Chapter 2
Biologging

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Abstract In recent years, the habitats of wild animals and humans have overlapped remarkably as economic activity intensifies and expands. As a result, human activities in the biosphere have brought about a decrease in biodiversity and have become a destabilizing factor of the ecosystem; these can no longer be ignored. Human activities cause various frictions in the ecosystem, which in turn cause serious social problems such as damage to residents, agriculture, and fisheries. This is a pressing issue to be solved if society is to achieve sustainable use of natural resources. Thus we obliged to assess human impacts on the ecosystem and reclaim our role as a member of the biosphere in the ecosystem. Towards this cause, using behavioral information about wild animals helps to clarify their relationship with man. In this chapter, we introduce methods for acquiring animal behavioral information using the latest information technology.

2.1 Acquisition of Animal Behavioral Information

Visual observation is a basic technique to survey wild animal behavior. However, direct observation of wildlife is generally difficult because of their high mobility, nocturnal activities, and the dangers of accessing their habitat, among others. In addition, it is impossible to observe them in the hydrosphere, which accounts for about 71% of the earth's surface, including lakes, marshes, and rivers. Therefore, the collection of behavior information on wild animals living in these areas has been overlooked for the simple reason that direct observation is difficult.

Recently, researchers have begun to observe wild animals using a Cessna or helicopter, which makes large-scale observation possible. This is effective for

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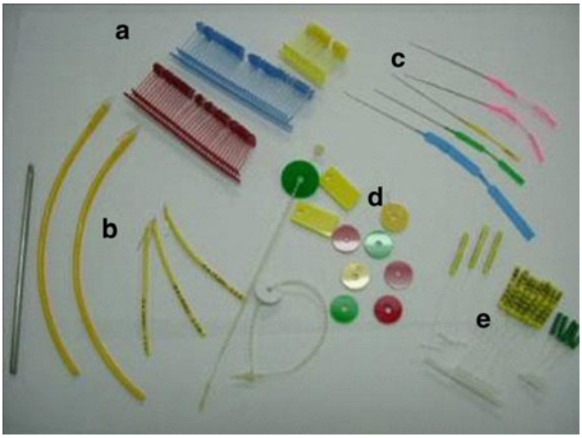

Fig. 2.1 Various tags are used to measure the movement of aquatic animals: (a) anchor tags, (b) dart tags, (c) ribbon tags, (d) Atkins tags, (e) spaghetti tags

observation of aquatic animals. The realities of the biological community, which have far exceeded our imagination, have been illuminated through observation even in the deep ocean by submersibles or remotely operated vehicles (ROV). However, because such observation cannot be conducted over long periods, we are able to get only a snapshot of animal activities.

As for follow-up observation, tags have been attached to target animals to understand how they move from the release point to the recapture point. For example, the pathways of migratory birds are investigated using tags to assess the effects of sea farming on their behavior. This brings us the basic information on their habitats and migration route. A variety of tags are used according to species and size (Fig. 2.1).

We get only the location information at release and recapture point in a tagging survey. On the other hand, wild animals move around in their habitats throughout their life histories. If environmental information that they experience can be measured in detail, it becomes possible to guess their behavior based on this background. The desire for this type of information is one of the driving forces in the development in biologging technology.

2.2 Techniques of Biologging

Biologging is a technique to observe animals in their habitat where we have limited access. Japanese scientists and engineers have been playing an advanced role in the technological development of biologging. Roughly, there are two methods of biologging. One is a method to accumulate information with small data recorders (micro data loggers or archival tags) attached to or implanted in the animals. Archived data can be obtained after collecting the recorder. The other is a method of installing a beeper and an ultrasonic transmitter in the animals, which is called biotelemetry. It is possible to acquire data on the movement and physiology of object animals, in addition to the environment they experience. Prof. Naito of the National Institute of Polar Research and Prof. Sakamoto of Kyoto University developed the data logger in the 1980s, and, they succeeded in recording the behavior of sea turtles and other marine animals. A digital data logger miniaturized and can be installed in a number of animal species. As for the latter, biotelemetry with a small beeper has been used for birds with a vast home range since 1970s. Biotelemetry with an ultrasonic transmitter has been used to measure fish behavior in water.

The word biologging was first used at an international symposium held at the National Institute of Polar Research in 2003 (Naito 2004). The Japanese Society of Biologging Science was organized in 2004, and since then biologging has been an established technique for behavioral analysis of animals. In recent years, we are able to obtain a large amount of data through data loggers, thanks to multi-itemization of the sensor and increase of the memory capacity. Information technology makes a significant contribution to improvements in data analysis.

From the viewpoint of observing action and activity, biologging can be understood as a kind of human-sensing information technology. In human-sensing, the object is the same being as the observer. The observation site can be artificially set. It is easy to understand acquired data because the observer can communicate with the testee. On the other hand, biologging observes the behavior of animals living in places where it is impossible to access. The measuring instruments must be able to endure various environments. Furthermore, the installation and settings of the instruments for data acquisition are very difficult. Acquired data sometimes exceeds our expectations, and requires consideration and examination from all aspects.

2.2.1 Acquisition of Behavioral Information Using Micro Data Logger (Archival Tag)

The development of micro data loggers (archival tag) began as a clockwork-powered analog process writing data to a recording chart stored in a waterproof applicator. It was reduced in size to below 10 cm in total length in the 1980s. Analog data loggers were first attached to penguins, seals and sea turtles with easy collection in the late 1970s. In addition to the diving behavior of subject animals, other data such as a water temperature was obtained. In the 1990s, the recording medium changed from paper to electronic memory, an epoch-making increase in storage capacity, and various sensors were loaded. This made it possible to acquire data that needed a more high-speed sampling rate, such as acceleration and terrestrial magnetism (Table 2.1). This is commonly called micro data logger or archival tag. At first, it was called Time-Depth Recorder (TDR) since sensors were commonly used for only acquiring water temperature or hydraulic pressure data. There are no problems in practical use in data sampling with recording intervals of about one time per second for water temperature or depth. However, there are restrictions imposed by the capacity of built-in memory and battery life. Memory capacity and

Table 2.1 Sensors installed in a micro data logger and obtainable information

Sensor	Obtainable information
Pressure	Depth
Temperature	Ambient/body temperature
Acceleration	Movement, posture
Propeller	Convection velocity
Light	Light intensity, rough location
Magnetic	Geomagnetism, azimuth direction
Electric potential	Heart rate, myogenic potential, brain wave
Image	Still image, moving image
GPS	Location

battery life still has a problem, even now, because the micro data loggers are used for the purpose of obtaining image and sound information. The latest micro data loggers used at present are listed in Fig. 2.2.

The micro data loggers can obtain the data of physiology activity of subject animals, and environmental information as well. Recently, GPS data loggers using Global Positioning System (GPS) were developed, and the location information of object animals can be acquired. Because the signal from a GPS satellite cannot be received in water, the GPS data logger cannot be used for aquatic animals except for animals surfacing when they breathe, like sea turtles and marine mammals.

All data is stored in built-in memory in the micro data logger. Unless the data logger is collected, data cannot be acquired. In general, it is very difficult work to collect the released animals again. Therefore, micro data loggers have been attached to nesting birds and sea turtles expected to return to the same place. Automatic devices that release the data logger after a fixed time (Fig. 2.3) were also developed. The micro data logger was also collected by the telemetry technique. In this way, development of biologging techniques has expanded (Rutz and Hays 2009; Cooke et al. 2004).

2.2.2 Acquisition of Behavioral Information Using Transmitter (Biotelemetry)

Using the micro data logger in the preceding section, we can analyze in detail the behavior of subject animals corresponding to the native habitat and the environment, based on the large and detailed data from the recaptured logger. However, precise position data cannot be obtained without the use of a GPS data logger. Biotelemetry is a technique to acquire the behavioral information with a transmitter, which is useful for measuring the position of the animals in detail. In biotelemetry, the researcher pursues the animal in order to receive the signal from radio waves or the ultrasonic transmitter installed in the object animals. Radio wave transmitters are used on land and in freshwater environments. Because radio waves cannot be transmitted in seawater, ultrasonic waves are used for the observation of fish. Satellite transmitters are used for observation of animals that move terrestrially.

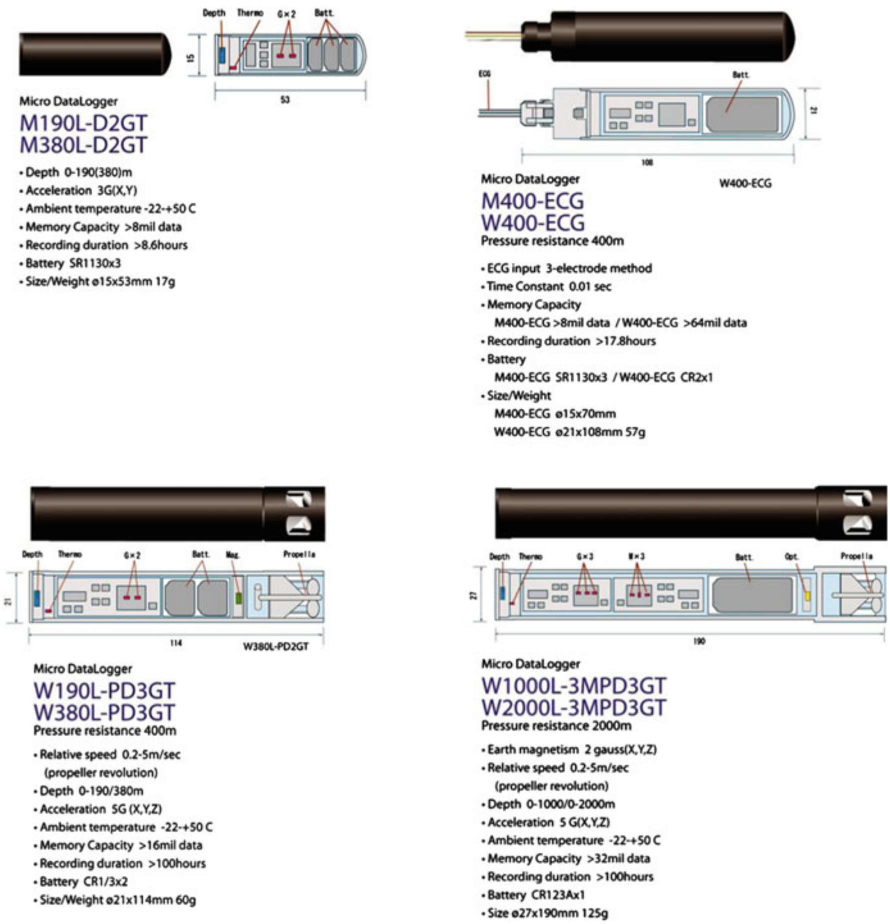

Fig. 2.2 Catalog of the latest micro data loggers (archival tags) (Photos and drawings by courtesy of Little Leonardo Ltd.)

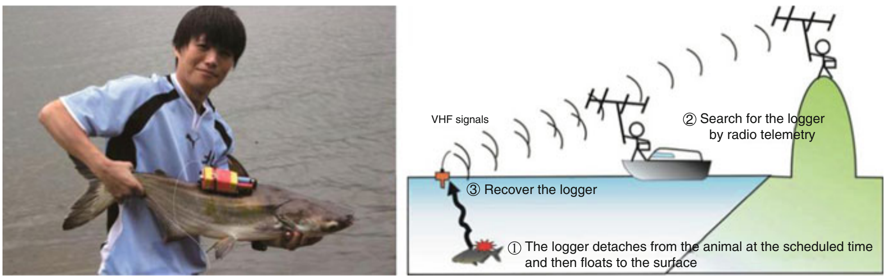

Fig. 2.3 Mekong giant catfish with attached micro data logger and a timer type logger collection device (*left*). Procedure of collection of the micro data logger using an automatic timer type logger collection device (*right*)

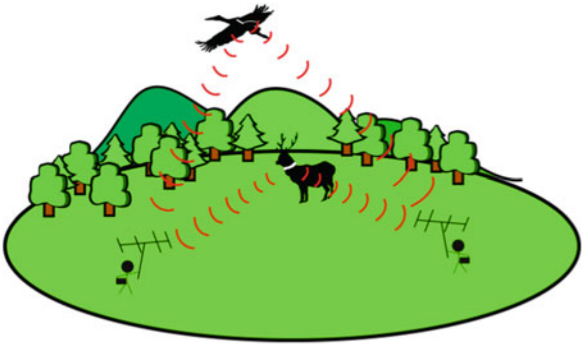

Fig. 2.4 Conceptual diagram of radio wave biotelemetry. Using radio wave telemetry, the researcher receives radio waves from two or more points and locates the sending source (subject animal)

Radio wave biotelemetry is used for terrestrial animals like birds and mammals. The frequency of the radio wave ranges 30–300 MHz, and VHF is often used. A directional antenna such as the Yagi Antenna is used for detecting radio waves. The position of the subject animals is estimated by maximum azimuth of the radio wave from two or more points (Fig. 2.4). An accurate map with appropriate scale is needed to locate them. It draws a straight line to the azimuth of the maximum receiving sensitivity from the position of two or more points. The estimated positions are filled in on the map, and the intersections of those points are the positions of subject animal. When the intersection is not corresponding by three or more points, the polygonal center of gravity can be done using the straight lines. When researchers use biotelemetry, they carry the receiver and the antenna, and pursue the signal source. If the antenna and the installation type receiver can be fixed, allowing animals to be tracked with the range of reception of the base station (Cooke et al. 2004). Recently, a multitelemetry system has been developed. Two or more base stations are set up and connect them by a communication network. It makes it possible to clarify the position of the animals within the range of reception with high accuracy. However, it should be noted that some of the units may infringe on the Radio Act, so it is necessary to pay attention in making observations.

Biotelemetry with ultrasound is used for observation of marine animals including fishes. There are two tracking methods. One technique is tracking with a receiver on board a ship. Another is a technique tracking with receivers arranged within the expected route and distribution of the animals. In the former case, the researcher monitors the signal onboard with suspending a hydrophone in water, and the location of subject animals is presumed from the direction and strength of the signal (Fig. 2.5). In the latter case, the presence of the subject animals can be known by downloading the data accumulated in a built-in memory of the fixed-type receiver (Fig. 2.5). The ultrasonic transmitter currently used with unique identification codes (ID) is adjusted by the interval time of ultrasonic wave pulse (69 kHz).

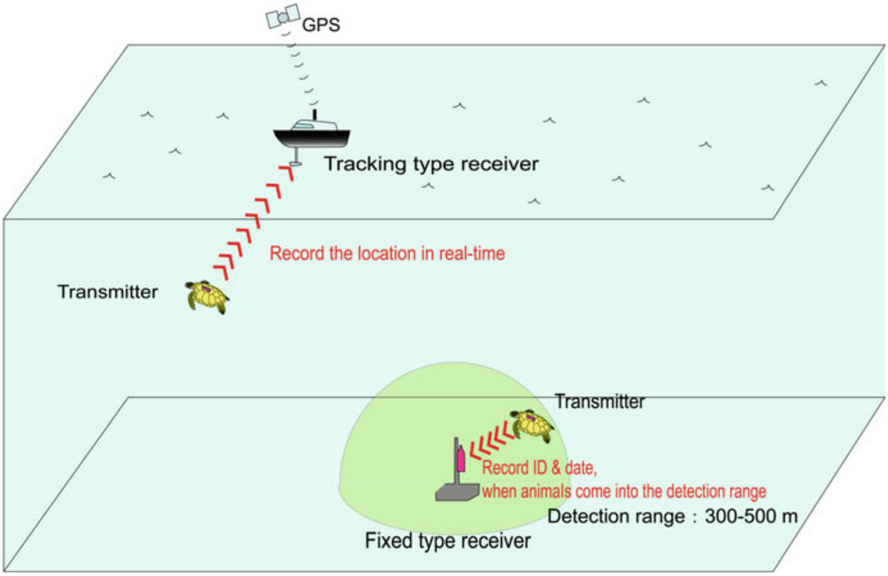

Fig. 2.5 Conceptual diagram of ultrasonic biotelemetry. The subject animals are tracked in real time using the tracking receiver onboard a ship. On the other hand, fixed receiver records transmitter ID and the detection time of the animals within the range of the reception

This can pursue several individuals at the same time even with ultrasonic wave signals of the same wavelength. It is also possible to measure the water temperature or depth by setting the ultrasonic wave pulse interval value.

A real-time positioning system that can pursue the behavior of the animals within the reception range with high accuracy by recording the ultrasonic wave signal at the same time with the installation type receiver at three or more points has been developed.

It is extremely difficult to pursue animals with a broad range of movement such as birds, whales or sea turtles, with radio or ultrasonic telemetry. These animals can be pursued with the Argos system using space satellites. The Argos system was developed by the French Centre National d'Études Spatiales (CNES), the United States National Oceanic and Atmospheric Administration (NOAA), and the National Aeronautics and Space Administration (NASA) in the 1970s. It is maintained and managed with the cooperation of France, the United States and the Japan Aerospace Exploration Agency (JAXA). The principles of measurement by the Argos system are summarized as follows. The space satellite orbits the earth every 102 min at an altitude of about 850 km. It receives the signal (401.650 MHz ± 4 kHz) of the Platform Transmitter Terminal (PTT) from about a 5,000 km diameter on the ground. The signal that the satellite receives changes by the Doppler Effect by the relative speed of the satellite and PTT. The distance between a certain momentary satellite and PTT is obtained to take into account the

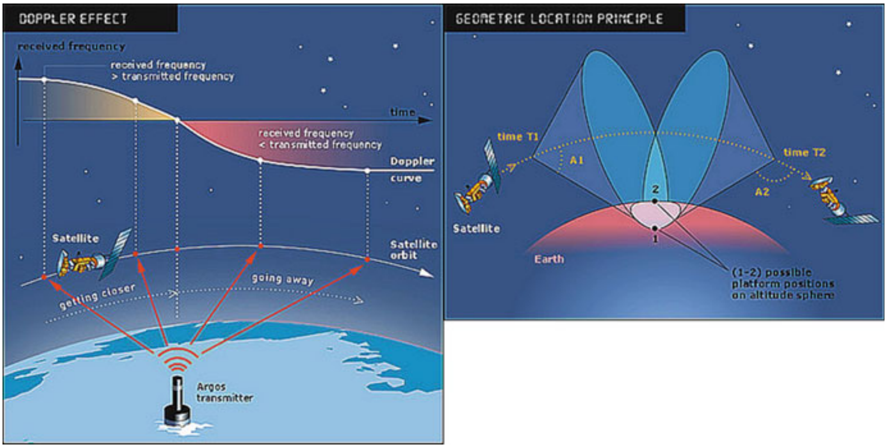

Fig. 2.6 Principle of measurement using the Argos system. The signal from the earth station (PTT) is received by the satellite. Its receiving frequency varies depending on the Doppler Effect (*left*). Because the relative distance between the satellite and PTT is understood from the Doppler Effect, the intersections (two points) of the distance and the ground are obtained. Which of these is appropriate between two points is judged from the discharge point (*right*)

frequency variation of the signal by this Doppler Effect. The intersection of the distance and the ground becomes the position of PTT (Fig. 2.6). Thus, PTT on the ground only sends the signal including ID to the satellite, and the Data Collection and Location System (DCLS) installed in the satellite calculates the position. After the downlink to the earth station (about 50 stations worldwide), the location information is sent to the user.

The Argos system can obtain location information everywhere because the data is transmitted to the user at the same time as measuring the position. The location information is divided into classes (3, 2, 1, 0, A, B, Z) depending on the accuracy. The highest accuracy class 3 is guaranteed for an accuracy of less than 150 m, although the positional precision is inferior to GPS. Accuracy worsens greatly in class A or B, and whether to use the positional data is entrusted to the researcher's judgment. Therefore, satellite tracking using the Argos system is used for the observation of animals with broad range migrants without good accuracy.

The new tracking system combining various data loggers with the Argos system is more advanced, and transmits the data obtained by data loggers through the satellite communication system of the Argos system. For instance, the GPS-Argos system, which combines a GPS receiver and an Argos transmitter, was developed to offset the poor accuracy of positional measurements of the Argos system by accurate location of the GPS (Fig. 2.7; Yasuda and Arai 2005). The pop-up tag system that was built by combining the data logger and the automatic surfacing system into the Argos system was also developed. This makes it possible to clarify the broad range migration of large fishes that live outside the range of radio waves.

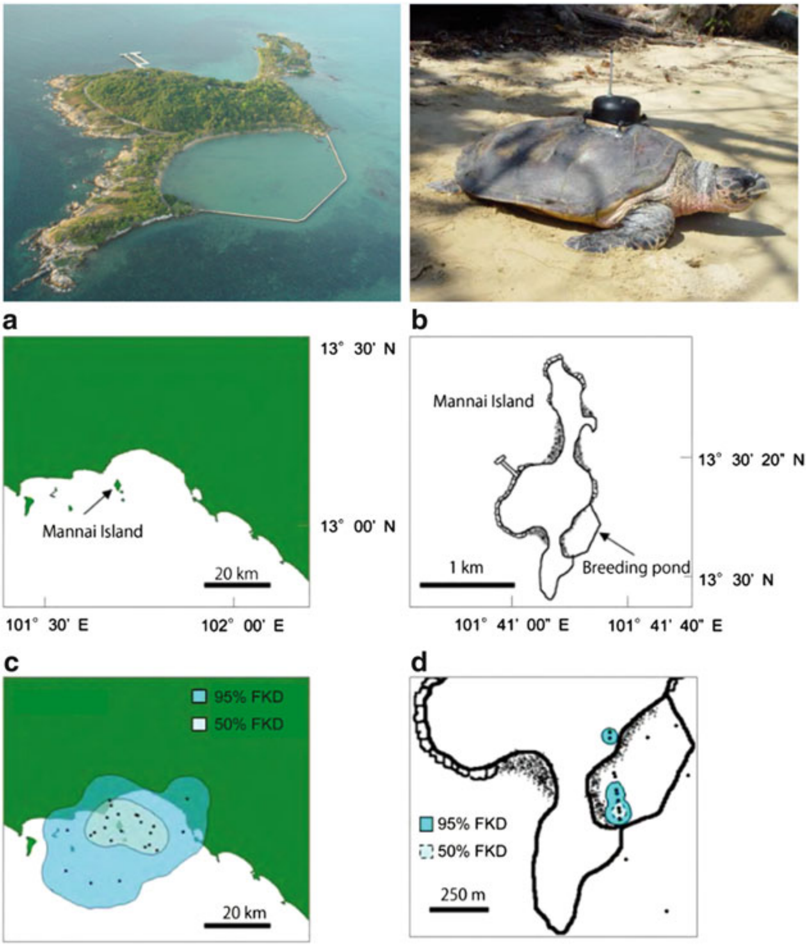

Fig. 2.7 Experimental tracking of hawksbill sea turtles with GPS-Argos transmitters was performed at the sea turtle protection research facility of the Department of Marine and Coastal Resource at Mannai Island, Thailand (*upper left*). A GPS-Argos transmitter was attached to the carapace of hawksbill turtle (*upper right*) (HB1). (A) and (B) indicate the maps of Mannai Island and its surrounding sea area. Based on the GPS-Argos transmitter results the home range of the turtle almost distributes within the breeding pond (D). To the contrary, however, the Argos system results indicated the home range extends to the surrounding area of the island beyond the breeding pond (C) ((A–D) are reprinted from Yasuda and Arai (2005) with permission)

2.2.3 *Features of Biologging Techniques*

The techniques that use the micro data logger (archival tag) and the technique of biotelemetry with a transmitter have advantages and disadvantages respectively (Table 2.2). Based on a good understanding of the features of these techniques, it is necessary to select the more appropriate technique when biologging is used.

Table 2.2 Features of each biologging technique

Micro data logger (archival tag)	Measurement item: activity, physiology, environment, and location information
	Merit
	In-depth data can be taken regardless of time or the place
	Labor is minimal as long as the collection method is established
	Demerit
	The data logger is expensive
	If the data logger is not retrieved, data cannot be obtained
Transmitter	Measurement item: location, environment, and activity information
Radio/ultrasonic (tracking type)	Merit
	The transmitter is relatively cheap
	Information can be acquired in real time
	Demerit
	If the signal is not received, data cannot be obtained
	It is labor intensive and costly to track
Radio/ultrasonic (fixed type)	Merit
	Labor is minimal
	Multiple targets can be tracked at the same time
	Demerit
	The range of the reception depends on the number of base receivers
	Data cannot be obtained if there are no subject animals within reception range
Satellite tracking	Merit
	If it is possible to communicate with the satellite, data can be acquired anywhere
	Labor is minimal
	Demerit
	The satellite transmitter and communication charges are very expensive
	The accuracy of the location information is bad

Activity, physiological and environmental information on various animals can be obtained now by techniques that use the micro data logger, as shown in Table 2.1. When terrestrial animals are tracked, detailed location information can be acquired by the GPS data logger. The biggest advantage of this method is to obtain fine-scale location data. Another advantage is that a detailed behavior record can be obtained regardless of place or time. On the other hand, difficulty in recovering the data logger is the worst disadvantage. Therefore, the researcher should make an in-depth research plan assuring that the data logger can be recovered using a timer type logger collection device or similar. Moreover, the expense of the data logger is also a disadvantage.

The technique with a transmitter (biotelemetry) is chiefly used to obtain the location information of the subject animals. In addition, some kinds of transmitters can transmit the information on the environment, animal physiology and activity like depth and temperature data at the same time. As described above, biotelemetry has two types of tracking to obtain data. One is a tracking type in which the researcher carries the receiver during the tracking. The other one is the installation type, where the researcher set up the receivers. As for the tracking type, the advantages are to obtain the data in real time, and at a reasonable cost for the initial investment for the research. However, the tracking type also has disadvantages, in that it requires a huge amount of work to pursue the target animals, and requires high personal cost for tracking. The researcher is not able to obtain any more data if the target animals are lost. The installation type does not require as much work as the tracking type because it only needs regular data download from the deployed receivers. There is also a receiver into which the automatic data transfer system to the researcher is built. A weak point of the installation type is that the researcher is not able to acquire the data at all if there are no target animals within the reception range. In addition, it is costly to obtain the information on wide-ranging movement because the tracking range depends on the number of the receivers.

As for biotelemetry that uses the Argos system, the features are different from those of the radio and ultrasonic telemetry. The merit of this method is that the researcher is able to get the location data wherever the target animal exists if the transmitter can communicate with the Argos satellite. Data obtained are transmitted to the earth station via the satellite, and delivered to the users by email. Therefore, the researcher does not need to recover the device and consequently the labor is very minimal. The disadvantages are that the communication charge for data transmission is high in addition to the charge of the main body of the transmitter. It might cost millions of yen when tracking exceeds 1 year because the satellite communication charge is calculated on a daily basis. Moreover, the position-fix accuracy of the Argos system is comparatively bad as described in the foregoing paragraph. Therefore, it is not for the observation of the animal that does small-scale movement, but for the animals that migrate across areas.

2.2.4 Method of Installing Measuring Instruments

It is necessary to pay close attention to the installation so as not to influence the behavior or the lives of the animals when the micro data logger and transmitter are installed in the animals. There is no clear basis although the size of the measuring instrument should be roughly within 3–5% of weight of the animal (Cooke et al. 2004). When the measuring instrument is installed on the subject animal, narcotics might be used for the safety of the observers and stress reduction for the subject animals. It is necessary to pay close attention to the use of narcotics, and to give subject animals an appropriate dose. The measuring instruments are installed on the back of birds and mammals in general. Other types of measurements are also used; the band type is used for birds, and the collar type for mammals. There are some installation types, such as an external installation, stomach interior wear, and the inside of the body installation for fishes. When the radio transmitter is installed on the subject animal, there is a possibility that the action (behavior) is restricted by the antenna because the antenna part is long. The transmitter is rarely expelled from surgical region after several hours or a few days when it is surgically installed in a body cavity. It is necessary to select the most suitable method by conducting a preliminary installation experiment, and to take into account the effect on the survival rate of animals after surgical operation. For at least 24 h before the experiment, one should check abnormal behavior of the animals that might be caused by the transmitter attachment. Before releasing animals with the micro data logger and transmitter to the outdoors, it is also important to confirm it works normally.

2.3 Analysis of Animal Behavioral Information

The data of the micro data logger are time-series data taken at a constant sampling interval. Time series analysis is needed to clarify the behavior of subject animals and environmental information. In recent years, animal movement obtained from the acceleration data has been observed. Acceleration data are obtained as numerical values from the acceleration by the movement of the animals based on the gravitational acceleration. The posture of the subject animals is estimated from the element of gravitational acceleration. The periodic movement of animals such as flipper/wing stroke of birds, and tail beat of fish can be identified by spectral analysis. In recent years, various sensors of the micro data logger enabled us to acquire a number of behaviors and physiology of the subject animals and their environmental information simultaneously. Behavioral information, including the acceleration data, enables us to classify the behavioral patterns of animals, and to know what, when, and where they do at specific times. Information processing technology such as the cluster analysis and data mining are necessary to ascertain the behavior of the animals from many kinds of data in large quantities.

The home range of the animals can be presumed from the location information obtained by GPS data logger and various biotelemetry investigations. The home range is defined as a place where a certain individual usually uses to feed and breed. Places used only temporarily are not included in the home range. Animals know where there is food and safe retreats. In general, 95% of animal's positions are included within the home range of this animal. When we analyze the location data of animals, it is necessary to consider the objective of the study, the quality of data, and the condition of data collection. It is also necessary to choose a suitable method from the various home range analyses through comparison with other research. Maximum Convex Polygon (MCP), kernel (estimate), harmonic mean, grid cell, ellipse, and Fourier series, etc. are primarily used for estimating the home ranges of animals. The home range and movement data obtained by these methods can be analyzed in more detail by combining them with a variety of environmental information based on geographic information systems (GIS).

2.4 Case Studies of Biologging

2.4.1 Behavior Analysis of Green Turtles Using Micro Data Loggers

The Similan Islands in Thailand of Southeast Asia are a popular tourist spot known for recreational diving and other marine leisure activities. Therefore, the area was designated a national ocean park to protect its natural environment. It is very important to understand how the marine animals living in this region use the protected zone in order to appropriately manage this kind of area as a sanctuary. Therefore, the behavior and ecological information of the green sea turtles that are the symbolic species in the Similan Islands were obtained by using a micro data logger.

We investigated the green sea turtles on Huyong Island, which is one of the Similan Islands, and a nesting area in the rainy and dry seasons of 2003 and 2004. Sea turtles crawl up to the beach and lay eggs two or more times at an interval of 10–15 days during one nesting season. Therefore, if the micro data logger is installed in laying sea turtles, the researcher can recover the data logger at high rates during the next landing, and obtain the data about what the sea turtle does during the internesting period.

The depth data loggers (Little Leonard Co. Ltd., Japan) were installed in the carapace of three green turtle individuals that had laid eggs in March (dry season), June (shift period), and August (rainy season) by using an epoxy resin adhesive (Fig. 2.8). To obtain detailed behavior information, the sampling time of depth was determined to be 1 s. The object individual was captured after egg laying ended in the landing next time, and the data logger was collected.

Figure 2.9 is the time-series data of the stay depth during the internesting period of individual 1 and individual 3. It is understood from this figure that individuals 1 and 3 use the depth zone of 0–40 m and 0–90 m, respectively. Sea turtles need to swim up to the ocean surface for breathing. The interval of the surfacing can be read from the depth data of the figure. These green turtles dove 772 times on average during the internesting period, and the average dive duration was 16.7–22.6 min.

It is known that during the internesting period green turtles take a rest at the bottom of the sea. From the results of the average of stay depth of each individual, the dive depth tended to become deep while shifting from the dry to rainy season (Fig. 2.10). This indicated that the resting place (depth) of the green turtles is different between the rainy and dry seasons. In the sea area around the Similan Islands, the oceanographic conditions often deteriorate because of monsoons in the rainy season. The deterioration of this oceanographic condition may have changed the depth where the green turtle stayed.

Fig. 2.8 Green turtle installed depth data logger (Courtesy of Dr. T. Yasuda)

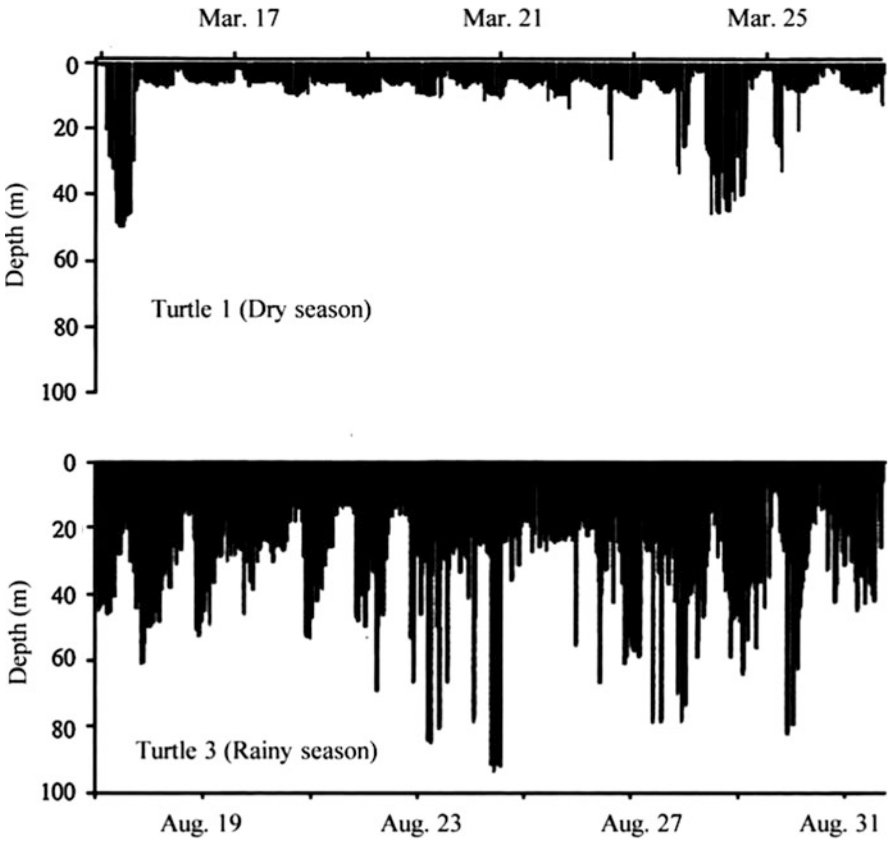

Fig. 2.9 Time-series diagram of depth of a green turtle from the depth data logger during the internesting period (Reprinted from Yasuda (2006) with permission)

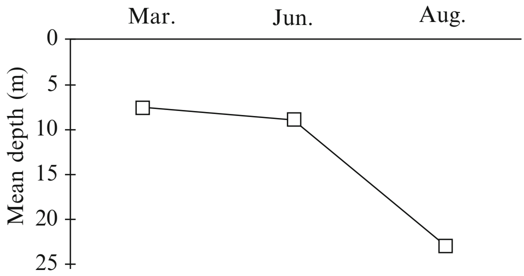

Fig. 2.10 Average dive depth and average dive efficiency of each laying turtle in March and June and August (Modified from Yasuda (2006) with permission)

2.4.2 Homing Behavior Investigation of Rockfish Using Ultrasonic Biotelemetry

Kansai International Airport in Japan opened in 1994 as a real seadrome that took into consideration the maintenance of the environment. The airport island is surrounded by mildly sloped shore protection and on most of these slopes are seaweed beds. The area surrounding Kansai Airport is assumed to function as a nursery for marine creatures because Osaka Prefecture prohibits fishing there. It is known that many expensive fish species such as rockfish, scorpion fish and sea bass live around this area. However, how such fish were using the area surrounding the airport island was uncertain.

It is known that most of the *Sebastes* genus show site-fidelity to their habitat and they return back to their habitat within a few days, even if they were displaced several kilometers away from the habitat. As for the rockfish that live in the shore reef region and the seaweed beds in the Japanese coastal waters, the range of movement is small, and it is known to persist in the habitat. However, whether they return back to the habitat after they are released after transportation as well as other *Sebastes* fish has not been understood. It is important to investigate in detail and to understand such homing behavior when the rockfish's resource is protected and cultured. Then, it was examined using the biologging whether the rockfishes return back to the habitat after transportation and release.

Because the rockfishes inhabit the sea, ultrasonic biotelemetry methods were used. We investigated the sea area around the Kansai Airport Island in the Osaka Bay (Fig. 2.11). An examination operation permit was obtained from Osaka Prefecture and 25 rockfish were captured in three places (A, B, C) of the Kansai Airport island east shore protection area. After 4–5 days, the ultrasonic coded transmitters (V8SC-6 L, Vemco Co., Canada) were installed in the body cavity through a surgical operation (Fig. 2.12). The size of the rockfish's ventral cavity was measured beforehand, and an appropriate transmitter selected. We confirmed the rockfish was not influenced by the transmitter installation. Then, we released them at two points (Fig. 2.11: R1 and R2) that were a maximum of about 4.5 km away from the place of capture. After the release, we performed a tracking study using an onboard receiver (VR28, Vemco Co., Canada; Fig. 2.13).

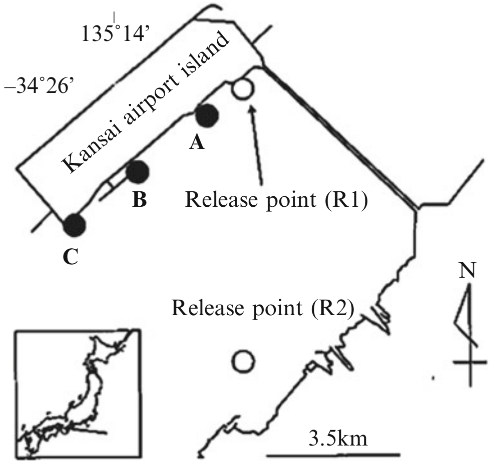

Fig. 2.11 Sea area where rockfish tracking experiments were performed. The ultrasonic transmitters were inserted in the rockfish collected in A, B, and C points. We released them at points R1 and R2 and tracked them (Reprinted from Mitamura (2006) with permission)

Fig. 2.12 Photograph of the insertion of the ultrasonic coded transmitter in a rockfish under anesthesia (insertion into the body cavity)

Afterwards, 20 rockfish released at the airport shore protection area (R1) began moving along the airport island east shore protection. While these individuals moved from the release along the shore protection area at random within 4 h, when 4 h passed they began moving in the direction of each capture place together. Fourteen individuals returned to the place of capture in several days. From the results, the individual detected the direction of each habitat in 4 h from the release and afterwards they returned back to their habitat. Five individuals that had been released in R2 on the opposite bank migrated along the tidal current just after the release. Afterwards, three individuals returned back to each place of capture within 11 days. The homing rates for point A, B and C were 100% (3 of 3 individuals), 60% (6 of 10) and 67% (8 of 12), respectively. From these results, it became clear that the rockfish returned back to their habitat, as did other *Sebastes* fish when the transportation and release was performed.

Fig. 2.13 Photograph of tracking experiment using a tracking type receiver (VR28, Vemco Co., Canada). A set of four hydrophones (a) is placed in the water from the gunwale (b). The hydrophone detected the ultrasonic coded signals from the sample fish and the signals were processed with the receiver on board. The direction and strength of the signals were displayed on the PC (d). The position is measured with GPS at the same time (c)

The measurement of difficult to observe animal behavioral information became possible with the biologging techniques, as described above. As for micro data loggers and various transmitters, further miniaturization and increased performance are expected through advanced electronics and communications technology. Moreover, it is expected that micro data logger and transmitters will become less expensive when biologging comes to be widely used and more easily employed as a research technique for various wild animals. We would be very pleased if biologging can contribute to solving social problems through this chapter. Biologging has the possibility to bring further findings by using it together with other surveying techniques, as introduced above. Particularly, combining biologging with remote sensing or geographic information systems (GIS) enables us to analyze animal behavior information, environmental information, and the range of the human activity from an integrated perspective. Moreover, the findings obtained by these methods can become the basic data of further system dynamics analysis and multiagent simulation.

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