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Tagging and Movement of Sirenians

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Sirenians occur in waters that range from crystal clear to chocolate-milk brown. They can live anywhere from inland small channels covered with overhanging vegetation to offshore marine waters. They may spend several months in one location or make long migrations or movements at a relatively fast pace of 20 to 50 km per day. In large portions of their range, sirenians behave very cryptically, so researchers must often rely on electronic telemetry tags for the challenging task of documenting sirenian movements, habitat use, and general behavior.

Telemetry, or the science of adapting transmitters to living beings to monitor a variety of biological parameters, has been successfully applied to sirenians since the 1970s in different parts of the world. The field of telemetry has evolved so rapidly that nowadays tracking may be conducted remotely and produce a wealth of information. When planning to use telemetry, one must first have in mind exactly which research questions to answer and tailor the telemetry tools accordingly. Each study plan should be critically analyzed beforehand as to project objectives, desired information, and level of available support, both financial and human.

Not all gear will work well in all environments, and as enticing as using sophisticated telemetry devices may be, tracking studies can be very costly. In this chapter we present the strengths and challenges of different tagging and tracking techniques that hold potential for use in developing countries, which may vary depending on species, different habitat requirements, and behaviors. Any use of trade, product or firm names does not imply endorsement by the U.S. government.

Sirenian Capture and Tagging Techniques

Several capture techniques have been used to secure sirenians. Capture by woven nylon nets of different sizes and mesh is perhaps the most common method for manatees. Study animals have been net-captured using land-based techniques at power-plant discharge canals and other sites in Florida[1], manual deployment from small craft (Brazil)[2], and open-water techniques with net deployment from specialized designed capture boats (Florida, Belize, and Puerto Rico)[3]. At some locations in Florida, manatees have been attracted to advantageous capture sites by their need to use warm-water sites or drink fresh water, even using fresh water as bait[4].

Other capture techniques have been developed that are specific to particular areas. Vegetation is used as bait for special manatee traps in Africa[5]. In clear and shallow waters of Mexico, manatees have been lassoed in the water and held for tag attachment using a rodeo method[6]. One person must jump from a moving boat to hold the lasso. Once the manatee's movement has been halted, a second person jumps from the boat to slip another rope onto the peduncle. In 2004 this technique was successfully used in clear deep water (>4m) in a coral reef area[7]. In the Amazon region of Brazil, small harpoons, similar to but dramatically smaller than the ones used by hunters, were used to restrain manatees prior to people transferring them to canoes and larger boats. Although no adverse effects were noted from this technique, its use was discontinued because of its invasive nature.

In some cases, manatees were tagged while free-swimming with an animal without the need to capture it, but this is limited to areas where the water is clear and the animals are not shy of humans. Captive sirenians have been tagged for monitoring upon release from rehabilitation facilities.

Because dugongs avoid human contact and largely inhabit turbid marine waters, they have primarily been captured using the rodeo method, which requires someone to jump from a moving boat and grasp onto a dugong that has been herded into shallow intertidal waters. Once the dugong's movement has been halted, it is secured alongside the boat within a flotation cradle that allows its well-being to be monitored while tags are attached, samples collected, and measurements taken[8].

When capturing dugongs in deep water (>3m) a 20 m padded tail rope can be attached by one of the jumpers to the animal's tail. The other end of the rope is attached to the catch boat and allows the animal to surface to breathe without escaping, until it is brought alongside the boat for tagging.

Although sirenians typically struggle to escape at some point during capture, most remain calm after being removed from the water and normally do not require excessive restraining. Nevertheless, accidents have happened, so a large crew of people is recommended to expedite handling, to avoid accidents with the capture crew and to ensure that no animal drowns from unnoticed entanglement. Respiration and pulse rate should be monitored at all times, handling time kept to a minimum (less than one hour if possible), and individuals released at or close to their capture location. Additional data recorded upon capture include morphometrics (total length and girths), sex, and photographs of scars or natural marks. Complete biometry and biological sampling (including DNA) should be performed to the extent possible, given the logistic and resource capabilities of the capture operation[9]. Additional markings or identification tags (e.g., freeze brands, PIT tags, or "cookies") may be applied at this time[10].

Sirenian Attachment Mechanisms

Although attachments and housings may vary with the type of transmitters used, all successfully tracked sirenians were tagged with a similar kind of padded belt/harness around the caudal peduncle (figures 13.1 and 13.2). With the fusiform body shape typical of all sirenians, the peduncle offers the only secure attachment point for external devices. Peduncle belts can incorporate attached transmitters capable of emitting signals in fresh water, or can accept tethered floating radio tags that enable manatees to be tracked in saltwater habitats.

Peduncle belts used on manatees consist of a length of neoprene machine belting inside one-inch internal diameter latex tubing[11]. Padding and temporary flotation are provided by applying one-component urethane foam inside the latex tubing. To allow for the different sizes and strengths of manatees, belts are built using various lengths of machine belting ranging from ¾- to 1-inch width, and 3 to 9 ply in thickness. Predetermine the peduncle girths of manatees to be tagged and build the appropriately sized belts, or build a range of possible belt sizes for various size classes. Strength of the peduncle belt is determined by the width and number of ply of belting material, which varies with belt sizes to enable

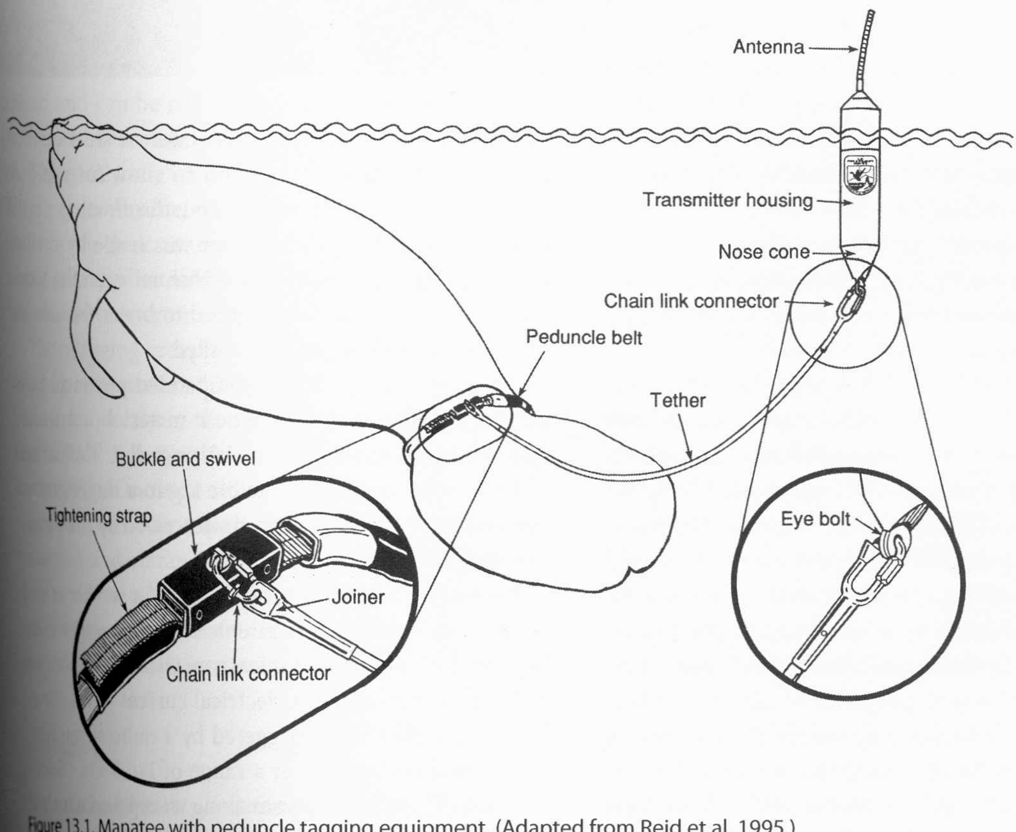

Figure 13.1. Manatee with peduncle tagging equipment. (Adapted from Reid et al. 1995.)

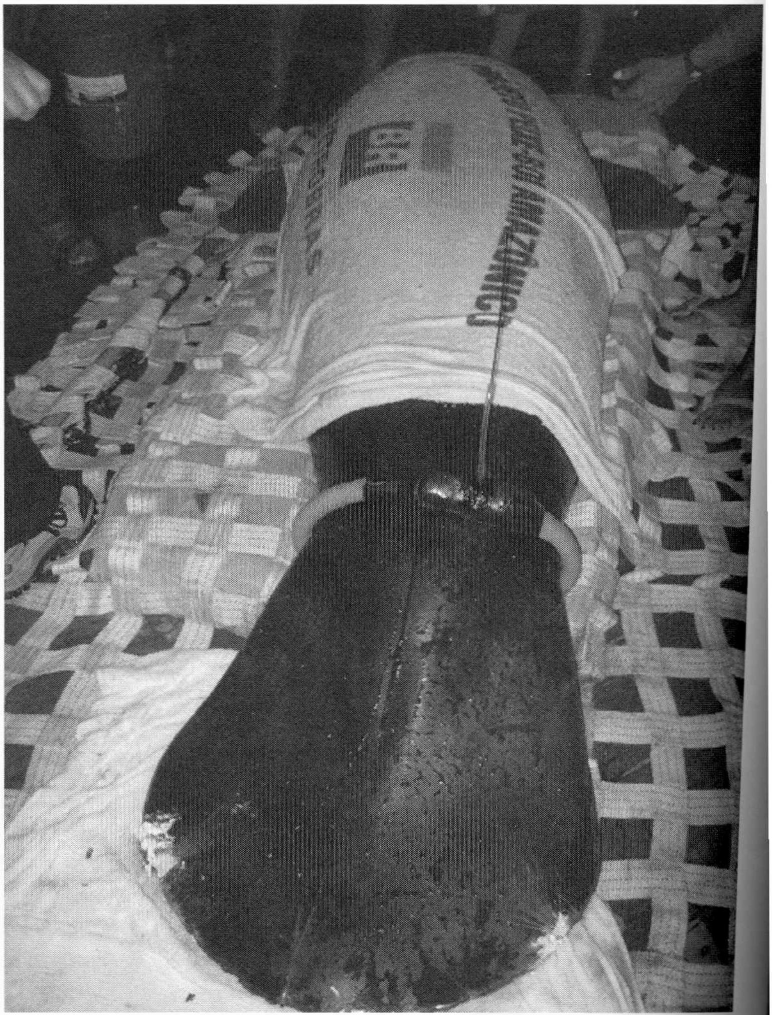

Figure 13.2. Amazonian manatee with peduncle tagging belt. (Courtesy of Miriam Marmontel.)

manatees to break free of the belts should they become entangled. Corrodible nuts and bolts of dissimilar materials allow belts to release over time.

Manatee belts used with tethered floating tags are typically secured using a spring-loaded "bear-claw" buckle, which enables a rapid attachment and provides a swivel for attaching the tether[12]. A less sophisticated but economical way to attach the belt is to use two plastic plates with corrodible nuts and bolts to secure the belt by sandwiching the ends. Likewise, this assembly can incorporate a swivel, similar to that used in the buckle but mounted within a hole in an outer stainless steel plate, for attachment of tethered tags.

Most of the floating tags for manatees, which are described in detail later, were attached using a flexible plastic rod. This "tether" between the belt and floating tag enables the tag to transmit in air, thus allowing manatees to be successfully tracked in saltwater environments. A 4- to 10-foot length of solid ⅜-inch-diameter plastic rod, made from low water absorption nylon (e.g., Nylon Type 158L), was used to construct the tether. Specially designed stainless steel connectors were attached to each end to allow for rapid attachment to the belt swivel and the floating tag. A weak link within the connector was made by drilling holes through the tether rod, which reduced the tether strength and enabled the animal to break free should the tether or tag become entangled.

Dugong tags also employed padded peduncle belts, although different construction materials were used and the belt size was significantly smaller. The harness system used to attach a satellite tag to a dugong was a modification of that previously described by Marsh and Rathbun 1990 (figure 13.3).

To ensure recovery of tethered tags, a remote release system can be built into sirenian harnesses. For a design used on dugongs, a release mechanism can be preprogrammed to send an electrical current down the attachment tether when triggered by a radio signal from a handheld transmitter at a range of 1–0.5 km (Telonics, Inc.). The current passes along an exposed wire link through which the peduncle strap has been wrapped,

Figure 13.3. A dugong secured alongside a catch boat in a rubber cradle so that it can safely breathe while the satellite tag is attached to its tail and measurements are taken. (Courtesy of James K. Sheppard.)

corroding it rapidly (10–15 minutes) owing to an accelerated galvanic reaction with seawater. Once the link breaks, the harness with tethered tag detaches from the animal and can be retrieved. A tag release mechanism used on manatees involves a programmable device (CR-2A, Telonics, Inc.) incorporated in the peduncle belt. These programmable, self-releasing units employ a miniature pyrotechnic actuator enclosed within a machined plastic housing that will release the harness and attached tether at a predetermined date and time.

The retagging or replacement of tethered tags on sirenians by researchers while snorkeling has been accomplished frequently in the field on manatees in Florida, Puerto Rico, Brazil, and Mexico but rarely on dugongs in Australia. On these occasions the manatee was not restrained while an experienced swimmer quietly approached and removed and/or replaced a tag. Given the shy nature of most sirenians, specialized tools and tether-to-tag attachment mechanisms have been developed to expedite this process.

Telemetry

The sirenian telemetry systems most commonly used today are radio tags that transmit in the range of very high frequency (VHF), for land- and boat-based tracking, or ultra high frequency (UHF), which are satellite monitored. Recently, satellite-monitored transmitters (also called platform transmitter terminals or PTTs) have been integrated with Global Positioning System (GPS) receivers. These tags enable remote monitoring and relay of detailed GPS locations. Ultrasonic tags or "pingers," typically used for fish tracking, also can be incorporated into the belt and/or tethered tag for close range monitoring, retagging, or capture efforts and tag recovery.

VHF-Only Tags and Tracking Methods

The conventional, simplest, and least expensive tracking method has been the use of VHF radio transmitters[13]. This technology was first used to study manatees in the late 1970s in the St. Johns River of Florida[14] and in the eastern Brazilian Amazon[15]. In this attachment method, a nonbuoyant, waterproof transmitter was mounted directly onto a custom-built belt that was fitted to the animal's caudal peduncle[16]. Because the transmitter remains underwater most of the time, its use has been restricted to freshwater habitats, as salinity levels (higher electrolyte concentrations) in marine and even brackish areas prevent signal transmission through the water column. To enable sirenian radio-tracking in marine or brackish habitats, a tethered floating tag assembly was designed for manatees and dugongs[17].

Typical VHF wildlife tags are within 148–152 MHz, 163–165 MHz, or 216–220 MHz[18]. For tracking manatees, the 163–165 MHz range has been most common in Florida, Puerto Rico, Belize, and Mexico. In Brazil a range of 163–164 and 173–174 MHz has been employed within the Amazon, while 148 MHz has been used along the coast. Choices among these ranges are determined by governmental frequency allocations within the study area or country and by wildlife equipment manufacturers.

With the VHF tracking system, minimum equipment needs include radio transmitters with an appropriate attachment mechanism, a portable wildlife-tracking receiver (either manual or scanning), and a directional antenna (typically a handheld "H" or Yagi antenna). Also valuable to promote successful field tracking ventures are a good pair of headphones and a handheld GPS receiver or detailed maps and a good compass. For aerial tracking, a pair of antennae with specific brackets for attachment to an aircraft and an in-line left/right switch allow trackers to monitor either or both sides of a plane's ground track in order to localize signals.

VHF tracking is usually accomplished by "homing" (following a signal toward its greatest strength)[19], or triangulation (getting at least two signal bearings from different locations, and plotting the animal at their crossing)[20]. Homing can enable visual observations, but trackers risk disturbing the animal and causing it to change behavior[21] and position. This disturbance can be minimized by using triangulation. Triangulation requires angles of about 90° between bearings and short intervals between readings, which may not be feasible under conditions of narrow channels and surrounding dense forest. Autonomous VHF signal monitoring can be accomplished by automatic receiving stations coupled with an antenna array[22].

VHF field data sheets should include a map, with fields for recording individual manatee identification, date and time, duration of listening, platform (land, boat, tower, aircraft), level of accuracy (general area, triangulation, sighting), triangulation points (recording in UTM coordinates recommended)[23], coordinate bearings and signal strength, details of equipment, and tracker comments (e.g., weather conditions). In areas where manatees can be seen, data should also include duration of observation, physical condition, and behavior; actual or estimated group size, including notation of presence and number of calves and presence of other animal species; condition of housing and belt; and environmental information, including, if applicable, species of plants present and consumed[24]. Field data can be entered in a computer database and analyzed with the help of software such as LOAS[25] and plotted as geographic information system (GIS) maps.

There are a number of caveats associated with field-based VHF tracking: the signal may be attenuated by distance, obstacles, and dense vegetation. It demands great field effort (e.g., transportation and personnel), and bad weather can limit tracking and observation opportunities. It is not uncommon for a manatee to detect boat noise at long distances and move before it is seen. The level of results will be variable, depending on the intensity of the monitoring, but field observations often provide insights on behavior and specific resource or habitat use.

Automatic tracking—utilizing fixed receiving stations that autonomously capture the signals of animals traveling in the vicinity—is effective for continuous monitoring in relatively small study regions. Programmed frequencies are scanned at user specified intervals and received signals logged to memory by frequency with date and time. As with any VHF tracking, signal detection range improves with the height of the receiving antenna, so automatic stations/antennas are often mounted on elevated platforms. Automatic tracking involves high equipment costs and maintenance, and data typically reflect presence/absence of study animals as opposed to determining precise locations.

Tags utilizing only VHF transmitters have limited efficacy in dugong tracking. VHF tags usually allow a field observer to locate only the general vicinity of a tagged dugong (i.e., within ~80 ha). When dugongs are approached by a boat they usually remain submerged for longer periods (>5 minutes) and/or head out to deeper waters where the VHF signal cannot be located. Consequently, too few VHF signals are typically acquired to triangulate the location of the animal accurately, especially for extended periods[26].

VHF tags are best used for general information on spatial distribution patterns, frequently used areas, site-specific use by individuals, site fidelity of individuals, and general estimation of movements. Field-based tracking also provides opportunities for visual contact with the subject, allowing a scientist to gather information on general behavior, identification of forage species, and associations with other individuals. Due to the limited transmission range, these tags are not well suited for documenting timing and route of long-distance moves.

However, VHF systems may be operational for several years, providing multiple-year tracking possibilities. In Mexico, in estuarine conditions, the longest VHF transmitter batteries have lasted for 837 ± 154 days (n=3) of continued manatee tracking[27]. VHF is a desirable component to have in addition to a PTT/GPS system, as it allows ground truthing of animal behaviors once their initial location is obtained via satellite, and it facilitates easy location and retrieval of detached transmitters from the field.

Satellite-Based Tags

PTT tags

In the late 1970s the Argos system was created, using receiving stations on satellites[28]. This made it possible to monitor long-range movements in remote areas and dramatically improved the continuity of monitoring across time and animal range. The first manatee satellite tag was deployed in Florida in the mid-1980s[29].

This category of radio tag incorporates a satellite link for remote location determination and relay of sensor data. The Argos system continues to be a standard for satellite monitoring of sirenians. This system consists of animal-based Platform Transmitter Terminals (PTTs), a network of polar orbiting satellites, and ground-based data processing with user interface. The ultra high frequency (UHF) signal (centered at 401.650 MHz) emitted by the animal's PTT is picked up by individual satellites. The tag's location is calculated by Doppler shift, and recent location and sensor data may be accessed through computer interrogation on the Internet or by email or fax. In addition to location determination, remote monitoring, and near real time data availability, these tags record transmitter temperature, activity and dive periods, and other sensor data.

Tagging technology keeps improving, and different configurations are being explored, but all existing tags in this category are tethered to ensure optimal signal reception and performance. Tethered tags may be disadvantageous in areas such as rivers, where the amount of submerged branches results in increased probability of entanglement or where heavy forest cover may impede signal transmission.

To enable field tracking and allow recovery of the tag, VHF beacons have been adapted to PTTs used in manatee and dugong studies. Remote and field monitoring capabilities of combined PTT/VHF tags enhance VHF field tracking and opportunities to get visual contact with the subject. Field tracking and observations are necessary to document resources or animal behaviors associated with use areas, to implement specific complementary studies, and to monitor or replace the tag if necessary. Argos location data may be used to obtain information on space distribution tendencies, frequently used areas, site-specific use and site fidelity of individuals, accurate estimation of displacements and movements, and strong support of other studies, such as addressing aerial survey bias and assessing habitat use.

The Argos system allows remote tracking of offshore animals, such as dugongs. Satellite-monitored tags require little field effort (except for capturing). This type of tag, which requires more energy to operate, usually has a shorter lifespan than VHF tags (6–12 months, depending on duty cycle). Because satellites have polar orbits, greater amounts of data are generated from tags deployed at higher latitudes. However, tropical sirenians can be effectively tracked with five operational satellites, which are capable of generating over 15 locations daily (satellite passes lasting five minutes or more) near the equator. Although initial investment and fees for data acquisition and processing are high, the system does not involve significant field costs in supplies and salaries (except during regular monitoring of the general condition of the housing and tether/peduncle belt attachment), and it does produce a wealth of data which might not be obtained through VHF telemetry.

GPS tags

The latest addition to wildlife telemetry involves the incorporation of GPS technology. In its basic form, a GPS receiver with an antenna mounted in a floating housing captures signals from a group of geo-stationary satellites, calculates a position, and stores it to memory at set time intervals.

Tracking may occur under any weather condition, with location fix time intervals down to a few seconds and accuracy of less than 5 m[30]. Operational time is dependent on programmed fix intervals and sensor operations, but deployments can span several months to one year, with sampling rates scaled for individual studies. Initial costs are high, but GPS tags produce highly accurate data[31]. This is a more cost-effective system than VHF in terms of the number and accuracy of data points obtained.

The data logging GPS tag, typically coupled with a VHF transmitter, must be removed from the animal or otherwise recovered to obtain the stored location data. Some researchers have incorporated preprogrammed or actively triggered release mechanisms for tag recovery as described earlier. In other GPS tag designs, data may be acquired in the field through periodic transmission of downloaded data sent by the tag via modulated radio frequencies at programmed intervals. With the Argos-

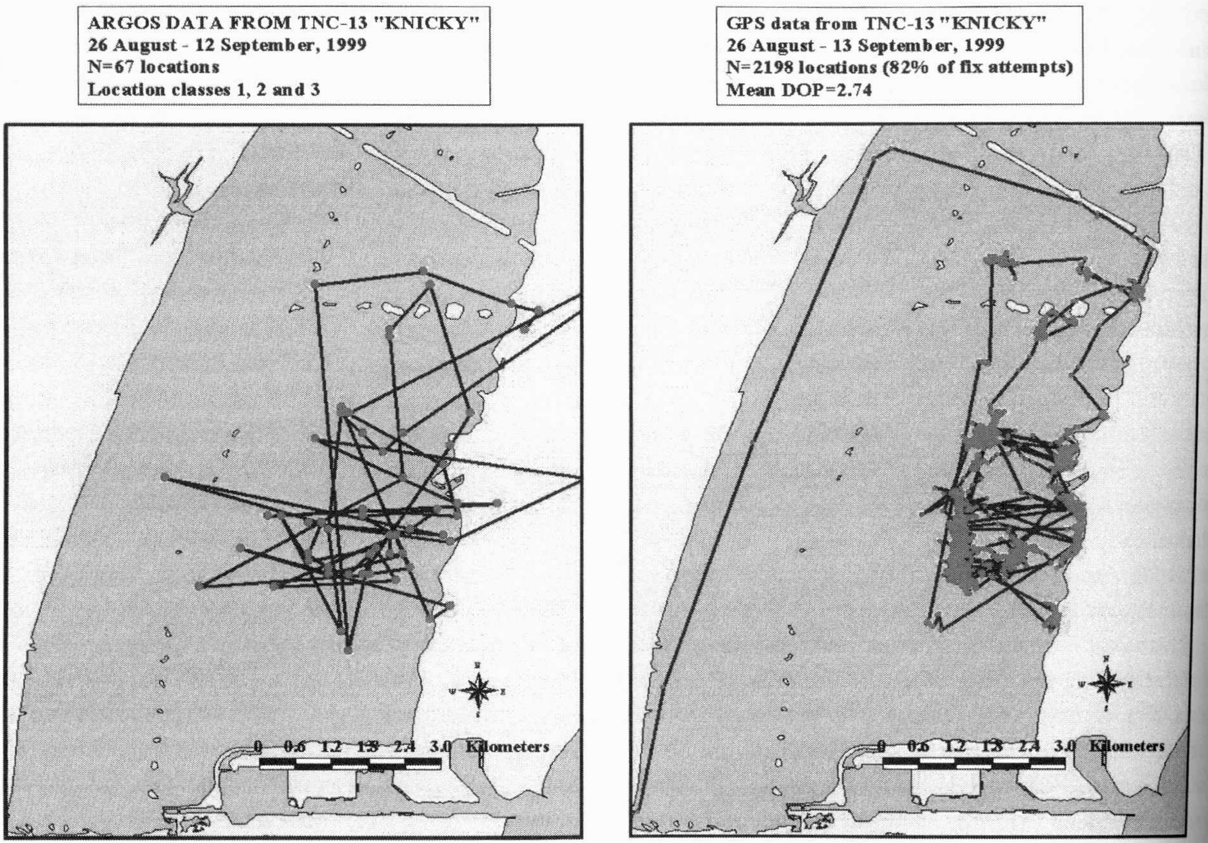

Figure 13.4. Comparison of locations determined via PTT and GPS tags deployed simultaneously on an individual in eastern Florida. (Courtesy of James Reid, U.S. Geological Survey.)

linked GPS tag, described in more detail later, GPS locations are relayed through a satellite link and acquired from the researcher's office.

Tests of GPS tags on manatees resulted in records from many locations, enabling detailed insights into the movements of the tagged animals. For 18 days, a GPS tag was deployed piggyback to an Argos PTT on a previously tagged adult manatee as it swam through the protected waters of the Banana River at the Merritt Island National Wildlife Refuge at Kennedy Space Center in Florida. Comparisons of the resulting data (figure 13.4) showed a distribution of Argos locations (mean # loc./day = 3.7) that reflected the animal's persistent use of an 18 sq km portion of the river; however, specific movement patterns are not discernable. Data from the GPS tag, operating during the same time period and programmed for ten-minute GPS fix intervals, recorded locations (mean # loc./day = 122) in shallow water along the shore at night and 1.2–1.8 km offshore within seagrass beds during the day. This diel use pattern was not evident from the Argos track[32].

GPS tags are a valuable tool in intensive investigations into how manatees utilize habitats. Compared to VHF or PTT data, these tags provide more specific information on space distribution tendencies, better definition of areas frequently used, more accurate estimation of movement and routes of displacement, and more specific data on site fidelity, all with a continuous, standardized localization method. The system works very well in most sirenian habitats, allowing researchers to follow large- and small-scale movements, and provides valuable information for ecological studies like habitat evaluation of both hotspots and general areas. Locations, when integrated in a GIS, can be correlated with seagrass habitats, bathymetry, and other detailed map coverages.

PTT/GPS tags

Perhaps the most popular tag currently employed for detailed, multi-month monitoring of sirenians is the Argos-linked GPS tag, or PTT/GPS tag. GPS locations are stored to memory, and then periodically relayed by an on-board PTT as encoded sensor data through the Argos satellite system. This combination allows both remote monitoring and fine-scale analysis of sirenian movement patterns, with user-defined sampling rates over three to nine months. Specific applications include identification of habitat hotspots, site fidelity, characterization of large-scale moves or movement highways, and characterization of foraging movements influenced by tidal cycles.

Compared to early PTT-only tags used on sirenians, Telonics PTT/GPS tags[33] are smaller, accumulate large amounts of precise location data, and can be programmed to require less energy to operate. Owing to battery/memory constraints, a trade-off must be made between obtaining temporally high-resolution fixes over a short deployment or fixes further apart over longer deployment periods. These considerations must be scaled with a duty cycle appropriate to meet study objectives. The duty cycle can be set from minutes to months depending on (1) the tag specifications, (2) battery capacity, and (3) the type of data required. For example, when early Telonics units were set to the minimum 15-minute cycle, battery power lasted around two months. A 20-minute cycle provided suitably high-resolution location data to capture the full range of dugong movement behaviors (fine and large scale) for three months at a time[34]. In manatees, a 20-minute cycle provided high-resolution locations data for five months. Recent versions of the Argos-linked GPS tags conserve significantly more power, which enables longer deployment periods or more frequent GPS fixes.

The units usually require a surface period of 4 to 40 seconds to acquire a GPS fix, depending on the version of the tag electronics. Newly incorporated Fastlock GPS tags (Wildlife Computers, Inc.) can fix within one second but provide lower position accuracy than standard GPS locations. If the animal is resident in deep water (>4m), the tag will typically spend less time at the surface and so fewer location fixes will be recorded. Similarly, when the animal is moving a long distance or otherwise continually swimming, the tag remains underwater for much of the time and there is less surface time to acquire a location fix[35]. Because the satellite tag can only acquire a location fix at the surface, to conserve battery life a saltwater switch is incorporated into the units to shut down transmission attempts when submerged (note that any antifouling compounds should be kept away from the saltwater switch terminals, as copper-based paints may conduct current and prevent the switch from operating properly). The lack of GPS location fixes acquired from dugongs tracked in deep water or while traveling rapidly can introduce a significant bias into analyses of habitat use, which must be accounted for, for example through summarization or weighting of the location data[36].

The utilization of GPS tags requires specific training and protocols to ensure proper programming and data recovery. We encourage the use of these GPS tags in collaboration with experienced research groups. Because the equipment is highly technical, tagging operations should be conducted with (reasonably) easy access to logistical support. Tag costs and maintenance, repair, and upgrading of satellite units are often prohibitively expensive. Fees for Argos monitoring may be reduced if the country has a Joint Tariff Agreement with Service Argos.

Integration of Other Equipment

Activity and mortality (lack of activity) sensors incorporated in VHF and/or satellite-monitored tags allow researchers to know when an animal is active or resting, and aid in determining tag detachment and enabling equipment recovery. Belt release mechanisms have been incorporated in dugong and manatee harnesses to allow for automated tag detachment and tag recovery; see earlier discussion. These can be self-activated at a preset time or activated by researchers within radio range.

Dugong dive profiles can be collected using a time-depth recorder (TDR: Mk9, Wildlife Computers, Ltd.) to analyze dive patterns within and between habitats. These compact units (~8 x 3 cm) can be fitted to the plastic block on the dugong harness as close to the animal's tail as possible. Current models can collect over six months of dive data with a reading taken every two seconds, and many concurrently measure light intensity, water temperature, and velocity. A sample rate of two seconds is of suitably high resolution to capture the dugong's dive profile. If the unit can also record light and temperature, these can be sampled at longer intervals (~five minutes) to conserve battery life. Dive recorders usually must be retrieved from the field to download the full-recorded dataset.

Several newly developed devices designed to record detailed observations over brief periods have been deployed on sirenians. National Geographic's Crittercam records video and audio and collects environmental data such as depth, temperature, and acceleration[37]. The Marine Mammal Behavior Laboratory at Woods Hole Oceanographic Institution developed a Digital Acoustic Recording Tag, or D-tag, to monitor continuously the behavior of marine mammals and their response to sound[38]. These tags, which can record the manatee's acoustic environment synchronized with the orientation of the animal (depth, speed, pitch, and roll) in three dimensions, have been used in studies for manatee-boat interactions.

Discussion

Insights into Sirenian Biology

The high cost of equipment and difficulties associated with tagging usually lead to small sample sizes, so caution should be taken when referring to tagged animals as representative of all animals in the region (this is common for VHF, PTT, and GPS tags). These techniques provide little information on the role of nearby animals in influencing movement patterns and resource use, and limited information on habitat characteristics or quality. Direct observations of tagged individuals can provide some insights on associations with conspecifics. Likewise, field characterization of habitat conditions can help correlate tracking data with resource needs.

GPS/PTT satellite telemetry has provided previously unobtainable fine-scale information on the movement, behavior, and habitat use of dugongs and manatees. For example, GPS/PTT tags deployed on 70 dugongs along the coast of Australia have provided detailed information on the large-scale movements of dugongs among core seagrass habitats along the coast[39]. Satellite tags have enabled the core seagrass habitats that dugongs use intensively to be identified so that they can be surveyed and mapped. Enhanced understanding of what constitutes "quality" dugong seagrass pasture will directly inform management policy for protecting important dugong habitats[40]. In Mexico, GPS tags have provided detailed information on the large-scale movements of manatees along the coast of Mexico and Belize and between distant areas of localized manatee occurrence[41]. Tagging data can also be used as baseline information to support ecological and habitat use research[42].

Tagging and Tracking in Developing Countries

Table 13.1 is a list of contact details for manufacturers commonly used by the authors. VHF is the most versatile technique. Given its low cost, long life, and reasonable accuracy, it is the natural technology to be used in developing countries and certainly a first step when starting a new tracking program. VHF is also the best option in relatively small areas like lagoons or rivers. The intensive field effort involved in conducting the monitoring and operating the equipment enables local people to be involved, which usually improves understanding and helps gain support for the project. However, in open areas too large for the reception coverage of VHF tags (with a signal range of 5 km from land or boat), the long-term intensive field monitoring effort needed may become problematic in expense, time, human participation, and administration support[43].

Though satellite tracking demands a much higher investment, it is useful and more efficient and provides higher quality data. Collaborative efforts may reduce limitations: neighboring countries sharing sirenian populations should consider collaborative research to reduce costs and improve data collection. While some PTT/GPS tags are available complete from manufacturers, most tags and the harness assembly for attaching the tag must be custom made. Technical training by scientists from countries where materials are becoming available allows for in-country belt construction. Strong coordination between regional partners is needed for training in capture techniques, the use of new software, and data analysis. Customs clearance of some materials, such as lithium batteries or transmitting devices, may be a problem at some international airports.

In Mexico, VHF-generated information on the spatial distribution of manatees supports manatee habitat use and management studies in lagoon systems[44]. It was used as the foundation for the first management plan of the Chetumal Bay Manatee Sanctuary. New and continuing baseline information about regional manatee movements between distant sites of manatee occurrence in Mexico and Belize, obtained by GPS tags, could strengthen current regional collaboration and promote new cooperation among neighboring countries with sirenian populations.

The documentation of a regular manatee movement between a preserved area of "white" (murky, sediment-laden) water environment and a large, deep blackwater

Table 13.1. Contact detail for manufacturers of sirenian tagging equipment.

GPS/PTT tags	Telonics, Inc.	http://www.telonics.com/
TDRs, GPS/PTT tags	Wildlife Computers, Ltd.	http://www.wildlifecomputers.com/
Dugong tether and harness	Ocean Industries Pty, Ltd.	http://www.oceanindustries.com.au/

lake as the water levels change in the Amazon served as further justification toward establishing a new protected area in the Brazilian Amazon.

Detailed maps of dugong movement corridors and core habitats identified from satellite tracking were directly incorporated into the Great Sandy Strait Marine Park Zoning in Queensland, Australia. The marine park was officially designated in 2006 and protects most of the dugong seagrass habitat within Hervey Bay in Habitat Protection Zones where professional fishing, development, and aquaculture can occur only with permission from the state government. Also within the new marine park are go-slow zones over the seagrass habitats identified by satellite tracking as those used most intensively by dugongs[45].

The application of radio-tracking technologies to study sirenians continues to evolve. The tagging and tracking techniques discussed here can be cost-effective and adaptable to most situations to address specific research questions or assist with captive release and other programs for sirenian management. The unique findings from radio-tracking can provide valuable information and insights about sirenian movement patterns, foraging strategies, and behavior that are unobtainable by, and yet complementary to, other research methodologies.