MOVEMENT PATTERNS AND BEHAVIORAL ECOLOGY OF ELASMOBRANCHS: A MINI-REVIEW OF TELEMETRIC METHODS WITH A FOCUS ON THE TRACKING OF SPOTTED EAGLE RAYS, *AETOBATUS NARINARI*, IN A BERMUDIAN SOUND

Karissa Lear
Department of Biology, Clark University, Worcester, MA 01610 USA
(klear@clarku.edu)

Abstract: Elasmobranchs around the world hold vital roles in ecosystem dynamics as apex predators and mesopredators, however these fishes are often difficult to study due to their large range of movement and tendency to live in relatively inaccessible and concealed environments. Here telemetric methods used for tracking elasmobranchs are reviewed and evaluated for their effectiveness in different systems. Additionally, past telemetric studies on eagle rays, *Aetobatus narinari*, are emphasized and compared with a current study using direct observations to characterize the movements of eagle rays in and out of Harrington Sound, Bermuda. The movements of rays correlated closely with the tidal cycle, a pattern that has been observed repeatedly in past studies. However, a much longer study would be necessary to confirm the movement patterns observed here.

Key Words: Aetobatus narinari*, elasmobranchs, telemetry*

Introduction

Sharks and rays around the world play vital ecological roles as apex predators and mesopredators. However, relatively little is known about the ecology of many of these important elasmobranch fishes. This is largely due to the difficulties in studying sharks and rays in the field. Elasmobranchs typically live in relatively inaccessible and concealed locations, often covering large distances in a single day and spending time in deep water (Sundstrom et al. 2001). These characteristics, in addition to their large size and frequent scarcity, limit the extent to which ecological data can be gained through direct observation. Behavioral studies through direct observation can lend some valuable information about elasmobranch ecology on small spatial and temporal scales; however, to study elasmobranch behavior on greater time and geographical scales, it is often necessary to employ tracking technology such as ultrasonic telemetry. Telemetry studies employ transmitters that, after attaching to a free swimming organism, can show the exact location and movement of the individual, either through storing information available for download upon recapture of the individual, or through radioing information back to a nearby transmitter. The use of telemetry in elasmobranch studies can not only elucidate general movement patterns, but can also give information on swimming speed, depth, and other factors that are important in understanding the overall ecology of these fishes (Sundstrom et al. 2001). This kind of information is crucial in making informed decisions about elasmobranch conservation.

This paper reviews the different types of telemetric methods and the relative merits of their use for elasmobranch research. Particular reference is made to the tracking and studies of behavioral ecology of spotted eagle rays, *Aetobatus narinari*, and their movement patterns in Bermuda.

Review of Telemetric Methods and Studies

There are many different techniques used to study movement patterns and behavioral ecology of elasmobranchs, ranging from direct observation in the field to using transmitters that show not only the location of an individual, but also record swimming speed, depth, tail beat frequency, temperature, and a number of other factors. These different techniques all render slightly different types of data, and while the more in-depth telemetric devices may be ideal for studying many elasmobranch species, often the less involved methods can also prove useful for some species or populations.

Direct Observation

Direct observations in the field can be limited by the difficult nature of finding and following larger elasmobranchs, and by being able to observe them in only one or a few locations within their larger range. However, studies using direct observation can still prove useful for gathering basic behavioral data, and even in studies that use tracking technology behavioral observations are often a necessary starting point to determine the basic ecology of the elasmobranch in question. Direct observations in the field are often used to determine if a particular elasmobranch species shows site fidelity, or if occurrence at particular locations is segregated by size or sex. This information can be used to establish how the elasmobranch uses the location in question. One such study used years of observational data about the sex and size distribution of whale sharks, *Rhinocodon typus*, at Ningaloo Reef in Australia to show that almost all sharks visiting the reef were immature males. These findings suggest that Ningaloo Reef is used by *R. typus* as a feeding ground, rather than a reproductive area, and that this species may use deeper offshore waters for reproduction (Norman & Stevens 2007). Another study compared observations of sharks and rays visiting cleaning stations on reefs in the Coral Sea and the Great Barrier Reef with tidal fluctuations, and found that elasmobranchs tended to visit cleaning stations during ebb tides (O'Shea et al. 2009). Studies such as these, while simple, help to elucidate the details of the complex ecology of elasmobranchs.

Additionally, direct observational studies can be paired with the use of photo identification methods to determine individuals and track re-sightings of individuals over time. This can offer important information about site fidelity and use of particular locations. One multi-year study investigating a population of reef manta rays, *Manta alfredi*, used photo identification paired with direct observations to investigate aspects of reproductive ecology. Based on observations of fresh mating scars and of mating events, the study area was determined to be a mating ground for *M. alfredi*. Additionally, re-sightings of individual rays from year to year revealed that female rays generally reproduce every other year, but are also able to give birth in consecutive years (Marshall & Bennett 2010). Such information about mating grounds and life history characteristics of sharks and rays can only be gained through direct observations in the field, and is invaluable when assessing the conservation needs of a particular species and how to put effective conservation methods in place.

Simple ultrasonic telemetry – the 'pinger'

Many different types of ultrasonic transmitters can be used to track individual organisms over time, the simplest of which is colloquially termed a 'pinger.' Pingers emit ultrasonic pulses at a metered time, showing simply the location of the individual being tracked. Most can be coded so that different individuals can be distinguished from one another. This type of information is useful for determining horizontal movement patterns, which can be helpful in showing the diel movements that are common in elasmobranchs as well as identifying core areas and feeding grounds. The information from pingers is also sometimes used to estimate swimming speed; however there can be substantial error involved in these calculations as pingers do not account for vertical movements or for individuals swimming in zig-zag or other patterns straying from a straight line (Voegeli et al. 2001).

Klimley et al. (1988) used pingers to track scalloped hammerhead sharks, *Sphyrna lewini,* at a sea mount in the Gulf of California over a ten day period. They found that the movements of *S. lewini* were correlated with light, with the sharks remaining grouped near the seamount during the day, and moving to deeper waters at night, theoretically to feed, returning to the mount near dawn. The study also found that the tagged sharks showed high site fidelity, all returning to the same site near the sea mount each day, rather than straying to other sites known to have hammerheads, some of which were located only 240m away.

Sundstrom et al. (2000) investigated differences in behaviors of small and large juvenile lemon sharks, *Negaprion brevirostris,* using pingers to track individuals and estimate relative changes in rate of movement (ROM) between times of day and between small and large juveniles near Bimini, Bahamas. Like the hammerheads in the Klimley et al. study (1998), lemon sharks in Bimini showed predictable diel movements patterns, travelling 7-8 km into a shallow bay near sunset, likely to feed, and moving back out to deeper water at sunrise. The study also found slight differences between the movements of larger juvenile and smaller juvenile lemon sharks, with the larger sharks travelling to deeper waters and starting the daily migrations earlier than the smaller sharks. There was also clear homing demonstrated by the tagged individuals (Sundstrom et al. 2000).

As shown by these two studies, simple transmitters such as pingers are effective in determining basic movement patterns and elucidating some life history characteristics, however they often do not offer explanations for the patterns observed. To determine the reasons behind some of these movement patterns, it is often necessary to use tracking devices that provide more information on physical and environmental factors.

Complex ultrasonic transmitters

Many studies have shown that the movement of elasmobranch fishes can be significantly affected by many different environmental factors such as temperature, salinity, tidal variation, current strength, magnetic gradient, food availability, and bottom type, to name a few (Sundstrom et al. 2001; Klimley 1993; Sims 1999). Because of this, using simple tracking devices such as pingers does not always provide a full picture of the movement patterns of elasmobranchs. To further illuminate the factors governing movements of sharks and rays, more complex ultrasonic tracking devices are needed. Current technology enables researchers to tag individuals with technology equipped to read a number of physical and chemical factors which can provide detailed information on the ROM, vertical movement patterns, swimming speed and other dynamic characteristics. These types of studies, while they can be very expensive to conduct, provide the most detailed information on the movements and reasons for movements of elasmobranchs and can provide a clearer picture of their behavioral ecology.

One study that has successfully employed complex ultrasonic telemetry investigated the movements of bat rays, *Myliobatus californica* in a bay in California. The study implanted transmitters in rays that read location and body temperature of the rays, and found that rays migrated between an inshore bay and a deeper oceanic environment on a daily basis. However the movements were not found to be correlated with the tidal cycle, as has been shown in many other rays, rather they were strongly correlated with the time of the day. Using the body temperature data from the transmitters, the study hypothesized that these movements were due to the rays' efforts at thermoregulation, moving to the warmer shallower waters during colder parts of the day, and back out to the colder deeper waters during warmer parts of the day (Matern et al. 2000). Another study by Ackerman et al. (2000) used transmitters that provided data on movement rates to determine diel differences in the ROM of leopard sharks, *Triakis semifasciata*, in California. The data from the transmitters showed that movements of the sharks in and out of the bay were highly correlated with the tidal cycle, and that the ROM of the sharks was much greater during dark periods than during light periods. The study also found that larger sharks tended to have greater ROM values than smaller sharks.

The information gained from these types of studies is valuable for determining the behavioral ecology of elasmobranch fishes and their larger roles in ecosystem dynamics. However, studies to date have investigated only a small number of shark species and a few ray species, and only a handful of studies have looked at movement patterns over long time periods or between seasons. Additionally, many elasmobranch fishes are hypothesized to have ontogenetic shifts in habitat use and movement patterns, but few studies have investigated these differences (Sundstrom et al. 2001). Many elasmobranch populations are declining quickly due to fishing pressures and habitat destruction, and gaining a full understanding of the types of environments utilized by these animals and the migration patterns and specific locations used as reproductive areas, feeding grounds, and core habitats is essential to establishing effective conservation measures. Future studies should focus on gaining a long term picture of annual movements and ontogenetic shifts in behaviors and movement patterns of elasmobranchs, especially for those groups underrepresented in the current literature.

Tracking of Spotted Eagle Rays,* Aetobatus narinari*, in Bermuda

The spotted eagle ray, *Aetobatus narinari*, is a species of large myliobatoid ray easily recognized by their patterns of bright white spots and circles on a black background (Fig. 1). They are circumglobally distributed throughout the tropics and are associated with coral reefs. Eagle rays are mesopredators that mainly feed on benthic molluscs including bivalves and gastropods in shallow sandy areas (Tricas 1980). They have been valued worldwide for their beauty and charismatic nature, however due to increased fishing pressures and habitat destruction, many populations are in decline, and eagle rays have been put on the IUCN red list of threatened species in Southeast Asia (Schluessel et al. 2010). Despite their charisma and conservation concern, however, little research has been done investigating the behavioral ecology, life history, or movement patterns of *A. narinari*. To date, only two published studies have investigated the movement patterns of eagle rays. Silliman & Gruber (1999) used ultrasonic transmitters to track rays around Bimini Islands, Bahamas, for up to 98 consecutive hours, and found that the movements of the rays were closely correlated with the tidal cycle, with rays moving into shallow waters to feed during rising tides, and aggregating in deeper core areas during falling tides. Using similar methods, Ajemian et al. (2012) tracked the movements of eagle rays around Bermuda to determine what effects they might have on the shellfish fisheries there. Ajemian et al. found that rays in Bermuda displayed similar movement patterns to those in the Bahamas, moving into the shallow Harrington Sound to feed during rising tides, and returning to deeper areas on falling tides. Additionally, they found that eagle rays feed on the calico clam (*Macrocallista maculata*) fisheries in the sound, with only modest effects on the shellfish population sizes.

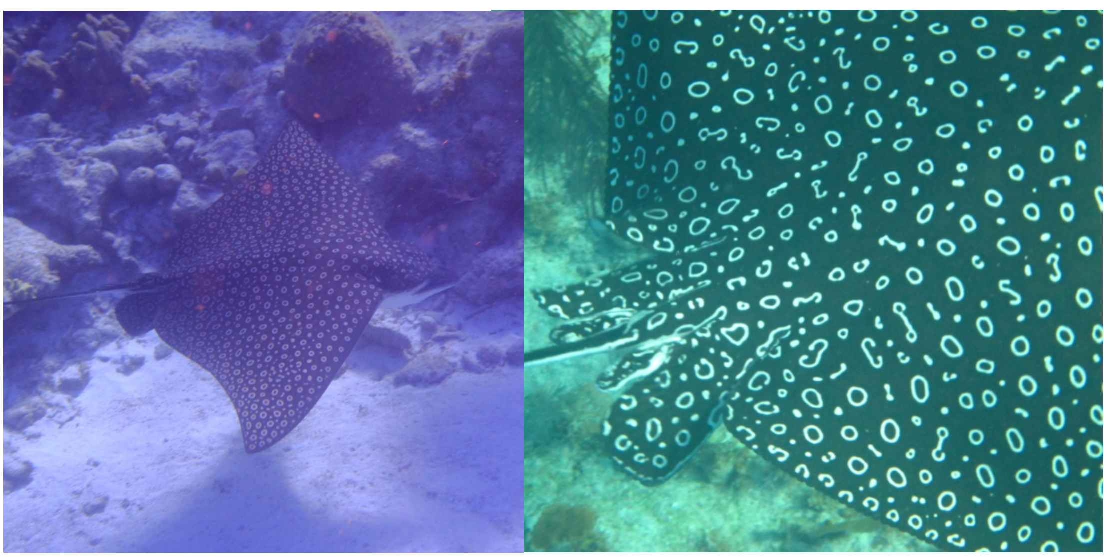

Figure 1: Photograph of a spotted eagle ray, *Aetobatus narinari* (left), easily identified by the white circles and markings on a black background (right).

Building on the information on the movement patterns of *A. narinari* in Bermuda determined by Ajemian et al. (2012), I assess the movements of eagle rays in relation to Harrington Sound, Bermuda through direct observation, and compare my findings with previous data to see if the patterns observed were typical of spotted eagle rays.

MATERIALS AND METHODS

Study site

Harrington Sound is one of several inshore sounds present in Bermuda. It has only one narrow connection to the open ocean, Flatts Inlet, which makes it an ideal location to observe ingoing and outgoing rays, as all rays travelling between the ocean and the sound must pass through the inlet (see Fig. 2). The sound supports a variety of habitats, including shallow seagrass, algal beds and sandy bottoms, as well as some deeper areas. Many different populations of mollusks live in the sound, including the calico clam (*Macrocallista maculata*), the turkey wing (*Arca zebra*) and the Bermuda scallop (*Pecten ziczac*), all of which are potential prey items for eagle rays (Ajemian et al. 2012). The mean tidal range in the sound is 19cm, with the tidal cycle lagging 2 hours and 53 minutes behind the oceanic tides (Morris et al. 1977).

Figure 2: Satellite image of Bermuda. Harrington Sound is labeled in white with Flatts Inlet labeled in yellow (image source: Google Earth).

Observations of movements

I observed the passage of eagle rays in and out of the sound from a bridge passing over Flatts Inlet. I watched the inlet for four to five hours surrounding the low tide on October 11th and 12th, 2012, and recorded each ray seen along with the time, point in the tidal cycle, and direction of movement. I compared these observations to the movement patterns reported by Ajemian et al. (2012) to determine if the patterns matched.

RESULTS AND DISCUSSION

I saw twelve rays on October 11th entering or exiting the sound, and 15 rays on October 12th. The majority of rays were seen within 20 minutes of slack tide (low). At the beginning of each observational period a few rays exited the sound, but starting 30 minutes before low tide all rays seen were entering the sound (see Fig. 3).

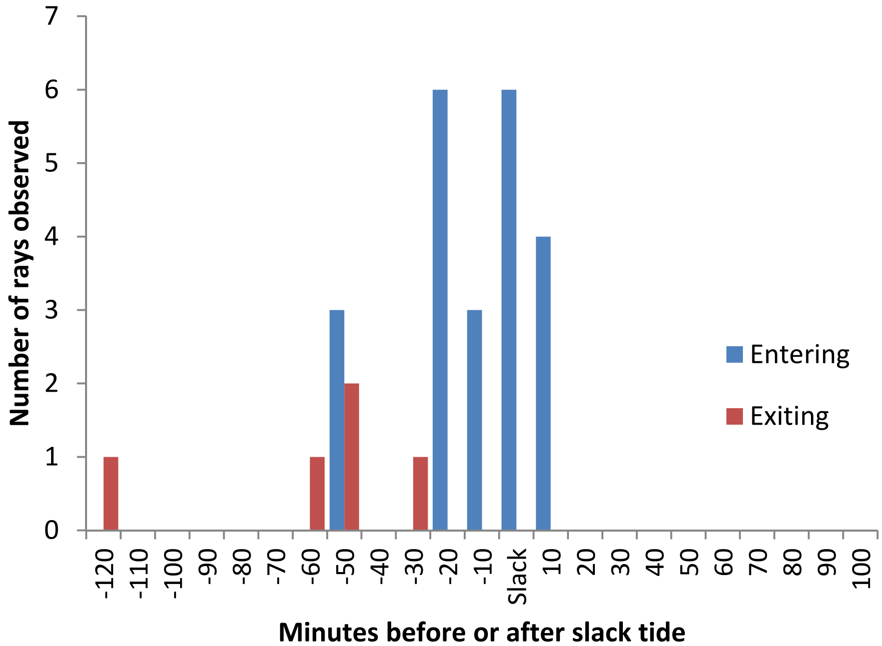

Figure 3: Number of rays entering (blue) or exiting (red) Harrington Sound compared to the point in the tidal cycle during the observations on October 11th and 12th, 2012.

These observations draw a strong parallel with past observations both in Bermuda and in the Bahamas, with rays entering shallow areas on rising tides and returning to deeper waters on falling tides. The rays observed in Bermuda did begin entering the sound shortly before low tide, but this could be due to the time lag in the tides between Harrington Sound and the open ocean. When rays sense the tidal change in deeper waters and begin their diel migrations into the sound, the rays would reach the sound before the tides would shift there. Some rays were also observed milling around the entrance to the sound prior to entry, possibly waiting for the current to subside closer to the slack tide before entering.

While the observations in this experiment do match with the movement patterns observed in prior investigations, a much greater observation time would be needed, especially including observations surrounding high tides as well as low tides, to confirm the movement patterns of eagle rays in Harrington Sound through direct observations. However, since the movements observed here were also observed during the telemetry studies conducted by Ajemian et al. (2012), which did have data from all points in the tidal cycle, the diel movements of rays in Harrington Sound in Bermuda probably adhere closely to what has been shown here. It would be interesting to examine the movement patterns of rays in Bermuda that do not use Harrington Sound as a feeding ground, since there are other shallow bays with mollusc populations that would also be suitable and are likely utilized by eagle rays. Determining site fidelity within Hariington Sound would also be pertinent, as this could impact the shellfish populations present.

It would also be useful to examine the movement patterns of eagle rays on an annual basis. The population of rays studied in Bimini left the islands during the summer months, most likely to reproduce, returning in the fall (Silliman & Gruber 1999). This migration pattern has not been described in Bermuda, and in fact eagle rays have been observed giving birth in Bermuda near the study site (Ajemian et al. 2012), so it is possible that annual migrations to mating and birthing grounds do not take place there. More information describing the annual migration patterns and populations of eagle rays in Bermuda other than those using Harrington Sound would give a clearer picture of overall population dynamics of Bermudian eagle rays. This would help determine how best to conserve *A. narinari* in Bermuda and what role they play in ecosystem dynamics as the main elasmobranch species around the island.

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