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Sea Turtle Research

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1. Introduction

1.1 Definition

Telemetry includes an array of techniques that allow remote monitoring, measurement and recording or reporting of information. It was first used in weather research and has expanded quickly to other disciplines. Relatively accurate measurements without direct observer participation allow some important research that was impossible to conduct in the past. This has an important implication for study of life history traits of species that migrates long-distances, such as sea turtles. The ocean habitat, wide distribution ranges and movement across political boundaries all create difficulties for direct study of sea turtle behavior. Telemetry can overcome these obstacles and is a cost-effect tool for behavioral ecology.

1.2 Importance to sea turtle researches

1.2.1 Life history trait studies

Animal migrations, especially long-distance movements, are to explore for resources across substantial temporal and spatial scales. They are often adaptations for avoiding seasonal depletion of local resources in order to survive and reproduce in suitable environments (Alerstan et al., 2003; Southwood and Avens, 2010). Sea turtle hatchlings, because of high predation pressure in nearshore waters and otherwise unsuitable habitats near nesting beaches, must migrate (actually they must "drift") after leaving their nests to suitable nursery grounds (Bolten, 2003). In addition, sea turtles evolved from freshwater turtles (Pritchard, 1997). Thus, even though these giant reptiles have successfully invaded the ocean, they must still return to their natal beaches to nest (called "natal homing"; Carr, 1967). Therefore, migrations play substantial roles in the survival of sea turtle populations.

Sea turtles are ocean-wide, long-distance migrating reptiles that spend more than 95% of their time at sea. Except for leatherbacks, olive ridleys, flatbacks and some loggerheads, hatchlings spend their early lives drifting in the ocean (often referred to as "the lost years"; e.g. Bolten, 2003; Carr, 1967). After 5 to 7 years in the open ocean, they migrate into food-rich nearshore waters and feed along the bottom (Carr, 1967; Plotkin, 2003). Some food-rich areas, such as coral reefs, seagrass beds and nearshore fishing grounds are the sites favorable for juvenile sea turtles (e.g. Hawkes et al., 2006). Due to the developmental shift in nutrient requirements and other needed conditions for growth, sea turtles often exhibit an ontogenetic shift in habitat (Crouse et al., 1987). In addition, different species may stay in different habitats. For example, green, hawksbill, olive ridley, flatback and some loggerhead turtles migrate into nearshore waters when they advance from hatchling to juvenile status, while leatherbacks and some loggerhead turtles remain in the open ocean until adulthood (Bolten, 2003). Therefore, understanding the population dynamics of these giant reptiles requires detailed information for each life stage.

1.2.2 Energy and material transformation among ecosystems

Sea turtles are important in the dynamics of material and energy in the ocean, especially in nearshore ecosystems. Even though the migration of sea turtles is resource-driven (Plotkin, 2003), they can transfer the energy and material they have gathered by feeding hundreds to thousands of miles away to their nesting beaches and nearshore waters. The materials are deposited in the form of excretion, feces and eggs, providing resources for the local ecosystem (Bjorndal and Jackson, 2003). Also, they can transfer the materials and energy from feeding during their post-nesting migrations to their foraging and resting areas in the form of excretion and feces (e.g. Bjorndal and Jackson, 2003).

1.2.3 Sea turtle conservation

Sea turtles appeared in the world more than one hundred million years ago. Due to their large body size, fast swimming speed and scales and scutes armor, they thrived through the age of dinosaurs and the radiation of mammals until two hundred years ago. The ancient character of sea turtles raises great interest in understanding their phylogeny, adaptive evolution, distribution and migratory behavior. Furthermore, the high commercial value and development of their nesting beaches for human recreation and housing projects, the losses they sustain to fisheries by-catch, the effects of pollution, the ingestion of marine debris and other human impacts have resulted in severe depletion of these once abundant marine reptiles (Hutchinson and Simmonds, 1992). The endangered status of sea turtles stresses the importance of understanding how they migrate from one life-stage habitat to the next, migrations being among the most vulnerable phases of their lives. Adequate knowledge of migrations is critical for design and adoption of effective conservation measures. The puzzles of migration can be largely solved through the application of telemetry tools, along with other techniques such as genetic markers of relationship (e.g. Bolten et al., 1998).

2. History of sea turtle telemetry studies

2.1 Initiation ages

Sea turtles are endangered or vulnerable species according to the list of the World Conservation Union (IUCN, 2003). They are difficult to track because a majority of their lives is spent in the ocean. In addition, the conservation status forbids extensive sampling and sacrifice of live specimens. Thus, the life history of sea turtles has remained largely unknown for a long period of time. In the past, Dr. Carr used helium balloons (Carr and Schroder, 1967) and flipper tagging (Carr, 1980) to track the whereabouts of sea turtles in the ocean, but without much success. The problems remained unsolved until the late 1970s when satellite telemetry techniques were first applied to wildlife studies (Stonburner, 1982;

Taillade, 1992). Solutions to the mysteries of sea turtle movement in the ocean have begun to emerge.

The first publications on satellite telemetry were by Timko and Kolz (1982) and Stoneburner (1982), based on studies conducted in 1979. The tags they used, designed to study the migrations of polar bears, reported to Nimbus satellites. Despite the cumbersome tags involved, the success of their work strongly encouraged researchers to apply satellite telemetry to sea turtle migratory behavior worldwide.

2.2 Early generation of satellite telemetries

The early generation of satellite tags was heavy and large, such as the Telonics ST-6 and ST-14 PTT. All the data were processed by the Argos system (Taillade, 1992). They only provides locations based on Doppler analyses, date and time of the data collection, location class, dive duration and on-site temperature. The accuracy and confidence limits of each location were determined based on how many transmitted data the satellites received during the passover period and were referred to a location class (LC). The most accurate LC (LC 3) has an estimated precision <150 m when at least four messages are received during a satellite pass. The worst available location class has only one message during a passover, with no estimate of location accuracy (LC Z; Argos, 1996). The relatively low accuracy of the location data and the diving behavior of sea turtles, only surfacing briefly for breath (e.g. Lutcavage and Lutz, 1997), resulted in small data volumes with high uncertainties. Despite these shortfalls, the widespread application of this technique allows us a thorough understanding of the behavior and distribution of animals, especially those most difficult to observe in the past. For example, by deploying 7 Argos-linked satellite PTTs (platform terminal transmitters) on green turtles that nested on Wan-an Island, Penghu Archipelago, Taiwan from 1994 till 1996, Cheng (2000) found that they migrate to coastal waters in Northeast Asia after their nesting seasons.

2.3 Radio and sonic telemetries

Distinct from satellite tags are directional radio and sonic telemetry and ultrasonic-pinger tracking. Directional radio and sonic telemetry have been used widely to track terrestrial animals such as rabbits, raccoons and striped skunks (e.g. Cochran et al., 1963), and also birds (e.g. Fuller et al., 1988). However, application of these techniques to sea turtle migration study is very limited. Because positions of animals are determined by triangulation, radio telemetry can only be applied in areas where three receivers can be set up. Thus, most studies on sea turtles are limited either to the coastal zone during short-term studies of movements between nesting visits to the shore (e.g. Dizon and Balazs, 1982) or to estuarine environments (e.g. Brauna et al., 1997) where the detection range is less than 5 km. Ultrasonic pinger tracking involves attaching a pinger to the trailing edge of a sea turtle's dorsal carapace, and then locating its position by listening with a hydrophone from a boat. Theoretically, the receiver can detect signals within 1 to 2 km. In practice, however, due to the attenuation of the sound and contamination of the sound by noise from waves, turbulence, marine organisms, etc., the signal can only be heard clearly within 100 to 200 m. Thus, this system, like radio tracking, works better for very short-range studies, such as diel migration in foraging grounds or coastal movements. (e.g. Addison et al., 2002). The labor-intensive aspect and the short range of detection have curtailed extensive development of these telemetry systems.

2.4 Diving behavior studies

Since 1980, researchers have turned their attention to the study of sea turtle diving behavior. This is based on the general interest in animal behavior and to serve conservation purposes Techniques have indeed been developed to record turtle diving behaviors. Time-Depth Recorders (TDRs) have been used for this purpose since the late 80's (Eckert et al., 1986; Hays et al., 2001). A TDR contains pressure and light sensors and a clock. Thus, one can calculate the depth and record the diving behavior of a sea turtle during the course of monitoring. A TDR is a self-recording device without transmitting function, so the instrument and data must be retrieved before the dive sequences can be analyzed. This limits application mainly to the study of diving behavior for short durations in narrow geographic areas, such as the intervals between nestings (e.g. Cheng, 2009).

2.5 Advancement in satellite tag performances

For satellite telemetry studies, the advances of computer techniques in the 1990s enabled development of satellite tags that are smaller, lighter and with greater battery capacity. These improvements allow application of satellite tags to a wider range of both species and ages for longer tracking durations. For example, Shaver and Rubio (2008) used satellite tags to study the migration of the "head-strated" olive ridleys. They confirmed that nearshore areas close to the release points of the "head started" turtles are their main foraging grounds. In addition, the migration behaviors of the "head started" release turtles were similar to those of wild-born turtles. Recently, Wyneken et al. (2008) used miniature satellite tags to track small juvenile loggerhead turtles, discovering the migration of the hatchlings during their "lost years" proposed by Carr (1967).

Advances in tag performance include addition of new sensors. Thus, more information on the life history traits can be measured. Among the most useful and widely used are pressure sensors, which enable us to characterize the diving behavior of the tagged animal along the migration route. We can now view sea turtle migration patterns in three, rather than two, dimensions. An important example is the SDR (Satellite Depth Recorder) produced by Wildlife Computer Inc. Depth sensors require extended recording, enabled by the SPLASH, MK-10 tags and SRDL (Satellite Relay Data Logger) produced by the Sea Mammal Research Unit. Other sensors attached to turtles and reporting via satellite tags include IMASEN (Inter-MAndibular Angle SENsor), which is used to understand the foraging behavior of a sea turtle during migration (e.g. Fossette et al., 2008), and a body temperature logger, which is used to understand how large sea turtles like leatherbacks maintain body temperatures suitable for survival in both warm tropical and cold polar waters (Casey et al., 2010). These improvements in data collection provide more complete understanding of sea turtle life history traits other than simple migration routes in the wild. After review of more than 130 relevant publications over 20 years, Godley et al. (2008) confirmed that detailed information on sea turtle life history traits in the ocean can be gathered through this technique. However, the limit on the available storage space on the environmental polar orbiting satellites curtails the detailed information provided from the sensors themselves.

2.6 GPS satellite telemetries

A new technique emerged in late 2000—the GPS (global positioning system) satellite tag. This advance acts as the stepping stone to a new era of telemetry studies. GPS was developed in the early 1970s to overcome the limitations of navigation systems and mainly was used for military defense purposes at that time. A code (i.e. SA; Selective Availability) added by the US government resulted in poor resolution (± 100 m) for the civilian purposes. Lifting of the SA interference in 2000 increased the accuracy of GPS positions substantially (< ± 10 m). This enables us to apply GPS to the study of animal behavior more widely. Despite this improvement, the application of GPS to marine organisms, especially those emerging briefly for breath like sea turtles, is still impossible. Each geographic location determined by the GPS device requires confirmation from at least 6 satellites, which takes about 3 minutes to complete. The breath duration of sea turtles is equal to or less than 90 seconds. Thus, the GPS can only be applied to general oceanographic studies, such as buoy tracking. Only in recent years has the development of Fastloc technology allowed combining GPS with satellite telemetry technology. According to a document available from Widllfie Computer Inc. (www.wildlifecomputers.com), this software can acquire position signals within 10 mS. This makes possible the study of sea turtle movement on fine scales, such as home-range studies during the inter-nesting interval (e.g. Schofield et al., 2009).

2.7 Underwater video camera--Crittercam

In recent years, underwater video camera systems have been introduced to “visualize” an animal’s behavior in the water by attaching the camera to the carapace aligned toward the head. This system is called “Crittercam” and has been funded mostly by the National Geographic Society. Seminoff et al. (2006) used this system to determine that there are six different diving patterns and three foraging strategies of the green sea turtle. Furthermore, they found that sea turtles may conduct different types of activities during the same dive. Thus, one has to interpret diving behavior with caution. Because this system provides more information than the TDR, it provides us new interpretations of the diving behavior of sea turtles in the wild. However, due to the expense of the instruments and lack of transmission capability, Crittercam has to be retrieved and the data downloaded. Therefore, application of this technique to the diving behavior of sea turtles is still limited.

3. Retrievable recording studies

3.1 Time-Depth Recorders (TDRs)

Retrievable recording instruments are self-recording devices without data transmitting ability. They are mainly used for the study of animal diving behavior. The most important instrument in sea turtle research is the TDR.

Sea turtles spend more than 95% of their time in the ocean, and their migration behaviors are not simply swimming in surface water and recordable in just 2-dimentions. Rather, they dive during their migrations; thus, migrations are three-dimensional movements. Similarly to marine mammal activity, how sea turtles adapt to changes of water temperature and pressure when diving is an interesting physiological question. For example, Boye (1997) discussed the relationships among foraging depth, lung oxygen content, dive duration, water temperature and the size of sea turtles. TDR has been used widely to record the diving behavior of sea turtles since late 80’s (e.g. Eckert et al., 1986; Hays et al., 2000a), enhancing our understanding of sea turtle diving substantially.

3.2 Dive patterns

Based on the high frequency of TDR sampling (1 second or less per sample) the pattern of each dive can be represented graphically. Basically, six diving patterns have been identified, U, V, W, S (include inverse S), shallow and "others". U dives are mainly used during rest intervals or for moving along the seabed (Cheng, 2009); V dive are mainly used for traveling or exploring the environment (Hochscheid, et al., 1999); W dives are commonly considered as foraging dives during which turtles spend time in a food patch (Fossette et al., 2008); S dives are apparently related to energy conservation (Hochscheid et al., 1999); shallow dives are mainly used for swimming in near-surface waters (Houghton et al., 2002); and "others" are dives that combine more than one dive type. The high resolution of the diving pattern allows us to explain what turtles really do during diving periods, including the diel variability of the behavior (Storch et al., 2005). This instrument has used to study the diving behavior of immature hawksbill (van Dam and Diez , 1996), wild hawksbill turtles (Storch et al., 2005), gravid leatherback turtles during the inter-nesting interval (Eckert et al. , 1986; Southwood et al., 2005), green turtles (Hays et al., 2004) and loggerhead turtles (Houghton et al., 2002). It is generally found that most gravid females conduct resting U-dives during the inter-nesting intervals, decreasing this dive type and switching to shallow dives a few days prior to nesting events, apparently searching for the proper nesting beach (Cheng, 2009). Recently, a new device has emerged on the market, the G5 tag. It is a miniature tag, 8 mm long and 1.3 g weight in the water. This instrument has been used to study the diving behavior of jellyfish (Hays et al., 2008). It may enable us to study the diving behavior of turtle hatchlings after they enter the sea.

3.3 Long-term migration studies

Only a few researchers have employed TDR tags to conduct long-term migration studies that include pre-nesting, inter-nesting and post-nesting periods (e.g. Rice and Balazs, 2008). A requirement for conducting such TDR studies is that researchers must understand the whereabouts of sea turtles in detail. Then they can determine when and where to retrieve the TDR. Based on the results of the above studies, one can clearly define the diving behavior and the physiological significance of different dive patterns, as well as the responses of sea turtles to the temporal and spatial variations of both food availability and hydrodynamic features. This has made an indelible contribution to the understanding of the diving behavior of sea turtles.

4. Non-retrievable telemetry studies

4.1 Satellite telemetry studies

Non-retrievable telemetry instruments use an antenna to transmit data they have collected via radio to a boat or shore station or via radio to a satellite and from the satellite to a ground receiver. They do not require having the instrument in hand to download the data. Therefore, they can be used to determine movement patterns across wide geographic areas and under varied environmental condition. Due to the size limit of this chapter, I will only focus on the instruments most widely used to date such as satellite telemetry.

There are two kinds of satellite tag; the conventional satellite PTT (platform terminal transmitter) tag and Pop-up Archival Transmitting (PAT) tags. Each tag is designed for a specific purpose and provides slightly different information.

4.2 Conventional satellite telemetries

A conventional satellite PTT transmits its data to a satellite at frequency determined by the user, e.g. 6 h on (transmitting) and 6 h off (not transmitting). Because radio signals cannot be transmitted under water, there is a salt-water switch installed on the tag that stops transmission of signals 5 seconds after the sensor is covered by the water, in most cases when the sea turtle starts to dive. It allows transmission when the turtle surfaces. Combining the salt-water switch with intermittent transmissions maximizes tag performance and extends battery life significantly. Because sea turtles are air breathing, this kind of tag enables us to track their migrations in detail.

Sea turtles are capital breeders, investing heavily in their beach deposits of eggs (Southwood and Avens, 2010). They must use hydrodynamic features effectively in order to arrive at nesting destinations at suitable seasons, reduce unnecessary costs and increase their fitness. However, both genetic and tagging studies show that sea turtles migrate several hundreds to thousands miles to both forage and nest (Bowen et al., 1995; Cheng, 2000), even crossing entire oceans (Bolten et al., 1998; Hughes et al., 1998). There is much evidence also showed that, except for a few species like flatbacks (*Natator depressa*), sea turtle species have widespread distributions in the oceans (Bowen et al., 1992). Thus, use of environmental information to determine their migration routes is essential to the survivor of their populations. Studies have shown that currents, fronts, winds, Earth's magnetic field variations, bathymetric features, path integrations and more factors are important influences determining the migratory navigation of sea turtles (Plotkin, 2003).

Many studies have shown that the highly migratory species tend to use surface currents to conduct their long-distance movements (e.g. across the ocean) (Bolten et al., 1998). From a physiological ecology point of view, swimming with the current can reduce energy expenditure. However, it is not easy to prove this argument. Usually, in addition to the migratory routes of animals, researchers also need the current trajectories or related information to determine the relationships. One may misinterpret the relationship if the two parameters are evaluated on the different scales. For example, when examining the overlap of migration routes tracked by the satellite telemetry with surface chlorophyll distributions in Atlantic, Hays et al. (2002) found no apparent relationship between the post-nesting migration of green turtles from Ascension Island and surface currents. It is possible that the scale of measurement for chlorophyll is much larger than that of the migration routes of the turtles. In other cases, the relationship is more straightforward. For example, Hawkens et al. (2006) combined satellite telemetry with surface currents and chlorophyll distribution, revealing that larger loggerhead turtles in the Atlantic migrate to the coastal waters, while smaller ones remain in the open ocean.

4.3 Study the diving behavior with satellite telemetries

Some researchers try to expand the function of conventional PTTs by using the dive duration to judge the diving behavior (e.g. Godley et al., 2003). However, due to the fact that this instrument does not provide detailed information on dives (see TDR functions in the previous section), researchers can only evaluate the diving behaviors in different waters. The application of this device to study diving behavior is quite limited.

Adding pressure sensors to satellite tags is a substantial improvement. In addition to the position data provided by conventional satellite tags, pressure data allows us to study sea turtle diving behavior during oceanic migration. Two of the most widely used combinations are the SDR (Satellite Depth Recorder) and SRDL (Satellite Relay Data Logger), already mentioned. However, due to the limited space available in the satellite to store data for transmission, not all the collected data are processed and send to the user. SDR only provides the percentage of time a sea turtle stays in a specific water depth. It does not describe the full diving behavior, but it does reveal the water depths where sea turtles explore most frequently. Howell et al. (2010) used SDR-10 and SDR-16 tags to track loggerhead turtles captured as longline by-catch in the mid-Pacific. They found that the seasonal diving behavior of these immature turtles is related to hydrodynamic features such as eddies and the depth of the mixing layer.

Sea Mammal Research Unit selects the five most representive positions in a dive profile from SRDL (Satellite Relay Data Logger) data and provides them to the user. One can then reconstruct the dive profile based on those five positions. By using this device, Hays et al. (2004) found that, once leatherbacks migrated well out into Atlantic Ocean, they go deeper and deeper the longer away from the nesting beaches. They suggested that this behavior was related to foraging activities. Hamel et al. (2008) deployed SRDLs to study the inter-nesting diving behavior of six olive ridley turtles offshore from Northern Australia and found that they spent most of the time resting on the seabed and decreased dive durations a few days prior to each nesting event.

In recent years, these instruments reporting to satellites have been used extensively to study the diving behavior of sea turtles during their post-nesting phase, even their whole migration periods. Among sea turtles, leatherbacks are the best candidates. This is because leatherbacks make cross-ocean migrations. They nest on tropical beaches and forage in sub-polar waters. Their exclusive food items - jellyfish – are distributed widely in the open ocean; from pole to pole and from surface to several hundred even a thousand meters depth. Thus, the study of their diving behaviors can provide long-term and rich information on their life history traits. López-Mendilaharsu et al. (2009) conducted a long-term study of leatherback turtles with SDRL, confirming the high use area for nesting in South Africa and the relationship between the dive depth and the concentration of zooplankton.

4.4 Dichotomous development in satellite tracking devices

The emergence of GPS satellite telemetry creates a new dimension in the study of animal behavior. For example, by combining GPS satellite telemetry with the local marine environmental data, Schofield et al. (2010) determined the home range of nesting loggerhead turtles at Zakynthos Island, Greece. Furthermore, they found that the females would adjust their home range and nesting beaches slightly, depending on weather conditions, to maintain the maximum fitness of the population.

There has been a dichotomous development in satellite tracking devices after emergence of GPS technology. Despite their fine-scale position resolution, GPS satellite tags are not equipped with pressure sensors, and thus provide no diving information. On the other hand, even though SDR or SRDL does provide good dive information it still relies on the Argos system to determine positions. There is an urgent need to combine these techniques to provide comprehensive information on 3-D behavior of sea turtles in the ocean. Furthermore, despite the improvements in tag performance, a major drawback is the limitation on power supply. The water-tight design of the satellite tag does not allow battery replacement. Thus, if the antenna has not broken during operation, the lifetime of the tag depends mainly on battery life. Even though the manufacturer uses lithium batteries, saltwater switches and pre-set transmitting intervals to extend tag lifetime, scarcely any telemetry study lasts more than 2 years. Some researchers try to extend their tag life by using 2 batteries instead of one or by refrigerating tags to protect the batteries. Still, tags cease transmission once their batteries are drained. The remigration interval of sea turtles usually lasts from 2 to 7 or more years, which is much longer than the battery lifetime. Therefore, the understanding of life history traits throughout the period before remigration will be limited. One solution to this problem is to use solar-battery satellite tags. This tag is still in the protocol stage at this writing. The other solution is to invent a hydrodynamically rechargeable battery.

4.5 Pop-up PAT tags

PAT tags are designed to track the large-scale movements and behavior of fish and other animals which do not spend enough time at the surface to allow the use of real-time satellite tags (http://www.wildlifecomputers.com/technologies.aspx?ID=4). In sea turtle research, PAT tags are used to study survivorship. A PAT must detach from the animal and surface before the data it collected (e.g. temperature, depth, light level) can be transmitted to a satellite. Thus, the length of attachment is a compromise between the requirements for the tag to release properly and the need for long-term attachment. The interval should also allow for operation of a break-away link should the animal become entangled (Epperly et al., 2007). PATs are usually used to determine the post-hooking survival rate of marine turtles interacting with fishing gear such as longlines. Sasso and Epperly (2007) deployed them on 15 by-caught loggerhead turtles in the North Atlantic Ocean and found that lightly hooked turtles may not suffer any additional mortality after release. Despite these important functions, the major drawback of PAT tags is that they only transmit signals when they surface, thus providing only one position datum (the tag surface position).

5. Multi-disciplinary telemetry studies

5.1 Combination the satellite telemetries with oceanographic features

Multi-disciplinary telemetry studies combine telemetering devices with other techniques, sensors and oceanographic instruments for sea turtle research. With advances in image processing in recent years, we can combine migration route data with oceanographic features like chlorophyll distribution, sea surface height, temperature, salinity, etc. Then, the influence of oceanographic features on sea turtle behaviors becomes graphically evident. Saba et al. (2008) found that ENSO, by influencing the abundance of major food sources, specifically jellyfish for leatherback turtles, determines the number in the nesting population in the next year; warm El Niño years had decreased nesting populations, while cold La Niña years had greater nesting populations.

Recently, the focus of telemetry studies has shifted to the relationship between sea turtle migration and currents. From the physiological point of view, migration routes of sea turtles are influenced by the distance to food sources (Godley et al., 2003). For example, in order to save energy on long-distance trips, sea turtles may divide migration routes into several sections and feed during the migration to reduce the energy depletion and replenish body energy reserves (Alerstan et al., 2003).

5.1.1 Qualitative evaluation the relationship between oceanographic features and migration behavior

Physical features in the ocean, such as tidal currents can influence the migratory behavior of sea turtles. Alerstan et al. (2003) believed that currents can be either beneficial or negatively impact the long distance migration of sea turtles. Some recent studies even estimate qualitatively the extent of current influence on the migration of sea turtles. For example, in a recent review paper, Sale and Luschi (2009) pointed out that sea turtles adjust their migration speed and direction to overcome the influence of currents to reach their destinations. Recently, Hay's research team fitted buoy tracks and particle drifts in the ocean into a Lagrangian drifter model. They compared the model results with satellite tracking trajectories of turtles, distributions of foraging areas, nesting sites and a genetic map to prove that, after hatchling green turtles enter the sea, they drift with the current to their distant foraging ground. Then, with the aid of surface current, they return to the vicinity of their birth places to forage after reaching the size of immature juveniles (Hays et al., 2010).

5.1.2 Quantitative evaluation the relationship between oceanographic features and migration behavior

In addition to qualitative studies, some researchers try to determine quantitatively the influence of current on the migration behavior of sea turtles. Most such studies are done by fitting the migration data to numerical current models and determining their relationship. The first publication of a model for turtle trajectories was done by Graper et al. (2006). They found that leatherback turtles in the Atlantic Ocean swim either with, against or across the current and forage in the dynamically active areas. They also suggested that the current has a noticeable influence on the migration behavior of sea turtles. Cheng and Wang (2009) compared the satellite tracking results from the post-nesting migration of green turtles from Wan-an Island, Penghu Archipelago, Taiwan, with the current strength and direction on each monitoring position from a sb-ADCP derived current model. They proved that the tidal current in Taiwan Straits does influence the migration behavior of green turtles: some migrated with the current to save energy; some migrated against the current, possibly using it as directional cue, while others were deflected by the current. In addition, even though they were able to adjust their speeds and directions when deflected by the current, they were not able to compensate completely for the deflection. Kobayash et al. (2011) compared the satellite telemetry from 34 by-caught loggerheads from pondnets in I-Lan County, Taiwan, with oceanographic features (e.g. NOAA Pathfinder sea surface temperature (SST), AVISO altimetry products - sea surface height, geostrophic u- and v-component, SeaWiFS ocean colour, bathymetry) and Earth magnetic-field data from the IGRF-10 model (total force, declination, inclination) and found that the East China Sea is their main region of congregation, and they prefer to stay on the edges of eddies. Sea turtles migrate in the ocean in three dimensions, sometimes diving down to hundreds of meters, and current strength and direction may be different at different depths. The above quantitative studies assumed that the animal swims entirely in the surface water, which is not true. Thus, there is a need to include diving data in the numerical models, as well as the migration speed, in order to determine the "true" influence of ocean currents on the migration of sea turtle.

In addition to satellite telemetry, combinations of other instruments have also been used to discover sea turtle migration patterns and diving behaviors. By combining TDR and electrocardiograph studies, Southwood et al. (1999) confirmed the increase in heart rate while leatherback turtles are air breathing during surface emergence. Makawski et al. (2006) used ultrasonic pinger with TDR recording and found that the home range of immature green turtles in offshore Florida waters is related to the distribution of seagrass meadows. They forage there during daytime and rest as well as avoid predators there in the night. All these results emphasize the importance of multi-disciplinary approaches for acquiring full understanding of the life history traits of sea turtles.

6. Telemetry studies for sea turtle conservation

6.1 By-catch post-release survivorship studies

Sea turtles spend the majority of their lives in the sea, only emerging on beaches to nest. Despite the intense conservation efforts on the beaches, some populations have still declined to the edge of extinction. Results of population stochastic model analyses, such as elastic and deterministic models (e.g. Heppell et al., 1998), show that fisheries by-catch is the major source of mortality. Therefore, understanding of the interaction between the sea turtles and fisheries is the key to solving the conservation problem. Telemetry, especially satellite telemetry, can be a useful tool for this purpose. Pop-up PAT tags described in the previous section were used to determine the post-release survivorship of by-caught turtles. Snoody and Williard (2010) combined satellite telemetry results and evaluated plasma biochemistry of post-release Kemp's ridley and green turtles caught in gillnets and found that entanglement by the fishery can disrupt the homeostasis of physiological functions, reducing their survivorship.

6.2 Identification of the “hot spot” regions in the ocean

In addition to study of the interaction of sea turtle migrations and diving behavior with fishing gear, the aggregation of sea turtles in the open ocean identified by satellite telemetry (so called “hot spots”) can also act as a focal point for conservation measures. Polovina et al. (2006) used SDR and oceanographic features (chlorophyll and geostrophic current) to prove that oceanic regions, specifically the KEBR (Kuroshio Extension Bifuration Region), represent an important forage habitat for loggerheads. They suggested that conservation efforts should focus on identifying and reducing threats to the survivorship of loggerhead turtles in that region of the North Pacific. Kobayash et al. (2011) trackedg 34 by-caught loggerheads carrying conventional satellite PTT tags that had been released near eastern Taiwan. They found that loggerhead hotspot areas are on the continental shelf next to the Yangtze River and in coastal and pelagic areas next to Taiwan, China, Japan, and South Korea. They noted that this area is also intensively fished, primarily by boats from China. The incidental or targeted takes of loggerhead turtles by these and other fisheries over the continental shelf need detailed investigation. Recently, GPS satellite telemetry was also apply to this issue. For example, Schofield et al. (2010) used GPS satellite tags to determine in fine scale the home range of loggerhead turtles nesting in Greece during their inter-nesting interval. The improvement in accuracy of the positions provides important information for delimiting and adjusting marine protected areas.

6.3 Application of the GIS (geographic information system)

With the popularization of GIS (geographic information system) since 2000, researchers have tried to combine the migration data from this technique with relevant physical, chemical and biological oceanographic information, and to determine their relationships, basically using mapping. For example Halpin et al. (2006) developed the OBIS-SEAMAP (Ocean Biogeographic Information System-Spatial Ecological Analysis of Marine Megavetebrate Animal Population) system in 2002, and they post the migration routes of marine animals at large scales on ocean and weather feature maps in order to understand the dynamics of animal populations. That not only serves research on animal biogeography, but acts as a reference tool for resource management, marine conservation and popular science education. Despite the fact that this system is still in the promotion stage, many research teams have published their results using this system.

6.4 Global climate change effects

The effect of global climate changes on living organisms and ecosystems has become one of the major scientific and social issues in recent years. For the marine environment, the rise in temperature will change wind patterns and influence both marine productivity and the survival of sea turtle populations (Reina et al., 2009). Besides, global climate change will also influence surface current patterns. This will influence the foraging behavior of sea turtles and the quality of their nesting environments, influencing the migration routes and behaviors of sea turtles (Hawkes et al., 2009). Thus, long-term application of satellite telemetry and relevant ocean features will provide valuable information on how sea turtles come to cope with the ever changing environment. Because the influence of global climate change is more pronounced in higher latitude regions than at lower latitudes, the leatherback turtle appears to be an excellent candidate for this kind of study. Leatherback turtles forage near the polar region and nest in tropical continents (López-Mendilaharsu et al., 2009).

7. Biologging

7.1 Definition

Biologging is a miniature self-recording device that attaches to an animal, records its behavior, physiological condition and nearby environmental information (Rutz and Hays, 2009). The collected data either transmits via antenna or is stored and decoded after the device is retrieved. Because it is not necessary to observe the animal directly, these devices are usually used to study animal behaviors that are difficult to track, especially those of endangered species.

7.2 New tools to study the behavioral ecology of the animal

Biologging research started in the 1960s' and 1970s' (Koyman, 2004) and has expanded substantially in the last 20 years. With the advances of computer technologies, these devices have become lighter and smaller, while their function improved greatly and memory capacity (e.g. allowing increased sampling frequency). The sensors on the device, such as oxygen content, pH, stomach temperature meters, have also increased substantially. In addition, the development of software to analyze the large quantity of data allows scientists to conduct more sophisticated research on the behavior of large animals, and to an extent on small animals as well (e.g. jellyfish; Lilley et al., 2009). With more accuracy in the data and improvement in the software to analyze the relevant environmental information, the researchers can obtain important details of animal behavior in the wild. These kinds of device act as diaries that faithfully record the animal's activities during the deployment

period and lead to possible explanations. Therefore, an entire field has opened in biologging research (e.g. Rutz and Hays, 2009). For example, Hochscheid et al. (2010) found, based on the diving data from SRDL, that the extended surface drifting period of the loggerheads in the Mediterranean is related to breathing and the absorption of solar energy to assist in digestion and to increase body temperature for deep dives.
Biologging-related research has increased substantially since the First International Symposium on Biologging Science in 2003. Because biologging systems allow us to record much unnoticed behavior, it cans both determine the relationship between the animal behavior and the environment and bring new explanatory power to the field of behavioral ecology (Cheng, 2010). Sea turtles are oceanic migratory animals and are difficult to track directly. Thus, one can use biologging data to obtain much greater understanding of sea turtle behavior in the wild.

8. Conclusion

Sea turtles are ocean-wide, long-distance migrating reptiles that spend more than 95% of their time at sea. The study of migratory behavior is important to demographic studies, dynamics of marine ecosystem and conservation measures of these marine reptiles . Telemetry devices developed since the late 70's, enhancing our understanding of sea turtle migratory mechanism substantially. In addition to conventional satellite tags, directional radio and sonic telemetry and ultrasonic-pinger were also developed in 1980's. However, the low resolution and labor-intense efforts limited their developments. The retrievable device—TDR developed since 1980's enables us to interpret the diving behavior of sea turtle in great detail. With the advancement of computer technologies, the new generation of non-retrievable satellite tags allows more sensors add to the satellite tags, thus enhance the tag performance. The combination of the oceanographic instruments with the satellite telemetries allows researchers to conduct multi-disciplinary approach to study the sea turtle migratory behavior, both qualitatively and quantitatively. These approaches allow us to conduct proper conservation measures in the ocean. The miniature, high resolution and multi-function telemetry tags emerges the biologging concept and may bring new explanatory power to the field of behavioral ecology.

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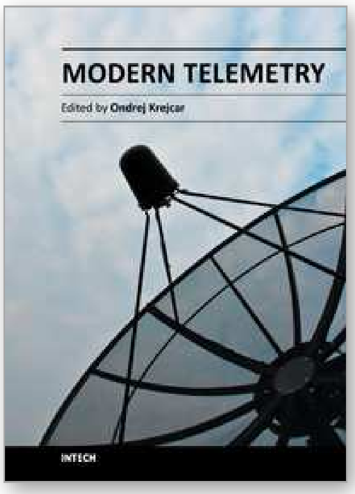

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Telemetry is based on knowledge of various disciplines like Electronics, Measurement, Control and Communication along with their combination. This fact leads to a need of studying and understanding of these principles before the usage of Telemetry on selected problem solving. Spending time is however many times returned in form of obtained data or knowledge which telemetry system can provide. Usage of telemetry can be found in many areas from military through biomedical to real medical applications. Modern way to create a wireless sensors remotely connected to central system with artificial intelligence provide many new, sometimes unusual ways to get a knowledge about remote objects behaviour. This book is intended to present some new up to date accesses to telemetry problems solving by use of new sensors conceptions, new wireless transfer or communication techniques, data collection or processing techniques as well as several real use case scenarios describing model examples. Most of book chapters deals with many real cases of telemetry issues which can be used as a cookbooks for your own telemetry related problems.

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