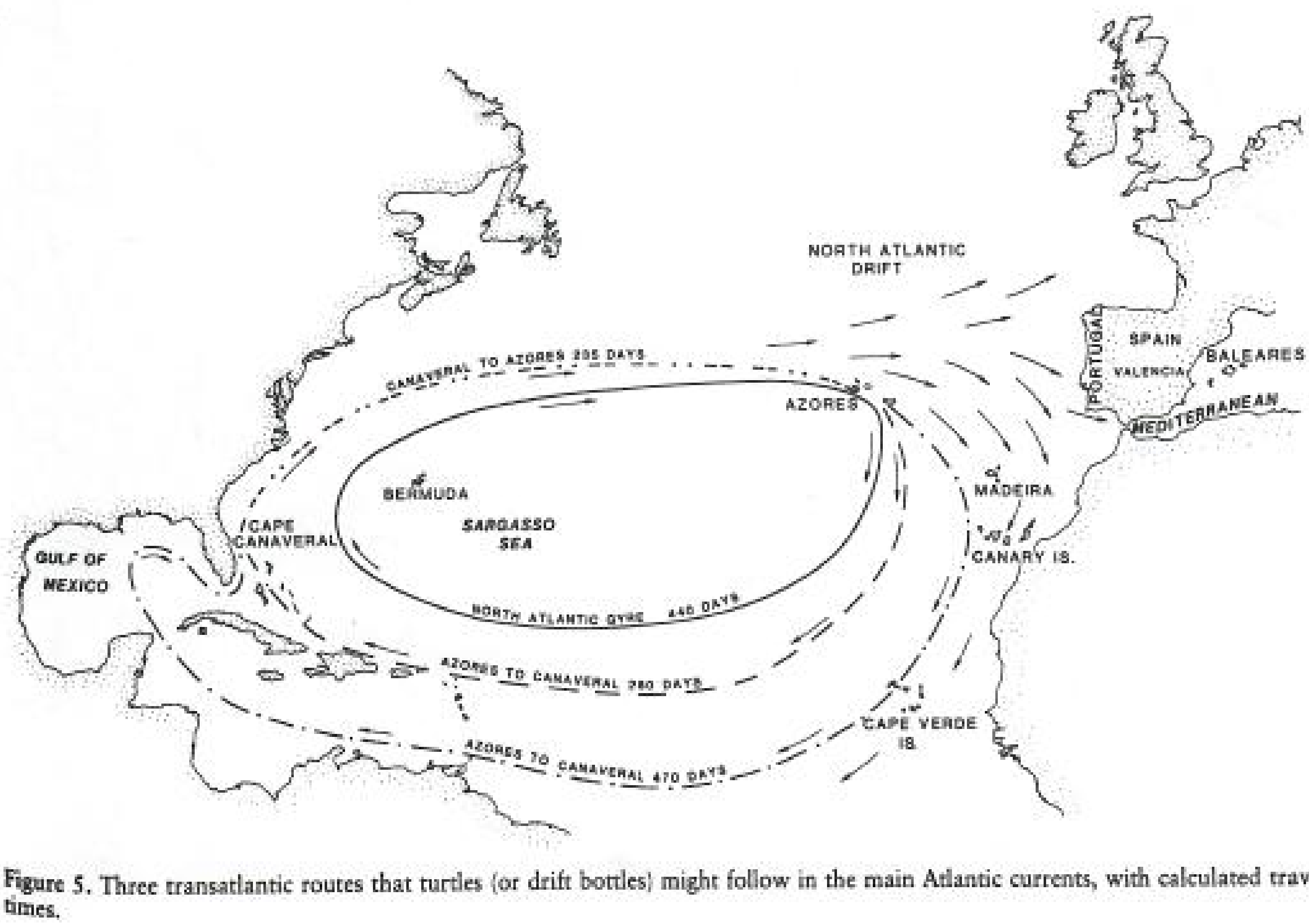

Figure 5. Three transatlantic routes that turtles (or drift bottles) might follow in the main Atlantic currents, with calculated travel times.

industry's public relations were already strained because of its bizarre custom of setting nets around porpoise schools that had tuna under them. The industry decided to seek less troubled waters in the western Pacific, and a research vessel was sent out to explore.

When the exploratory vessel came back, the captain was enthusiastic over what he called log-fishing as the best possible way to catch tuna. "Find the right log," he said, "and you're in business." That meant an old log, he said, "with barnacles, crawling with little crabs, with a lot of bait breezing around, and usually with some little turtles there." He reported seeing logs attended by groups made up of several species and different age groups of tuna. The collective weight of one of these he estimated at 500 or 600 tons. The fishing technique he described was to search the fronts until a log was found and then to let it drift freely, with a float carrying a blinker and radio beacon attached by a short line. When a set was made around the log, a small fast boat tended it and made sure it didn't tangle in the net or get too close to the vessel when the net was being pulled in.

Today the procedure has been refined. Searching for drift logs in the wilderness of the western Pacific—even when positions of the main convergences are known—can try a fisherman's patience. In 1978 the NMFS Honolulu laboratory embarked on a project to devise "structured flotsam," as they call human-made substitutes for drift logs. Beginning with rafts of steel drums filled with plastic foam, the devices gradually evolved into buoy-type floats hung beneath with various kinds of drapes, which markedly enhance their appeal. These buoys have been anchored around the Hawaiian Islands in water up to 1250 fathoms deep. They have been a dramatic success, attracting many different kinds of pelagic fishes and bringing happiness and profit to sport fishermen and commercial tuna boats alike.

These high-tech driftlogs have been christened FADS, for fish aggregating devices. According to Shomura and Matsumoto (1982), commercial pole-and-line fishermen visited FADS 247 times in 1978 and caught 523 metric tons of tuna. The biggest aggregation observed at a FAD was a school of 55–70-kg yellowfin tuna, estimated by R. E. Block of the University of Hawaii at 1600 tons. Twenty-three countries have deployed FADS in the western Pacific, and the IATTC has put them out in the eastern equatorial Pacific for use by both pole-and-line fishermen and purse seiners. So the FADS are here to stay—for as long as the big ocean fishes can stay out of the Star-Kist cans and sushi bars.

And as long as the driftlines are not wrecked by the accumulating waste of our civilization.

A man I know is master of the MV *Freedom*, a tanker that makes frequent trips across the Gulf of Mexico from Corpus Christi to Jacksonville. His course takes him straight through the wild midsection of the gulf, a place where you can feel very far away from the human race. But you are not, really. In one crossing last year, the *Freedom* cruised for 30 miles in a crowded lane of garbage.

The next trip, the garbage had moved on, and at almost the same position there was a dense field of immature Portugese men-of-war. The grotesque clutter of human waste and the little *Physalias* were no doubt both held in by the same front, very likely the eastern wall of the West Gulf Gyre. Their coming together out there, drawn in by the same force, in that remote place, makes one wonder how long it will take for the wastes of our race to ruin the driftlines of the world.

In recent reports on marine pollution, I seem to have noticed a tendency toward optimism. Maybe it isn't as bad as Heyerdal and Cousteau say, I read the other day. The spread and depth of the sea should keep our soluble exudates harmless indefinitely, and the heavy stuff will do no harm for centuries, down on the abyssal plains.

I doubt the sense of that, but right or wrong, it ignores the growing threat to the fronts, where life is arranged in lanes. In a way, driftlines are like English hedgerows or like the zones along which terrestrial habitats meet. The comparisons are superficial, though, because the rips draw in not just organisms and their food but everything else that floats as well.

And of all the driftline inhabitants, little sea turtles seem the most vulnerable to the pollution the fronts gather. Along the coasts bordered by the Gulf Stream, young turtles choked with tar or with impacted digestive tracts frequently wash ashore. And lately, van Nierop and den Hartog (1984) tell of finding tar, plastic scraps, and nylon in the stomachs of young loggerheads of the East Atlantic size class from Santa Maria and the islands off West Africa.

So the satisfaction of finding viable American loggerheads on the other side of the Atlantic is made a little less by the thought of the additional years they face getting home in waste-burdened driftlines. But for the present, their home colonies back in the United States show no sign of decline, and before many years go by, I am looking for the turtles Helen Martins is tagging on Princesse Alice Bank to turn up in Lew Ehrhart's nets in Mosquito Lagoon—or out in Canaveral Channel, dodging the dredges and nuclear submarines.

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BioScience

American Institute of Biological Sciences

February 1986 Vol.36 No.2

BioScience (ISSN 0006-3568) is published monthly, with a combined July/August issue, by the American Institute of Biological Sciences. Individual membership: Sustaining, $55/yr; individual, $37.50/yr; family, $52.00 (includes $23 for *BioScience*); student/emeritus, $19.50 ($12 for *BioScience*). Institutional subscriptions: Domestic, $72/yr; foreign, $77/yr. Single copies: $4.75. Second class postage paid at Washington, DC, and additional mailing offices. POSTMASTER: Send address changes to *BioScience* Circulation, AIBS, 730 11th St., NW, Washington, DC 20001-4584.

EDITORIAL CORRESPONDENCE: 730 11th Street, NW, Washington, DC 20001-4584; 202/628-1500. See p. 64, January 1986, for information for contributors.

ADVERTISING CORRESPONDENCE: Scherago Associates, 1515 Broadway, 10th floor, New York, NY 10036; 212/730-1050.

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Cover: Colorado potato beetle (Chrysomelidae, *Leptinotarsa decimlinata*) larva. Because it is resistant to many insecticides, this beetle is today one of the most difficult agricultural pests to control. See articles beginning on page 78. Photo courtesy US Department of Agriculture, Photography Division, Washington, DC 20250.