Nature Watch

Tracking Turtles through Time and Space

Kartik Shanker

Marine turtles are known to migrate several thousands of kilometres between their feeding and breeding grounds. These migrations have been studied by the application of metal tags on flippers, with intense monitoring at nesting sites, and opportunistic recovery in offshore waters, providing information on turtle movements. Often, several thousands of tags have been applied with very low levels of recapture. Satellite telemetry is a high-tech, and expensive, method to track turtles during their migration across the open ocean. Molecular genetic techniques have offered ways to track turtles both through space and time. The comparison of genetic haplotypes from different regions makes it possible to study population structure, test theories of natal homing, and even assign feeding populations to nesting sites and vice versa. The study of these haplotypes has also made it possible to look at relationships between species and populations, and study evolutionary biogeography or phylogeography of these animals.

Kartik Shanker has been involved with sea turtle research and conservation for over 10 years. He was diverted from turtles for a few years by doctoral research on small mammals of the Nilgiris. He is the Editor of *Kachhapa*, a newsletter for the subcontinent on sea turtle conservation. He currently works with a national UNDP turtle conservation project and has initiated a long-term genetics project on marine turtles along the mainland coast of India and the offshore islands of Andaman & Nicobar and Lakshadweep.

Keywords
Turtles, animal navigation, conservation biology, nesting behaviour, telemetry.

Asking the Same Questions

After all that has been written and said about marine turtles (*Box* 1), it is indeed amazing how little is known about them. This is nowhere more apparent than at the stage of their life cycle when they leave their natal shores as hatchlings and reappear as dinner plate sized juveniles in various habitats, a period that scientists called the lost year, but now know to be much longer. Indeed, sea turtles are lost to us for much of their lives and to learn even a little about them continues to be a massive struggle. Does a turtle nest on the same beach where it hatched? How do females (and males?) navigate to the same nesting beaches again and

Box 1. Marine Turtles of the World

Eleven of the twelve families of turtles are essentially aquatic, and two of these are marine, while the others are adapted to the freshwater environment. There are at least 6 extant species of marine turtles, with dispute over the status of two taxa (see 'A tale of two turtles', in this article). The leatherback turtle (*Dermochelys coriacea*) is the largest, measuring over 1.8 m (6 feet) in length and weighing over 500 kg. It is distinctive as it has a leathery skin and does not have scales or shell scutes. The carapace has seven ridges that run longitudinally from head to tail. Green turtles (*Chelonia mydas*), so called for the colour of their fat, are also very large turtles, with carapace lengths in excess of 1m and weighing 200–300 kg. These have been heavily exploited the world over for their meat. Loggerhead turtles (*Caretta caretta*), marginally smaller than green turtles, are found the world over like the green and leatherback turtles. Hawksbill turtles (*Eretmochelys imbricata*), also globally distributed, are exploited for their exquisite scutes, which are used to make 'tortoiseshell' articles. Flatback turtles (*Natator depressus*), however, are found only on the coast of Australia.The ridleys are the smallest turtles; the Kemps ridley (*Lepidochelys kempi*), found only on the Atlantic coast of Mexico, is considered the most endangered of the sea turtles, as a single nesting population was reduced to a few hundred individuals in the 1970s. However, a massive conservation effort, involving the expenditure of millions of dollars, has brought about the recovery of this species. There is some dispute about how different it is from the 'Pacific' or 'olive ridley' (*Lepidochelys olivacea*) which is widely distributed in the Pacific and Indian oceans and also at a few sites in the Atlantic. Our work in fact shows that Indian 'olive' ridleys are the closest relatives of the Kemps ridleys. The ridleys are particularly known for their mass nesting events, or 'arribadas', where thousands of turtles nest synchronously during a few days (See *Resonance*, Vol.1, No.4, 1996, for more on marine turtles and Vol.4, No.7, 1999, for more on olive ridley Arribadas in Orissa).

again, covering several thousand kilometres? Where do the hatchlings go and where do they live after they leave the nesting beach? It seems that biologists have been asking these very questions repeatedly for the last thirty years. Tracking turtles used to be a humungous effort involving the application of tens of thousands of tags, few of which were ever recovered. However, recent technologies such as molecular genetics and satellite telemetry, though expensive, do offer an opportunity to probe deeper into the lives of these mysterious marine creatures.

Adult Female Green turtle.

To summarise their life cycle briefly, sea turtles begin life with 100 odd nest mates in small nests beneath the sand on tropical sandy beaches. The female turtle, having migrated from a feeding area perhaps thousands of kilometres away, mates in offshore waters, crawls ashore at night, digs a flask shaped nest with her hind flippers, lays 100–150 soft shelled eggs, covers the nest and returns to the sea. She may nest several times during a season, after which she returns to her feeding area, showing no parental concern. The eggs hatch after about 7 weeks, during which time they are incubated by the sun and metabolic heat, sex being determined by incubation temperatures (females being produced above a critical threshold, and males below). The hatchlings emerge en masse at night and scramble for the sea, swim steadily offshore, and are believed to spend much of their lives in seaweed rafts and drift-lines, until many years later, they move to other juvenile habitats. Mortality is particularly high during their initial escape from the nest and offshore waters.

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Orientation and Navigation

So how do turtles find their way around? To begin with, when the hatchlings crawl out of the nest they have to find the sea. Experiments have shown that they orient to the brighter horizon. Under natural conditions, the reflection of the moon and stars on the sea would make this a brighter horizon for the turtles. As soon as they swim rapidly through the surf, another instinct kicks in. They begin to swim against wave direction. This enables them to swim steadily in an off-shore direction. By this time they are beginning to orient to the Earth's magnetic field and this enables them to maintain their direction out at sea. It is believed that turtles can detect the Earth's magnetic inclination angle and magnetic field intensity, giving them a bearing, which can lead them very precisely to geographical locations. It is believed that this combination of inclination and intensity leads them back to their natal beaches. There may also be other factors such as chemical signals, which enable them to precisely identify particular beaches.

Leatherback Turtle (nesting).

Tracking Turtles with Tags

Since the 1950s, biologists have been attaching metal tags to the flippers of sea turtles. Most of the tagging has been done when the turtle comes ashore to nest. Tens of thousands of tags have

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been attached by dozens of research and conservation programs all over the world. One of the first turtle taggers was the first man of sea turtle biology and conservation, Archie Carr, who started tagging turtles at Tortuguero in Costa Rica and on Ascension island. These early tagging studies showed that females return to the same nesting beaches over and over again. This finding led to the natal homing hypothesis which suggests that turtles find the beaches they were born on for nesting as adults. Why would turtles do this? Often, turtle breeding and feeding grounds are fairly distant. This is because beaches that are suitable for nesting may not have vast quantities of food that sea turtles depend on. Moreover , the developmental habitats of hatchling and juvenile turtles are very different from adult foraging or nesting grounds. Hatchlings spend most of their life as pelagic drifters in oceanic currents and drift-lines. Juvenile turtles are often found in shallow nearshore habitats. Adult green turtles feed in seaweed pastures, which may be found off rocky shores, and leatherback turtles on jellyfish, which may be found in abundance in open seas. It is believed that some breeding and feeding grounds may have been established several million years ago and moved further apart due to continental drift. Now, given that the foraging and nesting areas are far apart, if a turtle had to search and find a suitable nesting beach as an adult, it might have far less success than a turtle which blindly nested where its mother had. This beach would have been a favourable environment for hatching, as signified by its own survival.

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In India, tagging studies by the Orissa Forest Department and the Wildlife Institute of India in the 1990s have given several interesting results. Firstly, they have shown that the same turtles use all the mass nesting beaches in Orissa (see *Figure* 1 for nesting sites in Orissa). A turtle may nest first in Gahirmatha and then in Rushikulya or Devi river mouth. Gahirmatha and Rushikulya are over 300 km apart and this represents amongst the highest known internesting distances for sea turtles. This showed that all these turtles may belong to the same large population and had to be managed as a single unit for conservation. On the other hand, turtles that visited the same beach from year to year were found to nest at sites very close to where they had nested in earlier years. It was also found in this study (and in other studies at mass nesting sites in Costa Rica) that the same turtles nested solitarily and in mass nesting events or '*arribadas*'. This demonstrated that this was not a behavioural polymorphism, where some turtles might be genetically programmed to nest solitarily and others en masse. Rather, it seems to be a strategy that these animals can choose between, sometimes opting for both. Furthermore, tags returned from turtles caught in southern Tamil Nadu and Sri Lanka demonstrated that the turtles spent some part of the year in those coastal waters. However, contrary to expectations, they were found there not during the feeding season, but during the nesting season. Were they caught there on their migratory path to Orissa or were they perhaps attempting to nest there? We don't know yet.

Turning it on with Transmitters

Tagging turtles using metal/plastic tags on flippers only gives two positions, one where the turtle was tagged and the other where it was recaptured. Often, tags are recovered from turtles caught by fishermen and as in the above case, one does not know where the turtle was headed when she was abruptly killed. For this, one needs to go hi-tech. The recent development of satellite telemetry as a tool in tracking wild animals has come as a boon to many scientists. Long distance migrants can now be tracked by biologists from the comfort of their offices (another reason why this might appeal to some). Essentially, satellite transmitters, also called PTTs (platform transmitter terminals) are attached to the animal whose long distance movements are to be studied. Once they are turned on, the transmitters send high frequency signals, which are received by polar orbiting weather satellites. ARGOS, a French company, has equipment on board these satellites for tracking animal movements. The transmissions are first decoded to identify the transmitter, each of which has a unique code. The position of the transmitter is then

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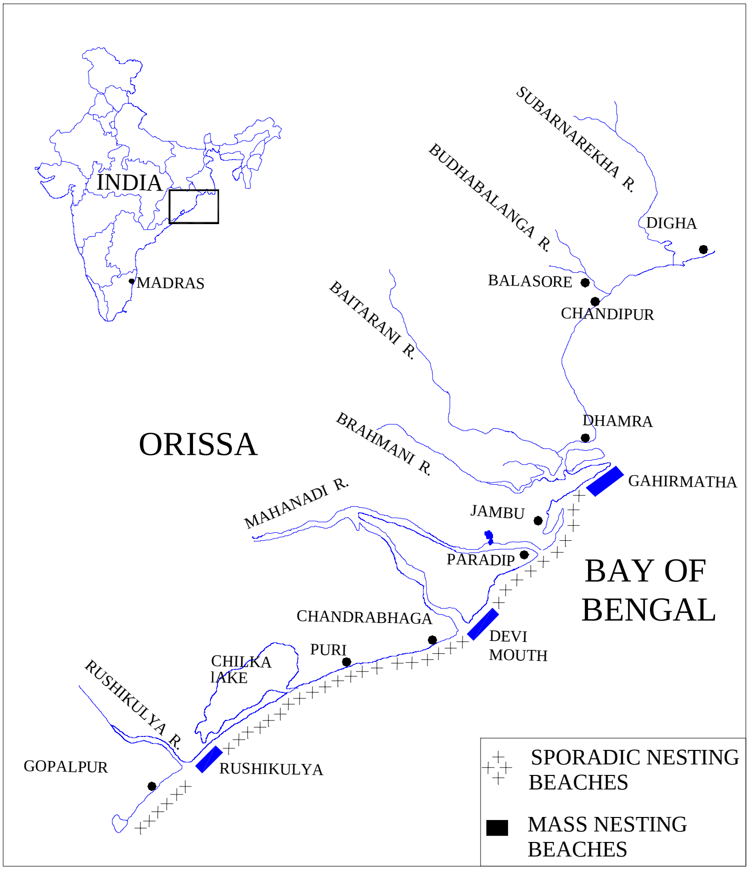
Figure 1. Map of nesting sites on the east coast of India.



calculated by Doppler shift. Many of us know that the frequency of sound from a moving object such as a car or train changes as the object approaches or leaves the receiver; this is called the Doppler effect. In this case, as the satellite moves across the sky, the frequency that it receives from the transmitter changes and based on this change or Doppler shift, it is able to calculate the position of the transmitter. The data are then downloaded by ARGOS and distributed to the client. Once the data are received, the latitudes and longitudes can be plotted on a map and the migratory routes of the animals can be traced. What makes marine animal tracking complicated is that the signals do not work when the turtle is underwater. A salt-water switch on the transmitter ensures that it is 'switched on' only when the turtle surfaces, thereby saving battery power when the turtle is under water. A duty cycle is also employed, wherein the transmitter goes off and on at periodic intervals. The duty cycle that we employ is 24 hours on, 48 hours off. During the 24 hours that the transmitter is on, it will transmit whenever the turtle surfaces.

From April 17-19, 2001, the team comprising the Orissa Forest Department and the Wildlife Institute of India in Dehradun accompanied Jack Frazier of the Conservation and Research Centre of the Smithsonian Institution to the Devi River mouth rookery. Once turtles had completed nesting, they were first measured and metal tags were attached to the flippers. Then, Kiwisat 100 transmitters, weighing about 600 gms (ridley turtles weigh about 50 kg) were attached to the carapace of the turtle using Epoxy, which does not generate heat and does not harm the turtle (*Figure* 2). These transmitters are hydro-dynamically shaped unlike previous models and have a keel to protect the antenna. They also have temperature sensors and surface time counters, which gives an idea of the proportion of time the turtle

Figure 2. Attaching satellite transmitters to turtles on the Orissa coast.

1. *The carapace of the turtle is first cleaned with alcohol.*

2. *The bottom of the transmitter is cleaned with alcohol.*

3. *Using a special gun, the two part epoxy is applied to the bottom of the transmitter.*

4. *The epoxy is then applied to the carapace of the turtle.*

5. *The transmitter is then pushed onto the back of the turtle and the epoxy is smoothened around the transmitter.*

(Photographs 1-5 by BC Choudhury)

6. *The exercise was followed closely by the local village community and two of the transmitters were turned on by children from the community (Photograph by Bivash Pandav).*

The strong nest site fidelity of adult female turtles prompted Archie Carr and others to propose that these turtles were returning to their natal beaches.

spends at the surface. They are provided with a battery that should last about a year, if the turtle spends about 30% of the time on the surface. After the transmitters were attached, the turtles were released by the collaborating scientists and a small group from the local fishing community. The data were received by all the project collaborators and are being analysed and mapped at the Wildlife Institute of India (*Figure* 3). Unfortunately, all 4 turtles ceased transmissions after 2 to 4 months. While there could be a variety of technical reasons for failure, the abrupt failure of all transmitters leads one to suspect mortality in trawl fishing nets, which is very high, especially in Orissa waters, where three of the turtles had remained till the end of June. These turtles were moving in large circles (100–200 km in diameter) which seemed to coincide with offshore currents or gyres. This was a surprising finding as all the turtles were expected to leave the offshore waters of Orissa and migrate to Sri Lanka as earlier tag returns had indicated. The fourth turtle did indeed migrate directly south till the coast of Sri Lanka, after which her transmissions also stopped.

Doing it with DNA

While satellite telemetry and tagging can help follow the movements of adult turtles, this still leaves the question of natal homing. The strong nest site fidelity of adult female turtles prompted Archie Carr and others to propose that these turtles were returning to their natal beaches. Do female turtles indeed return to the same beaches where they were born to nest as adults? This was a seemingly impossible question to answer, considering that hatchlings half the size of one's hand grow into 50 kg ridleys or 500 kg leatherback adults. Further, given the low survival rate from hatchling to adulthood (somewhere in the range of 1 in a 1000), the question seemed destined to remain forever a mystery. However, about 10 years ago, scientists started using molecular genetic analyses to study these questions. Now, a technique called mitochondrial DNA sequencing has been used most widely in these studies. Mitochondrial DNA is maternally inherited and a particular sequence or hap-

Box 2. Molecular Genetic Techniques in Evolutionary Biology

Molecular genetic tools have been useful for tracking turtles, not just through space, but also through time. Mitochondria are cellular organelles, known as the powerhouses of the cell, as they are the site for aerobic respiration, providing energy for cellular function. Mitochondria have their own DNA, independent of the nuclear DNA. During sexual reproduction, only mitochondria from the ovum become part of the zygote, and hence, mitochondrial DNA is always maternally inherited (there are currently some challenges to this belief in scientific literature). Since some regions of the mitochondrial DNA are hypervariable (have relatively high rates of mutation), these have served as useful areas of the genome to study relationships between species and to infer phylogenies, i.e. evolutionary pathways. The most commonly used tool in phylogenetic studies is sequencing analysis. DNA is composed of a series of nucleotides, each of which comprises a pentose sugar, a phosphate group, and a nitrogen base, which can be any of 4 compounds i.e. Adenine, Guanine, Thymine, and Cytosine. Each DNA strand can thus be characterised as a unique series of nitrogen bases (e.g. ....TTACGTCTAG...). In sequencing analysis, the base sequence of a very specific section of the DNA (usually 400–1000 bases) is elucidated. Due to mutations, this sequence may differ between individuals, populations and species. Each unique sequence is known as a haplotype and the difference between haplotypes is used to infer population structure and phylogeny. Another popular technique today in the study of nuclear DNA is microsatellite analysis. Microsatellites are short multiple repeats (e.g. TATATA or GCGCGC, usually 100 to 400 bases long), found throughout the genome. These microsatellites vary in the number of the repeats and it is this variation that is used to study the difference between individuals and populations. This technique is used widely to study fine population level difference in genetic makeup, and in paternity analysis.

lotype is passed on from mother to offspring (see *Box* 2). Therefore, if hatchlings did not return to the same beaches where they were born, one would expect that haplotypes would be mixed between populations, especially when turtles from two nesting sites occupied the same feeding area. In one of the most dramatic demonstrations of natal homing, it was found that within a group that occupied the same feeding area off the coast of Brazil, one population migrated north to Surinam and another east to the Ascension Island in the middle of the Atlantic. The haplotypes of the two nesting populations were completely different. This meant that green turtle females did in fact return to their natal beaches to nest as adults. Initially, this was taken as confirmation of the natal homing hypothesis for sea turtles in general, but more studies now suggest that the picture is not quite so clear for some of the other species. Studies on the nuclear DNA of marine turtles shows a much lower level of

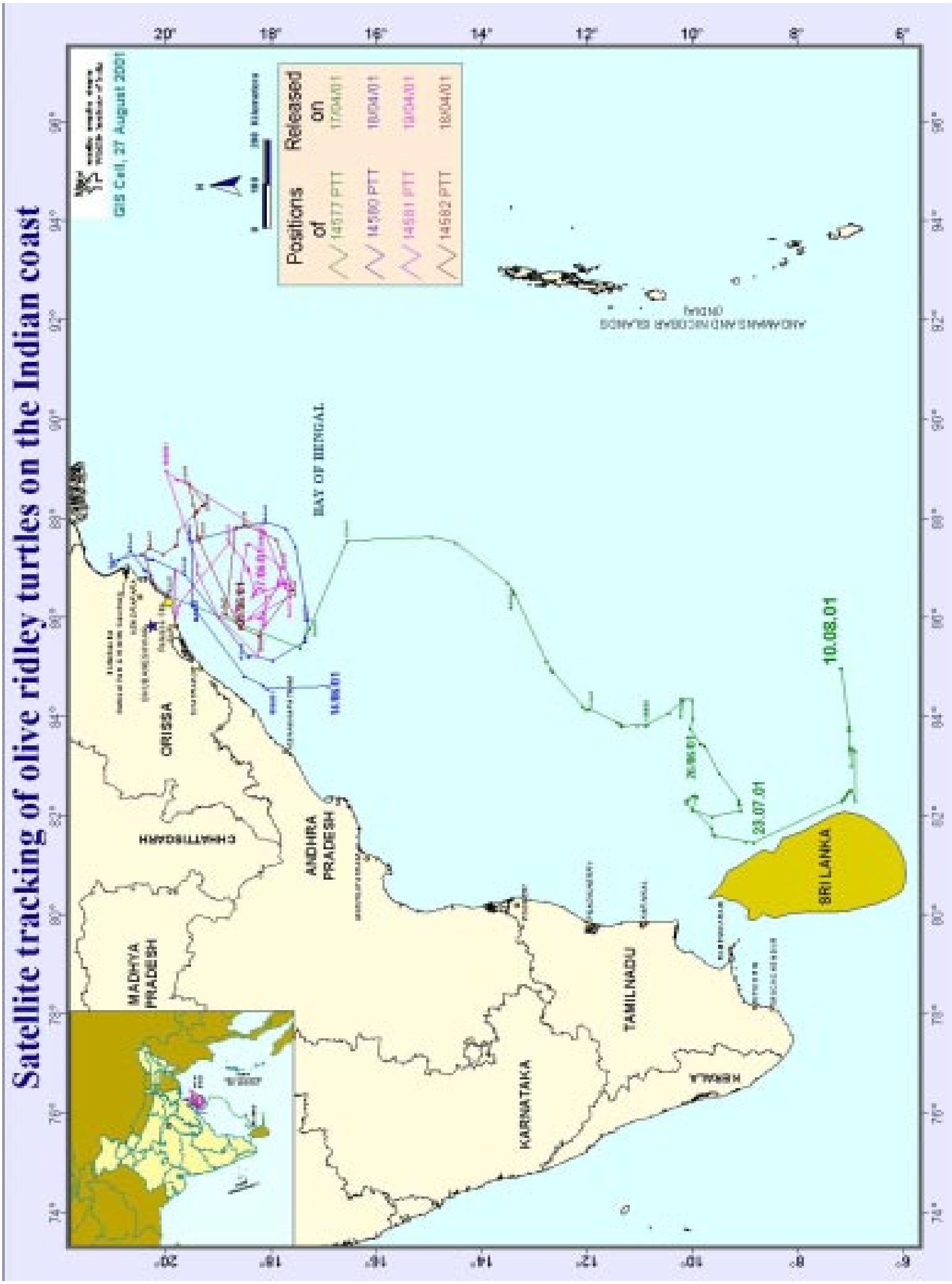

Satellite tracking of olive ridley turtles on the Indian coast
BAY OF BENGAL
ORISSA
CHHATTISGARH
MADHYA PRADESH
ANDHRA PRADESH
KARNATAKA
TAMILNADU
KERALA
SRI LANKA
10.08.01
23.07.01
Positions of
Released on

Figure 3.

population structure, indicating that there is gene flow between populations brought about by males. A recent mt DNA study on male green turtles in Australia shows that they also return to their natal beaches for breeding, suggesting that cross population gene flow might be a consequence of mating during breeding migrations.

Molecular genetic studies have now also been used to compare the haplotypes of turtles from different oceanic regions to trace migratory routes. For example, juvenile loggerhead turtles in Baja California had the same haplotypes as females nesting in Japan, thus proving that these turtles make extraordinary trans-Pacific migrations, which has now also been confirmed using satellite telemetry.

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A Tale of Two Turtles

Genetic techniques have been instrumental in shedding light on one of the oldest and most acrimonious of sea turtle debates, the species status of the east pacific green turtle or black turtle, *Chelonia mydas agassizi*. The green turtle, *Chelonia mydas* is found globally and the status of the East Pacific black turtle has long been debated by sea turtle biologists and conservationists. The black turtle is smaller, has a domed carapace and has a darker coloration than most greens and has been considered by some taxonomists to be a separate species. However, all molecular studies show a Pacific–Atlantic dichotomy in green turtle populations, with black turtles being a subset of the Pacific population. Black turtles are not genetically distinct and therefore not a full species, but they may however be an incipient evolutionary lineage i.e., a species in the process of formation. Bowen and Karl, sea turtle geneticists, suggested that the taxonomy of the black turtle had been motivated by factors other than objective scientific considerations, and they suggested the term 'Geopolitical species concept' to describe this process. Many biologists have now argued that a population need not require to be conserved only if it is a different species and as a corollary, species descriptions should not depend on conservation considerations. Conservation prioritization is (or should be) dependent on a variety of considerations, some of which may be scientific, while others may be cultural, political, logistic and commercial. The taxonomy and phylogeny of species, unlike conservation, are purely academic concerns, and neither should influence the other, especially when there is currently so little agreement on what a species really is.

Regardless of these ongoing debates, there is no doubt that mitochondrial DNA studies have helped elucidate the global population structure of marine turtles. Since mitochondrial DNA is maternally inherited, the strong population structure evidenced by this technique proves the natal homing hypothesis, while less distinct patterns in nuclear DNA suggest male mediated gene flow between populations. Nuclear DNA analysis, using regions of the DNA called microsatellites, have also been used to conduct paternity analysis. How many males contribute to a clutch? Despite a promiscuous reproductive life, where many males mate with many females, most populations of turtles studied so far seem to have single paternity in clutches and often, across clutches as well. In future, rookery specific DNA markers can resolve nesting cohorts in feeding colonies of mixed genetic stocks, as well as permit forensic identification of marine turtles from meat, shell and other products.

Genetics work on the east coast of India shows that the Indian ridley population is the oldest stock and in fact may be the source for all contemporary ridley populations. Perhaps Orissa is the cradle for the world's ridleys.

With regard to ridley turtles, it was hypothesized that they diverged into the Kemps ridley and olive ridley turtles, when they were isolated in Atlantic and Pacific by the formation of the isthmus of Panama. However, this theory means that east Pacific olive ridleys should be the oldest stock amongst ridleys. However, our genetics work on the east coast of India shows that the Indian ridley population is the oldest stock and in fact may be the source for all contemporary ridley populations. The evidence suggests ridleys in the Pacific and Atlantic may have gone extinct periodically over evolutionary time, and been recolonised from ridleys in the Indian ocean, specifically the population on the east coast of India. Perhaps Orissa is the cradle for the world's ridleys.

Where do We go from Here ?

As in all facets of science, particularly in a nascent field such as ecology, more information will help destroy many existing theories, reshape some and confirm a few. The more we find out about sea turtles, the less it appears we know. While these animals will continue to fascinate biologists for many years to come, it is important to maintain perspective with regard to their conservation and the protection of the marine habitats they occupy. East Pacific green turtles are endangered and must be protected regardless of whether they are classified as a separate species or not. Olive ridleys in India need to be protected on our coasts regardless of whether they migrate to Sri Lanka or Indonesia or into the open ocean. Despite protection measures enacted in India, when the turtles return to the sea - where they spend most of their lives – they are subject to numerous threats on the high seas and the Exclusive Economic Zone of various countries. Hence, Indian and neighbouring countries and their conservation organisations need to work in conjunction with the relevant fisheries sectors to develop marine conservation strategies.

Much as science will help us learn about the biology of these animals and formulate pragmatic strategies for conservation, building cooperation and awareness is probably a more important component of the long-term goals of conservation. Conservation is after all at least as much about the management of people as it is about the management of habitats. And sea turtles, being a shared resource, force diverse peoples from across disciplines – science, law, journalism, teaching, social science – to collaborate with and talk to each other. They are the 'Ocean's Ambassadors' for conservation, moving between countries and regions and forcing them to communicate and cooperate towards the common goal of conservation.

Suggested Reading

[1] P L Lutz and J Musick, *The biology of sea turtles,* CRC Press, USA, 1997.

[2] S A Karl, and B W Bowen, Evolutionary Significant Units versus Geopolitical Taxonomy: molecular systematics of an endangered sea

Box 3. *Kachhapa* – The Newsletter and the Web Site

Kachhapa is a newsletter for sea turtle conservation and management in South Asia with an emphasis on the Indian subcontinent. The newsletters are available online in PDF format and a limited number of printed copies are also available.

Call for Articles: Kachhapa, the newsletter, was initiated to provide a forum for exchange of information on sea turtle biology and conservation, management and education and awareness activities in the South Asia, particularly the Indian subcontinent. The newsletter also intends to cover related aspects such as fisheries and issues related to coastal habitats. For the moment, *Kachhapa* will come out two to three times a year. We request all our contributors to continue sending us information from their part of the subcontinent, including articles (which will be peer reviewed), short notes, letters and announcements. We welcome casual notes, anecdotal accounts and snippets of information. Online or electronic submissions are encouraged.

Help us with our Mailing List: Since this newsletter hopes to serve as a link for coastal and marine conservation, the more people we can reach, the more effective it will be. You can help by passing the newsletter around to people and organizations who are interested, and by helping us build up our mailing list. Please send us names and addresses of individuals, NGOs, research institutions, schools and colleges and anyone else who would be interested in receiving *Kachhapa*. Electronic versions of past and present issues of *Kachhapa* can also be received by email automatically. For subscription services, visit <http://www.kachhapa.org/subscriptions/>.

Web Site: The web site is available at: <http://www.kachhapa.org/> and has HTML and pdf versions of all newsletters featuring a full text search; subscriptions to receive the newsletter or just the table of contents directly in your email; searchable database of sea turtle researchers, conservationists and organizations in the south Asia region; news and articles from the south Asia region.

turtle (genus *Chelonia*), *Conservation Biology*, Vol.13, pp. 990-999, 1999. (And related articles in the same issue.)

[3] B W Bowen and S A Karl, Population Genetics, Phylogeography and Molecular Evolution, In *The biology of sea turtles*, Eds Lutz and Musick, CRC Press, USA, 1997.

Websites

http://www.kachhapa.org – Contains information on sea turtles of the Indian subcontinent, the *Kachhapa* newsletter, and updated map of the olive ridley satellite telemetry in India (see Box 3)

http://www.seaturtle.org – General information on sea turtles and the online version of Marine turtle Newsletter

http://www.tamar.org.br/satellite.htm – Project Tamar's satellite tracking project of loggerheads in Brazil

http://www.accstr.ufl.edu – Archie Carr Centre for Sea Turtle Research, University of Florida, Gainesville

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