Behavioral Biology of the Spotted Eagle Ray, *Aetobatus narinari* (Euphrasen, 1790), in Bimini, Bahamas; an Interim Report. (draft)

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Figure 1. Measuring the disc width of a spotted eagle ray, *Aetobatus narinari*, in Bimini, Bahamas. *Photograph by Tim Calver*.

Spotted eagle rays, *Aetobatus narinari*, have attracted wide attention throughout the years, yet have received surprising little scientific study. This interim report forms part of a larger investigation of the ecology of the spotted eagle ray. From the Fall of 1998 through the Summer of 1999 ultrasonic telemetry was used to determine the movements and behaviors of 17 free-swimming spotted eagle rays in Bimini, Bahamas. Ultrasonic transmitters were externally darted to rays with a modified harpoon and tracked continuously for periods up to 98 consecutive hours. The transmitters remained attached to these rays for periods up to 93 days post tagging. The spotted eagle rays of Bimini exhibited a tidally mediated diel behavior. Spotted eagle rays tended to refuge and show high site fidelity to a core area during the same tidal cycle. Eagle rays exhibited more transient movements during the remaining tidal cycle. These rays proved to be seasonal residents of Bimini as they moved off-shore during the early summer months only to return by the late summer months. Direct aerial and underwater observations were made of free-swimming rays. A behavioral catalog was created of about a dozen apparently stereo-typed action patterns and social interactions. Social interactions, aggregations and schools were not segregated by gender or size.

INTRODUCTION

In the 200 years since Euprhrasen, a European scientist of the 18th century, first described the spotted eagle ray, *Aetobatus narinari* this beautiful and compelling fish has been viewed by literally millions of people in aquariums around the world. Yet, other than the most basic information on their anatomy, distribution and abundance, virtually nothing is known about their behavior, ecology or life history. Gudger's work in 1914 was the last comprehensive scientific publication on the spotted eagle ray.

Euprhrasen named the spotted eagle ray *Raja narinari*, in 1790. He retained the native Brazilian name *narinari*, which first appeared in a book on the natural history of Maranhao, Brazil (Gudger, 1914) published in 1614 by a French monk. The word *narinari* seems to have been a native Indian word meaning stingray. Finally, in 1816 Blainville established the genus *Aetobatus* as we know it today.

The spotted eagle ray is a typical myliobatoid but can be easy distinguished from all other myliobatoid rays by it's striking color pattern consisting of bright white spots, rings and lines on a black background (Figure 1). Additionally eagle rays have some unique structures such as multiple spines, an exceedingly long whip-like tail and specialized mouth parts including their unique inter-nasal flaps. They also have unusual teeth, which consist of 1-7 rows of specialized, plate-like teeth (Bigelow & Schroeder, 1953). The lower jaw actually protrudes out of the buccal cavity. While eagle rays can attain a disc width of 350cm and a weigh up to 150kg, the average eagle ray at Bimini, Bahamas is much smaller, perhaps 120cm with a weigh of only 15kg.

Spotted eagle rays do not live all of their life in the open-ocean. They may spend a good portion of time out in the pelagic zone but at Bimini they make frequent movements to the inshore tidal flats once or twice daily presumably to feed. The spotted eagle ray's diet primarily consists of gastropod and bivalve mollusks (Bigelow & Schroeder, 1953; Iversen *et al.*, 1986) but they have been noted to consume small fish and squid (Gudger, 1914; Bigelow & Schroeder, 1953). Thus, it's diel and social behavior, spatial distribution, and foraging patterns are key to understand this predator's potential impact on the already protected queen conch (*Strombus gigas*) stocks. In turn, the spotted eagle ray is a common food source for the great hammerhead, *Sphyrna mokkarran*, the tiger shark, *Galecerdo cuvier*, the bull shark, *Carcharhinus leucas*, and the lemon shark, *Negaprion breviostris*. Thus, the spotted eagle ray occupies an important, intermediate trophic level in the marine food web, funneling energy from benthic invertebrates to the top predators in its environment. Most aspects of the spotted eagle ray's ecology and biology are unknown. Once activity space is known, factors such as local distribution, feeding sites and sociality become apparent and insight may be gained into mechanisms of spatial utilization (Morrissey, 1991).

Spotted eagle rays are cosmopolitan, found throughout the tropical waters of the Worlds Ocean. At Bimini they are ubiquitous but apparently seasonal residents. The taxonomic status of this species is in flux right now; many people feel that there is but one species of *Aetobatus narinari,* world wide. Others believe that there are two or more species. Today several ichthyologists such as John McEachran, Matt Sthemann, Tom Miyake and Kiyo Nishida are researching the systematics of the spotted eagle ray.

Most of the information on the ecology, behavior and life history of the eagle ray has come from fisherman's accounts, anecdotal field observations and informed scientific speculation. Other than the few focused papers by Gudger (1914), Chapagan (1964), Tricas (1980), Uchida *et al.* (1990) we are unaware of any published studies on the behavior or ecology of the spotted eagle ray.

Because of this lack of information and because the eagle ray is ubiquitous to our study area and preys heavily on the endangered queen conch, we decided to carry out this study. But in addition, we were intrigued by their physical beauty, complex social groupings and the fact that they have one of the largest brain to body weight ratio of any. Therefore, for the past 16 months we have studied the spotted eagle rays at Bimini, using the ethological methods of direct underwater and surface observations as well as aerial surveys. Indirect observations have also been made of the eagle ray's behavior by remote telemetry tracking. Observations were also made on captive specimens held in the natural environment at Bimini.

From the results of this study, we concluded that the spotted eagle rays at Bimini exhibit diel behavior correlated with the tidal cycle, show high site fidelity and display complex motor patterns and social interactions. We also created a catalog of about a dozen apparently stereotyped behaviors and are able to recognize over 150 individual spotted eagle rays and their social grouping patterns through the use of underwater photo-identification (see following paper).

MATERIALS & METHODS

Study Site

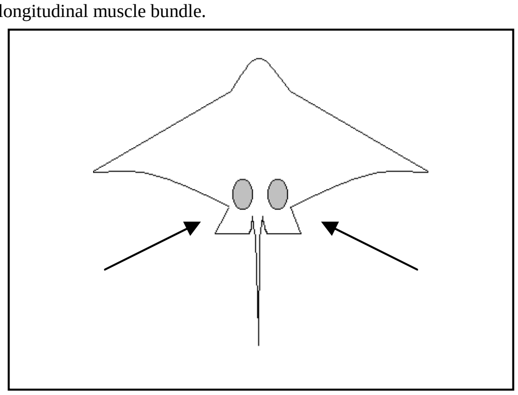
Bimini in the Commonwealth of the Bahamas is located 88Km directly east of Miami, Florida. The Biminis are a cluster of subtropical islands located on the Western edge of the Great Bahama. The climate is subtropical and the marine flora and fauna belong to the Floridian-West Indian faunal province. The Bimini Lagoon averages <1 meter in depth at mid-tide. The floor of the lagoon consists of a large sand flat with beds of turtle grass, *Thallassia testudinium*, and manatee grass *Cymodocea manatorum*, which supports a complex soft bottom community. Detailed ecological and geological descriptions are given by Turekian (1957), Jacobsen (1987) and Brattstrom (1992).

Tagging Methods

Between November 1998 and August 1999 seventeen spotted eagle rays were tagged with 75 kHz crystal controlled ultrasonic transmitters (Sonotronics, Arizona). Each ultrasonic transmitter produced a different pulse-code to

Figure 2. The ultrasonic transmitter dart attached to the modified pole spear. *Photgraph by Tim Calver.*

Figure 3. Location of the saddle area on the spotted eagle ray is located on either side of the posterior portion of the dorsal longitudinal muscle bundle.



allow for individual identification of different rays simultaneously. Transmitters were secured to a steel dart head with standard monofilament fishing line and press fittings (Figure 2). Transmitters were externally applied to the ray's saddle area with a modified harpoon (Brill *et al.*, 1993; Chaprales *et al.*, 1998). The saddle area is a small ovoid area located along the dorsal longitudinal bundle on the posterior portion of the rays pectoral base (Figure 3). Typically rays were tagged from the bow of a small skiff, but in several cases tagging was accomplished by free-diving.

Telemetry and Tracking Methods

Twenty-three tracks were performed on seventeen spotted eagle rays using small skiffs (J16 Carolina Skiff with a 4-stroke 25hp Mercury engine) (McKibben & Nelson, 1986; Morrisey, 1991; Holland *et al.*, 1992; Holland *et al.*, 1993; Morrisey & Gruber, 1993; Correia *et al.*, 1995). We estimated the sizes of the rays using a calibrated, t-shaped ruler. Sexes were confirmed visually by free-diving. The ultrasonic signal was detected with a staff mounted, directional hydrophone (Sonotronics, Arizona). Tracks lasted for 48-98 consecutive hours (Nelson, 1978; Smith & Merriner, 1987; Gruber *et al.*, 1988; Morrissey, 1991; Blaylock, 1992; Holland *et al.*, 1992; Brill *et al.*, 1993; Holland *et al.*, 1993; Klimley, 1993).

Based on signal intensity, the tracking skiffs attempted to remain approximately 300 m from the ray. Ray locations were stored every 10 minutes using with a Garmin 12 handheld GPS unit. The position data were downloaded into a GPS mapping program (FUGAWI, Canada) at the conclusion of every track. Environmental data such as: tide, wind speed and direction, water depth, water temperature, cloud cover and surface conditions were recorded hourly. Behavioral observations were also recorded throughout the course of each track when possible.

The transmitters were left on the rays to monitor their movement patterns over time. On a daily basis we would search the entire lagoon and surrounding waters for these transmittered rays. Once found we would record the time, date, position and environmental. Transmitters were typically removed from the ray, either from the bow of the skiff or by free-diving .

Behavioral Ethogram: Methods

The spotted eagle ray was studied in detail using the ethological methods of direct underwater and surface observations as well as aerial surveys. Free divers would stay within visual distance on the surface and record the number of rays, gender, group configuration, motor patterns and social interactions. Data were reviewed and quantified to establish a catalog of behaviors. Two aerial surveys were made per fortnight to confirm the location and distribution of spotted eagle rays.

RESULTS

Table 1. Summary of tracking data for the seventeen spotted eagle rays tracked in this study.
*Note these rays were tracked more than once.

Ray #	Date Tagged	Sex	Size (cm)	Hours Tracked	Days Contact	Location
*1	14-Nov-98	??	~100	12	12 hrs	East Bimini
2	17-Nov-98	F	~100	98	29 d	Bimini Lagoon
3	8-Dec-98	F	~120	48	26 d	Bimini Lagoon
4	18-Jan-99	M	~140	48	89 d	Bimini Lagoon
5	26-Jan-99	M	~140	73	51 d	Bimini Lagoon
6	3-Feb-99	F	~150	58	54 d	Bimini Lagoon
*4	3-Mar-99	M	~140	91	89 d	Bimini Lagoon
7	19-Mar-99	F	~100	72	28 d	South Bimini
8	4-Apr-99	F	~140	48	12 d	South Bimini-Southeast Point
9	21-Apr-99	??	~130	53	04 d	East Bimini
10	30-Apr-99	F	~150	0.5	0.5 hrs	Bimini Lagoon
*11	30-Apr-99	M	~120	0.5	0.5 hrs	Bimini Lagoon
*12	4-May-99	F	~130	8	08 hrs	North Turtle Rock
13	18-Jun-99	F	~160	12	15 d	Bimini Lagoon
14	2-Jul-99	??	~120	13	13 hrs	Bimini Lagoon
*15	6-Jul-99	F	195.2	6	25 d	Bimini Lagoon
*11	15-Jul-99	M	~120	16	93 d	West of North Bimini
*11	18-Jul-99	M	~120	72	93 d	East of North Bimini
16	24-Jul-99	F	~140	72	14 d	East of North Bimini
*11	30-Jul-99	M	~120	72	93 d	East of North Bimini
*15	31-Jul-99	F	195.2	~30	25 d	East of North Bimini ATC
16	6-Aug-99	F	~140	48	14 d	East of North Bimini
17	8-Aug-99	F	~130	48	2 d	East of North Bimini

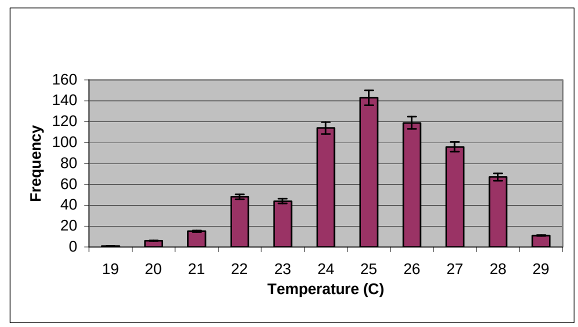
Tracking

Although we did not directly study the effects of the transmitters placement and presence, we do not suspect that they significantly affect the behavior of the rays. We tracked 17 individual spotted eagle rays for periods up to 98 consecutive hours. Total disc width (DW) of the tagged rays ranged from 100cm to 195 cm (Table 1). However, tracks that were less than 12 hours were excluded from data analysis, because they did not encompass a complete tidal cycle. Transmitters were left on and an effort was made to locate these rays on a daily basis for long periods after each track. For example, the transmitter on ray No. 11 had a retention time of 93 days and was tracked on three separate dates (Table 1).

Core Area

Although all of these tracks did not occur contemporaneously during the research period, all of the rays seemed to share site

Figure 4. The three core areas of Bimini, North Rocks, Alicetown Channel and Round Rock.



attachment to a specified core area at low tide. A core area may be defined as a specific site to which an animal is strongly attached. Core areas are typically used for resting, refuging and aggregation. The core areas at Bimini had a depth of 3 to 6 meters in with a strong current.

Three core areas were found in Bimini, (1) the southern portion of the Alicetown channel, (2) the deep water west of Round Rock and (3) a small cay off the northern tip of Bimini called North Rocks (Figure 4Tracking data revealed that several of moved between these core areas freely. When moving between core areas core the rays still followed their usual diel behavior pattern, which was correlated with the tidal cycle.

Diel Behavior

A consistent diel or daily behavior was shown for all of the rays tracked 24 hours or longer. Visual analysis of the tracking data established that these rays were driven by tidal influences. From these preliminary data, diel behavior was established relative to tidal movements. Our working hypothesis is that the spotted eagle rays diel

Figure 5. Diel tidal behavior of the spotted eagle rays in Bimini, Bahamas.

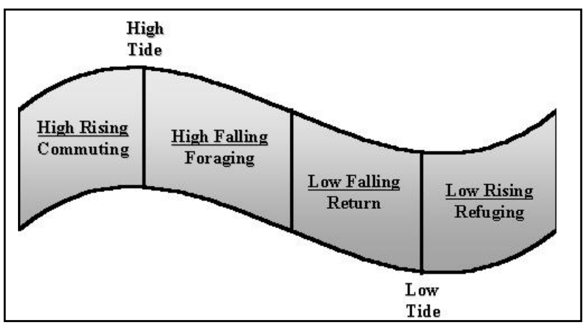


Figure 6. Temperature selection in spotted eagle rays (5% error bars).

behavior is correlated with phases of the tidal cycle (Figure 5). We found that eagle rays were apparently refuging in the core area during the low rising tidal cycle and showed more transient movements, during the remaining tidal cycle.

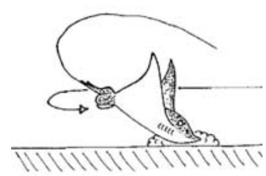
During the High Rising tide rays were highly active and typically increased their swimming speed as they traveled to the further regions of their activity space. We called this phase "Commuting." Commuting was observed in all tracks and was characterized by the greatest rates of movement and distance covered.

The High Falling tide or what we termed the "Foraging Phase" movements consisted of slow circles and a patrolling the as rays presumably fed or socialized. During the Low Falling tide the behavior shifted to the "Return Phase." During this period, rays usually made an effort to return to the core area by low tide. Movements during this phase were usually slow and rays appeared to be randomly grouped.

Most activity during the Low Rising tide was restricted to one of the established core areas. At this time, the ray entered the Resting Phase of its diel behavior. The resting behavior of these rays was typically categorized by slow, circling behavior primarily orientated into the current. Ray rested within the core area for a period of 2-4 hours. In several cases a ray was stranded on the flats in very shallow water and was unable to return to core area. Yet these rays still exhibited a resting behavior on the shallow flats.

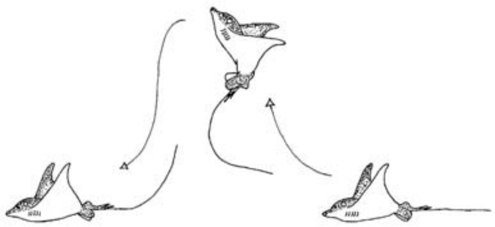
Rays showed a thermal preference for 24-27 degrees C (Figure 6). The tidal data were most obviously correlated with the ray's behavior and seemed to have the most influence on their distribution. Other environmental factors were not as obviously correlated.

A behavioral catalog or Ethogram was compiled from approximately 50 hours of direct observations .

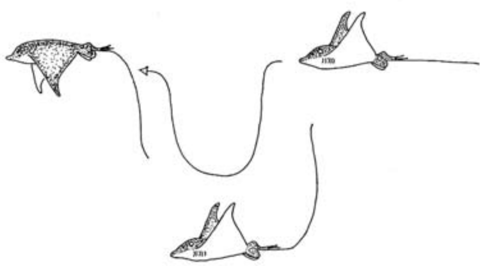


Digging: Several rays were observed actively digging through the substrate. During digging a large plume of sand envelopes head, as sand is expelled out the gill slits.

Pelvic thrust: This behavior was seen during every ray observation period. We saw free-swimming rays make accentuated downward thrusts of their lower abdomen and pelvic fins. The pelvic fins were either adducted or abducted as the abdomen was flexed downward. Rays have exhibited the pelvic thrusts up to five times in a row in quick succession.



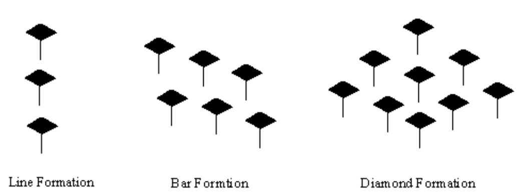
Extreme Pelvic Thrust: This behavior is similar to the pelvic thrust but is only exhibited when rays are in large schools. Usually the ray swims up out of the school or formation until it is nearly vertical and makes an over-accentuated thrust of its abdomen and pelvic fins while curling it's wings over its body.



Dip: A dip consists of a rapid descent and ascent in swimming behavior. It begins in mid-water as the ray dips down to the substrate and back to mid-water. A single individual typically exhibited the dip one to five times in rapid secession. In some instances the rays actually came in contact with the substrate hard enough to disturb the sediment. This behaviour appeared to affect other rays within the vicinity. Tricas (1980) noticed a similar pattern when a male made an exaggerated 'bobbing' behaviour, which produced brilliant white flashes of the ray's ventral surface.

Jumping: There are two different jumping styles of the spotted eagle ray. The first is a vertical jump, where the ray launches itself straight up into the air and re-enters the water in a similar fashion. The second can be described as a "porpoising" jump, where the ray jumps out of the water at a 45-degree angle and re-enters the water at that same angle. These porpoising jumps are typically done at high speeds and repeated up to four times.

Aggregation Types: These aggregation types were behavioral observations originally described by McKibben & Nelson (1986) which we modified to fit spotted eagle rays:



1) **Lone Individual-** Solitary individual swimming alone. Such individuals are most commonly found over shallow sand flats near land as they forage or make lengthy transient excursions outside of their "normal" activity space.
2) **Loose Aggregation-** Consist of 3 to 16 individuals that are swimming together in no obvious formation. Occasional social interactions occur as groups or individuals join and depart the aggregation. These groups are formed in relatively deep water (2-4m) with strong currents. Such aggregations are commonly formed during the resting phase of the diel behavior .**Polarized School-** Consist of 5 to 50 individuals swimming at the same speed, equidistantly spaced, while maintaining a distinct formation. These groups are formed in relatively deep water (2-4m) with strong currents. Polarized schools often stay in formation as they change directions or are threatened. Polarized schools occur primarily in-groups greater than 20 individuals and usually occupy a single plane in the water column.

Schooling: A school consists of 6 or more rays that are within close proximity (>1 meter) that are swimming in a polarized fashion in the same direction and at the same speed. There seems to be three basic types of schooling formations: line, bar, or diamond. These schools then arrange themselves either in a two dimensional plane or in a stacked formation, two to five deep. Generally the schools travel in a bar or diamond formation.

1) **Line formation**- alignment of rays evenly in a head-to tail posture creating a single line .
2) **Bar formation**- consists of a school of rays arranged wingtip to wingtip in a single plane. This formation can take on a rhomboid-like shape that is arranged wingtip to wingtip and in head to tail fashion.
3) **Diamond formations** appear as a loose diamond shape and are arranged in either one plane or stacked up. The diamond formation of large schools of twenty individuals or more.. The smaller schools tend to be of one plane and arrange themselves in a broken diamond (triangular) formation at times.

DISCUSSION

Although the effects of the transmitters placement and presence were not studied, we do not suspect transmitter influenced the results presented here. Harpooning the transmitters to the saddle region described here was a simple and highly effective method for tagging spotted eagle rays. This method for tagging free-swimming rays avoids the trauma of capture and handling to the ray (Brill *et al.*, 1993; Chaprales *et al.*, 1998). Tagged rays exhibited normal behavior, swimming ability and appearance within thirty minutes to an hour post tagging. Heupel *et al.* (1997 & 1998) showed that tagging is an efficient way of marking elasmobranchs with minimal damage.

Blaylock (1990) demonstrated that the presence of an external, ultrasonic transmitter had little to no effect on the swimming behavior of myliobatoid rays, as long as the transmitter-to-ray mass ratio remained below 0.03. Our greatest transmitter-to-mass ratio was 0.0000857!

Rays showed signs of healing within 8-10 days of tagging and appeared to be completely healed within 23 days post tagging. Huepel (1997. 1998) found that tagging produced only localized tissue disruption and did not appear to be detrimental to the long-term health of the individual sharks or rays. Overall rays carrying transmitters exhibited normal appearance and behavior; and survived well for at least 93 days post tagging. Therefore, we conclude that the presence of a tag or transmitter does not greatly affect a ray's usual behavior.

Our results show that spotted eagle rays repeatedly returned to the same areas at the same tidal cycle for several days; often via different routes. Similar observations have been made on tuna and billfish (Brill *et al.*) and sharks (Gruber *et al.*, 1988; Holland *et al.*, 1992 & 1993; Klimley; 1993).

The biological definition of an aggregation is a group or mass of organisms of the same or different species gathered within close proximity of one and other. Three aggregations sites were found at Bimini wherein 12-50 individual spotted eagle rays came together during the same tidal cycle day after day. We classified the aggregations either as lone individuals, loose aggregations or polarized schools (McKibben & Nelson, 1986). Elasmobranches in general and eagle rays in particular organize themselves into loose aggregations, which are fluid in nature (Wakabayashi & Iwamoto, 1981; Blaylock, 1989; Blaylock, 1993; Klimley, 1993). However, in contrast to the usual situation of sexual and size segregation (Springer, 1967), eagle ray schools were always of mixed size and gender. The tracking results clearly show that eagle rays move according to the given tidal cycle at Bimini rather than to light cues associated with time of day. They aggregate during the low-rising and high-falling tides and forage during the low-falling and high-rising tides. Rays in pairs typically made one to two excursions each day to the sand flats to forage but they always tended to feed alone. Eagle rays are thought to use electroreceptors to locate their food. They then dig the prey out of the sand using their shovel-like nose and sucking apparatus.

We estimate that approximately 200 spotted eagle rays inhabit the waters surrounding Bimini. They are distributed throughout the island lagoon, yet they tend to aggregate at specific core areas where they rest, refuge and socialize in large numbers. Some sharks show a similar pattern of behavior (McKibben & Nelson, 1986; Holland *et al.*, 1992 & 1993; Klimley, 1993). At the Bimini core areas 12-60 individuals would congregate daily. Then, during the late the spring the spotted eagle rays began to shift their activity patterns as fewer and fewer congregated at the core areas. By June less than 4 rays remained in the lagoon Aerial observations indicated that the rays had moved off into the deeper waters around Bimini.

By the end the summer months the numbers began to increase, as rays slowly returned to the shallow, in-shore waters of Bimini. We suggest that their dispersal was due to rising temperatures on the flats but this does not rule out mating, seasonal migration or dietary changes as the causal factor. Photographic analysis showed the same rays returned to the lagoon (unpublished data). So this strongly indicates that these rays are residents of Bimini.

From the preliminary data that we presented here, I have proven that the spotted eagle rays of Bimini 1) exhibit diel behaviors that coincides with the tidal cycle, 2) that they show high site fidelity to the core areas, 3) that they do not segregate schools by gender or size, 4) that they perform various complex motor patterns and social interactions and 5) lastly that they are seasonal residents of Bimini

In summary, we have established a basis for understanding individual identification, social behavior and movement patterns of the spotted eagle ray. Once activity space is known in detail, factors such as distribution, movement, feeding sites and sociality will become apparent and hypotheses can be formed, allowing insight into the causality of this creature's behavior. However, this study has represents a mere beginning toward understanding the true nature of the behavior and ecology of the spotted eagle ray.

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