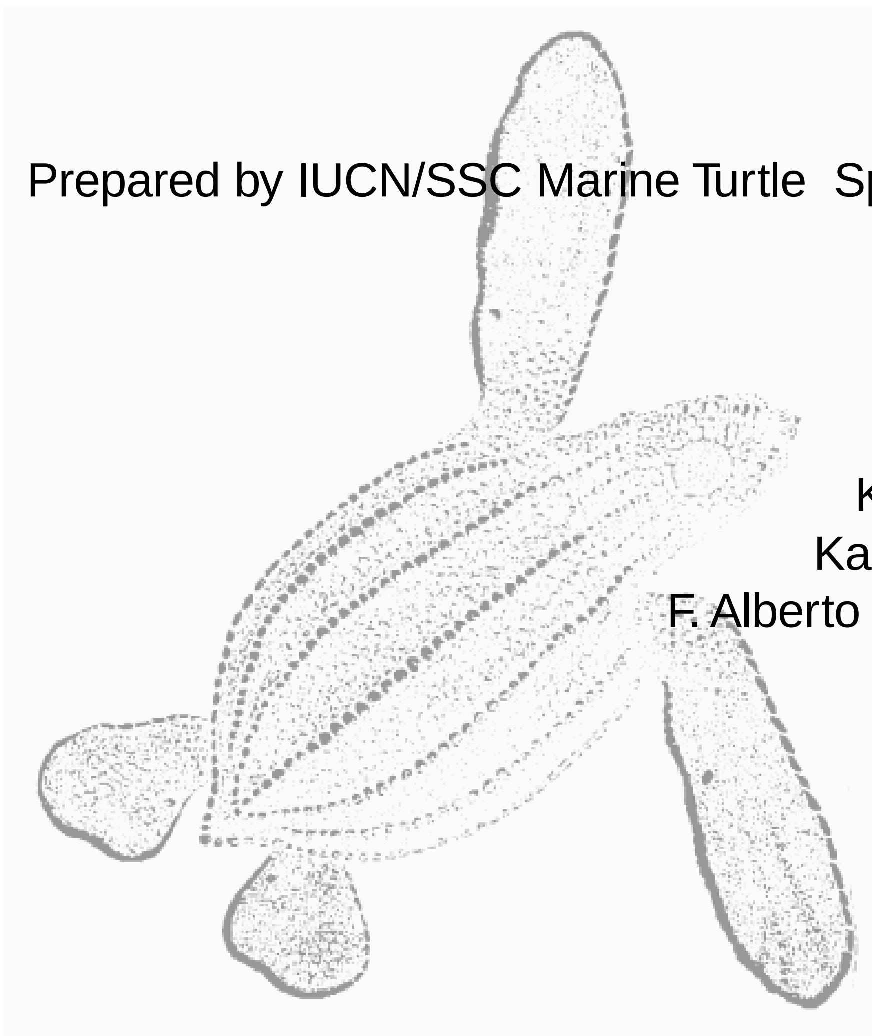
Research and Management Techniques for the Conservation of Sea Turtles



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Preface

In 1995 the IUCN/SSC Marine Turtle Specialist Group (MTSG) published *A Global Strategy for the Conservation of Marine Turtles* to provide a blueprint for efforts to conserve and recover declining and depleted sea turtle populations around the world. As unique components of complex ecosystems, sea turtles serve important roles in coastal and marine habitats by contributing to the health and maintenance of coral reefs, seagrass meadows, estuaries, and sandy beaches. The *Strategy* supports integrated and focused programs to prevent the extinction of these species and promotes the restoration and survival of healthy sea turtle populations that fulfill their ecological roles.

Sea turtles and humans have been linked for as long as people have settled the coasts and plied the oceans. Coastal communities have depended upon sea turtles and their eggs for protein and other products for countless generations and, in many areas, continue to do so today. However, increased commercialization of sea turtle products over the course of the 20th century has decimated many populations. Because sea turtles have complex life cycles during which individuals move among many habitats and travel across ocean basins, conservation requires a cooperative, international approach to management planning that recognizes inter-connections among habitats, sea turtle populations, and human populations, while applying the best available scientific knowledge.

To date our success in achieving both of these tasks has been minimal. Sea turtle species are recognized as "Critically Endangered," "Endangered" or "Vulnerable" by the World Conservation Union (IUCN). Most populations are depleted as a result of unsustainable harvest for meat, shell, oil, skins, and eggs. Tens of thousands of turtles die every year after being accidentally captured in active or abandoned fishing gear. Oil spills, chemical waste, persistent plastic and other debris, high density coastal development, and an increase in ocean-based tourism have damaged or eliminated important nesting beaches and feeding areas.

To ensure the survival of sea turtles, it is important that standard and appropriate guidelines and criteria be employed by field workers in all range states. Standardized conservation and management techniques encourage the collection of comparable data and enable the sharing of results among nations and regions. This manual seeks to address the need for standard guidelines and criteria, while at the same time acknowledging a growing constituency of field workers and policy-makers seeking guidance with regard to when and why to invoke one management option over another, how to effectively implement the chosen option, and how to evaluate success.

The IUCN Marine Turtle Specialist Group believes that proper management cannot occur in the absence of supporting and high quality research, and that scientific research should focus, whenever possible, on critical conservation issues. We intend for this manual to serve a global audience involved in the protection and management of sea turtle resources. Recognizing that the most successful sea turtle protection and management programs combine traditional census techniques with computerized databases, genetic analyses and satellite-based telemetry techniques that practitioners a generation ago could only dream about, we dedicate this manual to the resource managers of the 21st century who will be facing increasingly complex resource management challenges, and for whom we hope this manual will provide both training and counsel.

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Data Acquisition Systems for Monitoring Sea Turtle Behavior and Physiology

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The development of microchip and microprocessor technologies, along with improvements in battery design, has enabled researchers to expand the study of marine turtle biology in ways that could only be imagined a few years ago. New technologies allow acquisition of data on behavior, physiology, habitat use, and migratory movements at a reasonable cost and without once formidable logistical requirements. This chapter describes some of these methods, how and when to use them, and how to avoid misusing them.

Very High Frequency (VHF) Telemetry

VHF telemetry is probably the oldest and simplest electronic technology that has been applied to marine turtles. Generally the objective is to determine turtle location at distances too far for visual confirmation, or to "home in" on a turtle for visual verification of position. In its most basic form, the system consists of a fixed frequency radio transmitter, a receiver capable of detecting the transmitter's frequency, and a directionally sensitive antennae. Usually a compass or compass rose (where the perimeter of the disk is divided into graducules representing compass direction) is associated with the antennae to indicate where the transmitter is located relative to the receiver. The tracking technician simply rotates the antennae and records the bearing giving the strongest signal. Each transmitter is set to a specific frequency and individuals are identified by these unique frequencies; or, alternatively, by the signal repetition rate (the latter method is uncommon). Two bearings are recorded simultaneously (or nearly so) from two receivers at separate locations; the intersection of these bearings estimates a turtle's location. A number of published studies report results of VHF turtle tracking *(e.g.,* Dizon and Balazs, 1982; Mendonça and Ehrhart, 1982; Mendonça, 1983; Keinath, 1986; Chan *et al.,* 1991) and from these, as well as studies of other taxa, information on commercial providers of equipment can be gleaned.

The advantages of the VHF technique include its simplicity, relatively large number of reference materials, and comparatively inexpensive cost. The greatest disadvantage (and the most frequently overlooked problem) is its relatively poor accuracy. Few skilled technicians exceed a ± 5° accuracy. Consequently, the resulting "location" is not exact but rather falls within a polygon whose borders are determined by the angle of the bearing and the accuracy of the individual technician. For example, the precise location of a turtle 15-20 km from a receiving station with a 5° measurement error lies within a polygon whose area is 16 km^2 (Figure 1). Technicians should be thoroughly versed in methods for correcting inherent errors (see White and Garrott, 1986, 1990; Zimmerman and Powell, 1995). A second disadvantage is that transmitters must be on the surface to be detected. For some species of turtle, surfacing may occur for only a few seconds once each hour, greatly reducing any opportunity for triangulation. When this is the case, a rapid repetition rate *(e.g.,* 0.25-0.5 pulses per second) is recommended. Battery life is reduced more quickly in this case, but the technician receives more pulses per unit of time, enhancing his/her ability to locate the signal. Finally, daily variation in abiotic factors *(e.g.,* rain, humidity, radio interference) can degrade signal quality.

Sonic Telemetry

In many ways *(e.g.,* sensing and triangulating a signal), sonic tracking is similar to VHF tracking. In contrast to VHF telemetry, which relies on airborne radio waves, sonic signals are transmitted underwa-

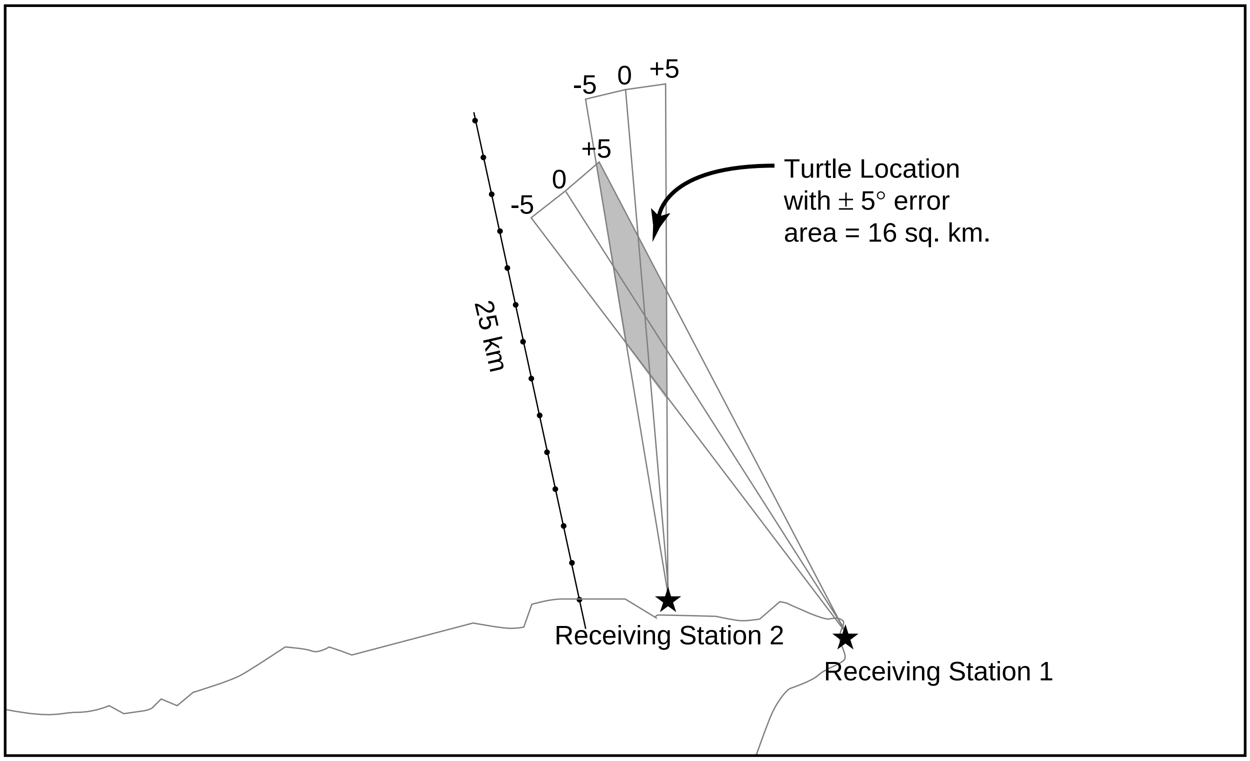

Figure 1. Location polygon established using VHF telemetry with a 5 degree measurement error.

ter, and instead of a directional antennae, a directional hydrophone is used and turtles are tracked beneath the surface. The technique is well developed, quite reliable and, while generally more expensive than VHF telemetry, still reasonably priced. Sonic pingers can encode data, such as temperature or depth, into the signal. Finally, sonic telemetry is often more accurate relative to the degree of error associated with the bearing; however, there are still a large number of potential errors that must be addressed (see Collazo and Epperly, 1995). The primary disadvantages are that range is limited and studies must be conducted from a boat. Moreover, sonic signals are more susceptible to interference and bounce than are VHF radio waves; thus, environmental conditions can strongly affect results. Since there is inherently more noise interference (biotic and abiotic) underwater, receivers must incorporate effective filters. Sonic signals can be degraded by heavy particulate loading in the water and blocked altogether by submarine structures. It is advisable to purchase the best receiver possible, thus taking advantage of superior noise reduction technologies.

Satellite Transmitters and Satellite Linked Data Recorders

Satellite telemetry provides a superior means of monitoring long distance movement, as well as various behavioral parameters, and has been used successfully by a number of researchers *(e.g.,* Hays, 1993; Plotkin *et al.*, 1995; Morreale *et al.*, 1996; Beavers and Cassano, 1996; Eckert and Sarti, 1997; Eckert, in press).

Currently, ARGOS CLS provides the only Earth-orbiting satellite system capable of establishing daily global locations of transmitters attached to wildlife. The system consists of two TIROS-N satellites in low Earth polar orbits with on-board radio receiver and transmitter units, a series of Earth based receiver stations, and several Earth based Global Processing Centers (GPCs). [N.B. At the time of writing, a third satellite has been put online but its future is uncertain.] Each satellite makes one orbit in 101 minutes, crossing the equator at a fixed time each day. The ground-track covered during each pass is about 5,000 km wide and overlaps 2,100 km with the previous pass at the equator. The amount of overlap increases with latitude so that satellite coverage (from two satellites) at specific locations increases from six satellite overpasses per day at the equator to 28 passes per day at the poles. The satellite is within radio view of any point on the earth for about 10 minutes. All transmitters utilize the same frequency, 401.65 MHz, with effective transmission power output between 0.25-1.0 watts. Repetition rate is limited by ARGOS to 40 seconds. Encoded in each transmission is an identification signal, as well as sensor data from each transmitter.

Transmitter locations, which are reported as latitude and longitude, are calculated by ARGOS using Doppler shift. As the satellite approaches the transmitter, the frequency of the transmitted signal rises; as the satellite moves away, the frequency falls. By comparing these values to the known frequency of the transmitter, distance (and subsequently the angle of the transmitter relative to the satellite) can be calculated. Since the zone of reception from each satellite is cone-shaped, the cone intersects any particular elevation on the Earth at two points. These two points are reported as the two possible locations of the transmitter. Locations presented by ARGOS are of variable accuracy and are classified by ARGOS as 3, 2, 1, 0, A, B or Z with "3" the most accurate and "0" the least accurate. A number of factors affect location quality, including numbers of uplinks, elapsed time between uplinks, and signal quality. A, B and Z location classes (LC) rarely have locations assigned to them. LC 3, LC 2 and LC 1 are reported by ARGOS to be accurate to <150 m, <350 m and <1000 m, respectively, while LC 0 is accurate to >1000 m.

The accuracies reported by ARGOS represent probabilities and can vary. Thus, it is prudent for investigators to field test individual transmitters prior to deployment. Routine post-analysis of reported locations is essential; any unrealistic locations should be discarded. The criteria used in editing the database should be reported in any published results. For a further discussion of satellite location accuracy, the reader is referred to Keating *et al.* (1991) and Stewart (1997). Since ARGOS is continually improving the accuracy of its reported locations, earlier critiques are obsolete.

The biggest advantage of this technique is the ability to transmit data other than location. Some satellite transmitter manufacturers equip transmitters with sensors capable of reporting data on water temperature, dive depth, dive duration, and other information. With an on-board microprocessor to control data acquisition and compile the data for transmission, the only limitation is that data acquisition is limited to the capacity of the ARGOS platform to handle the data stream. The biggest disadvantage is cost. Transmitters are priced at US$ 1,800-4,200 each and satellite usage time approaches US$ 4,000 per year per transmitter (although rate discounts are available). Moreover, data analysis requires a skilled technician. Notwithstanding, the potential to monitor the movements and behavioral patterns of multiple turtles for a year or more at great distances outweighs the disadvantages since, for example, attempting to gather equivalent data by other means *(e.g.,* tracking by boat) would be far more expensive and would likely yield poorer quality data.

Hybrid and Advanced Telemetry Systems

The development of the Global Positioning System (GPS), which utilizes a system of geosynchronous satellites and a land-based receiver, holds great promise for wildlife tracking. Off-the-shelf receivers are relatively inexpensive (< US$ 100 for simple designs) and have a typical accuracy of 100 m (accuracy can be improved to a few meters in areas where differential reception is available). There is widespread interest in adapting GPS to wildlife tracking, several companies and laboratories are currently developing instruments, a number of configurations are being tested, and a few prototypes have been deployed on terrestrial species. One style of GPS receiver simply stores locations at predetermined intervals for later recovery, a second style retransmits that information over VHF (or other short-range) radio frequencies, and a third style transmits location data via the ARGOS satellite system. The advantage of the latter style is that it allows accurate position referral on a single transmission as opposed to the 3-5 transmissions (spaced at least 40 seconds apart) currently required by ARGOS to establish a position. At the time of writing, none of these systems were available commercially for marine wildlife telemetry.

Geolocation Tags

Originally developed for marine mammals (Delong, 1992), this data logger utilizes day length and sunrise and sunset times to estimate its latitude and longitude. The instrument consists of an accurate clock and a microprocessor with sensors to measure pressure, temperature and light level. Accuracy is usually to 1°, except during Equinox periods when it may be more variable. Two configurations are available. The first simply stores a location at a preprogrammed interval (usually daily) until the tag is recovered, and the second (which should soon be available commercially) is coupled to a satellite transmitter and timed-release mechanism. In the latter case, the tag detaches itself and surfaces to transmit its stored location data set via the ARGOS satellite platforms. Currently these tags are in use on studies of marine mammals and migratory fish. Advantages include reasonable cost (ca. US$ 1300 for the basic tag; US$ 3,000-4,000 for the self-releasing tag) and self-locating ability irrespective of surfacing duration. The primary disadvantage is its relatively coarse resolution (1°) and the need to recover the tag.

Time-Depth-Recorders (TDR)

TDRs are electronic data loggers, often microprocessor controlled, that utilize pressure transducers to monitor pressure (depth) and store the data at predetermined intervals. The results can be integrated over time to determine dive depths and durations, ascent and descent rates, bottom time, and other behavioral variables. TDRs have been successfully utilized on diving marine mammals, birds and sea turtles *(e.g.,* Kooyman *et al.*, 1983, 1992; Eckert *et al.*, 1996). The cost is relatively low considering the resolution of the data; however, instrument recovery is required. Accuracy is typically good but variable among manufacturers. Some form of transducer error correction must be incorporated into the TDR (or into the data processing software) to account for calibration shifts that may occur during deployment. Further, most TDRs have resolutions relative to their maximum range (though there have been significant improvements recently from some manufactures). For example, one manufacturer reports a resolution of 0.25 m for a TDR with a range of 0-500 m, 0.5 m for a range of 0-1000 m, and 1.0 m for a TDR with a maximum range of 2000 m. It is important to choose a TDR configuration that is most suitable for target species and the research objective. Analysis of surfacing intervals and dive times should take the instrument resolution into account.

Other Data Loggers

The basic data logger design utilized with the TDR can be adapted to record other information such as temperature, swim speed, distance traveled or even compass direction. Many of the same caveats relative to understanding measurement and accuracy limitations apply as described for TDRs (above). As is always the case, an understanding of the basic biology of the target species is requisite. For example, if a velocity (swim speed) logger has a minimum startup speed (the minimum speed at which the impeller begins to turn) of 1 m/sec, then it would not be useful for turtles with average swim speeds below 1 m/sec. Further, care must be taken in data analysis to note that "0" speed records may actually represent periods when the turtle's speed was below the stall speed of the recorder; the turtle may not have actually been stopped.

Heart Rate Counters (HRC)

HRCs are a special type of data logger. Two varieties (analog recorders and digital counters) are available. The analog recorder is essentially an electrocardiogram (ECG) recorder that (in most cases) uses a magnetic tape to record a data trace. Sampling rate is usually high (in excess of 60 samples per second) and the unit has all the advantages and disadvantages of standard ECG traces, including an inability to avoid interference from myogenic sources. Probably the most significant disadvantages are size (when housed for underwater deployment) and the fact that most are capable of recording for only a few days. Digital counters attempt to count only the R-wave portion of the ECG signal and integrate that count over time. The advantage is that it only stores information on heart rate (and not the entire ECG signal) and therefore can be deployed in a small, entirely electronic package. The disadvantage is the difficulty these units have in distinguishing interference signals from the R-wave; as a result, they are highly prone to providing spurious data which often cannot be detected during analysis. In their current configuration (as counters), their use is not recommended. However, as technology improves, digital ECG recorders (as opposed to counters) should become available and the new technology may resolve many of the accuracy problems inherent in the digital counters.

Instrument Packaging and Attachment

Paramount to the success of any telemetry experiment is the packaging and attachment of the data acquisition instrument. A number of design parameters must be considered. First and foremost, the instrument must not interfere with the behavior or well-being of the turtle. This rule is inviolate, for it is important both ethically and scientifically. If the study animal is disturbed by an attached instrument (constrained by excess drag or hindered by painful attachment configurations), it will not behave "normally" and the resulting data will be erroneous. Instrument manufacturers are often hesitant to custom design an instrument package, due to cost factors and concern that a new package may reduce instrument performance. Therefore, it is the responsibility of the investigator to propose new instrument packages and to adequately field test them.

To minimize potential behavioral disturbance, instrument packages must be hydrodynamically clean. The profile should be as low and smooth as possible, and should slope both to the front and rear (the design of the posterior end of the tag is almost more important than the front, due to the effect of turbulence on hydrodynamic performance). Approximating a teardrop, or half teardrop, shape is wise (tapering to the rear). Size and weight of the transmitter package are also important, but less so than hydrodynamic form. In some cases there are advantages to choosing a comparatively larger package if it is neutrally weighted in water, and efficiently designed. Consideration should also be given to swim speed; hydrodynamic design is far more critical to the study of fast swimmers than it is to slower swimmers. Placement of the package on the turtle is also important. Attachment points on the posterior one-third of the carapace are preferred, but this is often not practical for transmitters which require reasonable antennae exposure.

Hydrodynamics should also be strongly considered when designing floating instrument packages. Too often floats are designed and tested in a tank, with little consideration to their performance when towed behind a turtle. The result can be a tag with unacceptably high drag and/or poor behavior in the water. A common mistake is to use spherical or bullet-shape floats. When pulled, a spherical float often spirals and creates high drag; a bullet-shaped float tends to dive below the turtle where it can foul more easily on the bottom. A final and oft overlooked hydrodynamic problem is biofouling. Biofouling increases drag and reduces instrument performance. For long term (> 3 weeks) deployment, the instrument package (including attachment) should be covered with a good quality antifouling paint. The potential for biofouling increased instrument drag is high.

For most species, attachment by polyester resin or epoxy adhesives are adequate. Beavers *et al.* (1992) provide guidance when studying hard-shelled turtles. There are a wide variety of adhesives that secure an instrument to a turtle. Care should be taken with quick setting epoxies. The heat of curing a quick setting epoxy can burn the tissue underlying the affected scute, causing it to peal off in a few days. For short term deployment with small instruments, small holes can be drilled through the outer edges of the marginal scutes; the instrument is then wired and glued in place. If marginal scute abrasion is a concern, it is prudent to mount the instrument under the carapace margin rather than on top. The use of screws to anchor the instrument to the carapace is not recommended because of the possibility of penetrating the lungs. A sea turtle's lungs are attached directly beneath the carapace and can occupy a surprisingly large area. In the case of leatherback turtles, attaching the instrument package to a flexible harness is recommended. In this case it is particularly important to consider biofouling. The harness should be constructed to allow break-away if the turtle becomes entangled, and it should have some means of self-release if the turtle is never recovered (see Eckert and Eckert, 1986).

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