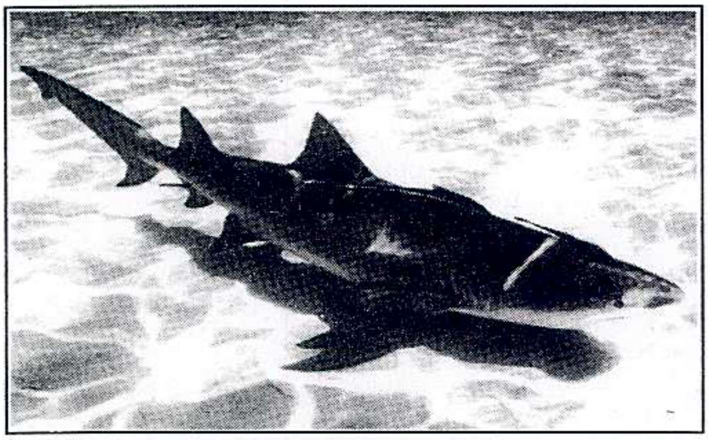
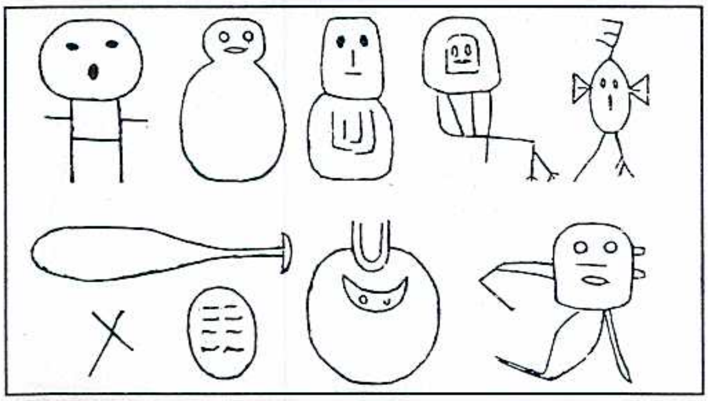
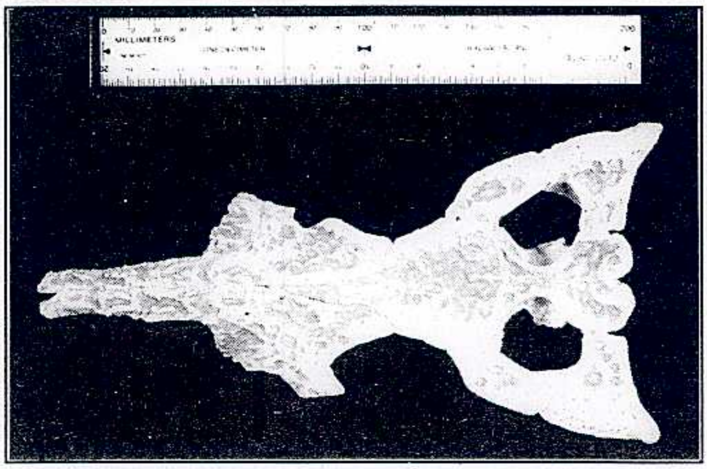
ISSN 1022-2189

BAHAMAS JOURNAL of SCIENCE

VOLUME 3 • NUMBER 1 OCTOBER 1995







ARTICLES

YOUNG LEMON SHARK BEHAVIOUR IN BIMINI LAGOON

JOÃO CORREA, JEAN DE MARIGNAC AND SAMUEL GRUBER

INTRODUCTION

This report forms part of a larger investigation of the life history of the lemon shark (*Negaprion brevirostris*) in Bimini Lagoon, Bahamas. For a period of three months in the Winter of 1994 we studied a group of four subadult lemon sharks by ultrasonic telemetry. Gruber *et al.* (1988) previously reported on telemetry data from subadult lemon sharks but their results were limited to incomplete tracks of a few hours duration only. Morrissey & Gruber (1993a, 1993b) published a comprehensive study of 38 young lemon sharks. These 75 cm total length (TL) animals were confined to a small nursery area in the northern part of the lagoon and results represent the first stages in the ontogeny of lemon shark's behavior.

Building on this data base, we have tracked older lemon sharks ranging between 151 and 186 cm TL for up to 16 days in a three month period. Results of the tracking show a consistent and repeatable pattern of activity whereby sharks appeared to refuge in the eastern part of the lagoon during the daylight hours and make their way to the western part of the lagoon at sunset where there is a deep channel leading to the open ocean. We suggest that the sharks feed at night in the swift moving waters of the channel, then at sunrise, move eastward across the 6 km lagoon to their original starting place.

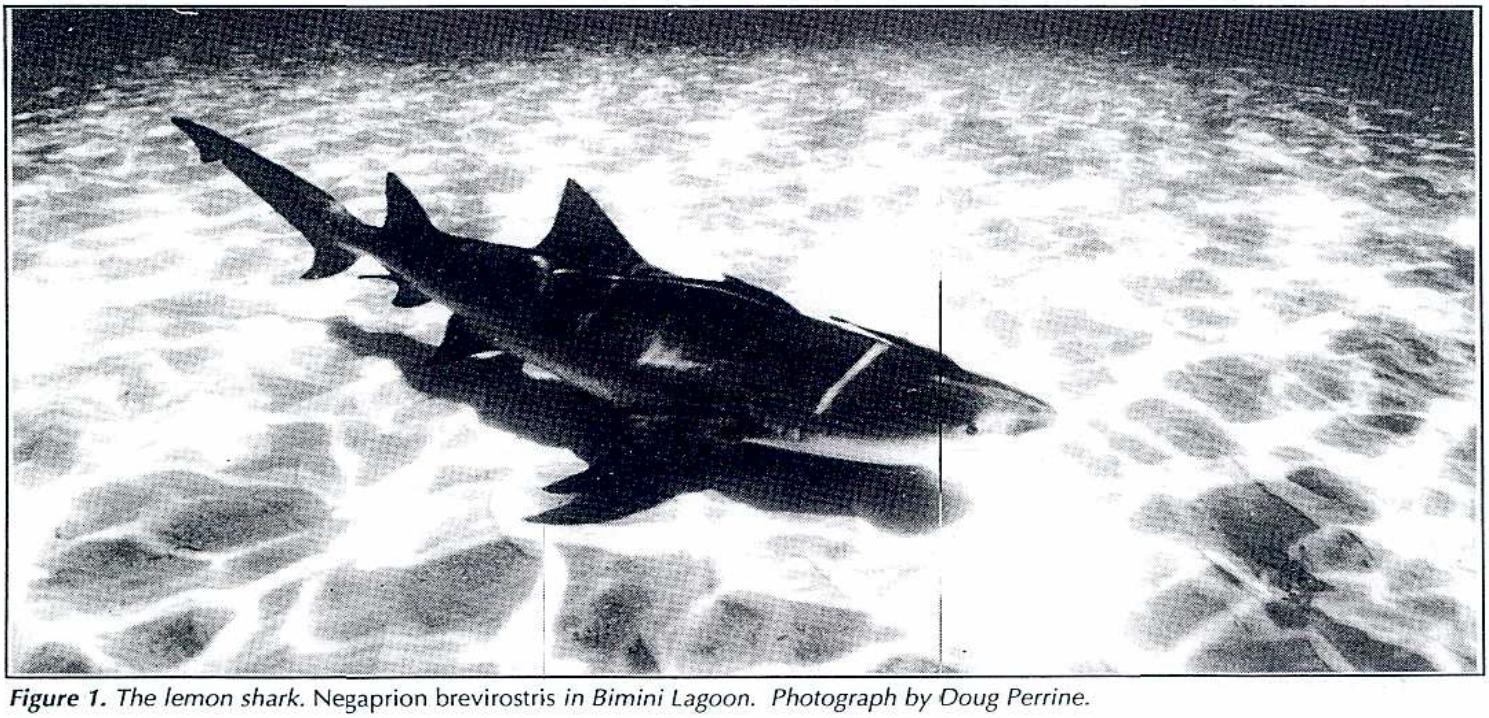


***Figure 1.** The lemon shark.* Negaprion brevirostris *in Bimini Lagoon. Photograph by Doug Perrine.*

MATERIALS AND METHODS

Study Species

The lemon shark (Figure 1) is distinguished morphologically from all other carcharhinids because of its large second dorsal fin, almost as large as the first (Garrick & Schultz, 1963). This species found from New Jersey to Brazil, occurs on the bottom at depths to 100 m and is often reported around bays, piers and river mouths (Compagno, 1984). Its diet consists mainly of demersal teleosts (80% of prey), though elasmobranchs, crustaceans and mollusks can also be found in their stomachs (Cortés & Gruber, 1990). The role of the lemon shark in Bimini was discussed by Gruber (1982) who established this species' status as a top predator.

Study Site

Bimini is a cluster of subtropical islands on the western edge of the Great Bahama Bank by the eastern edge of the Florida Straits. The Biminis are located approximately 86 km directly east of Miami, Florida (Newell & Imbrie, 1955). The Bimini Island complex (Figure 2) -North, East and South Bimini- is low in elevation, has undeveloped areas covered with mangroves, and is arranged in a triangle that encloses Bimini Lagoon. The area of Bimini Lagoon averages 21 km^2; the depth averages 1m at mid-tide and the tidal range is 0.75 - 1.0 m (Bathurst, 1967 and Thomassen unpubl.). The floor of the area enclosed by the islands is mainly sandy, with low turbulence levels and sediment movements conditioned by large concentrations of turtle grass *(Thalassia testudinum)* and manatee grass *(Cymodocea manatorum*; Bathurst, 1967). However, the floor of the Alicetown Channel and a few other areas in the lagoon is of a rocky nature (Harrison, *et al.*, 1970). Detailed geological and ecological descriptions are given by Turekian (1957) Jacobsen (1987) and Brattström (1992).

Capture and Telemetry

Between 17 January and 11 February, 1994, four lemon sharks were captured and fitted with ultrasonic transmitters. Total lengths of the tagged sharks ranged from 150.5 cm to 186.0 cm (Table 1). All sharks were caught on longlines, using barracuda *(Sphyraena barracuda)* and blue runner *(Caranx crysos)* as bait. A 1000 m longline anchored to the bottom was set close to the bank on the east side of the Alice Town Channel (Figure 2) and equipped with 32 hooks. The leaders were attached to the ground line with 2m of nylon line and an additional 2m of aircraft cable at the hook extremities. This allowed the shark to swim once it was hooked. The longline was set and baited at dusk, and checked every 3 hours until sunrise when it was pulled in. Lemon sharks within the targeted length interval of 150-200 cm were equipped with a transmitter. Transmitters were attached by inserting two mild steel darts through the skin into the epaxial musculature between the dorsal fins. Monofilament line was attached to

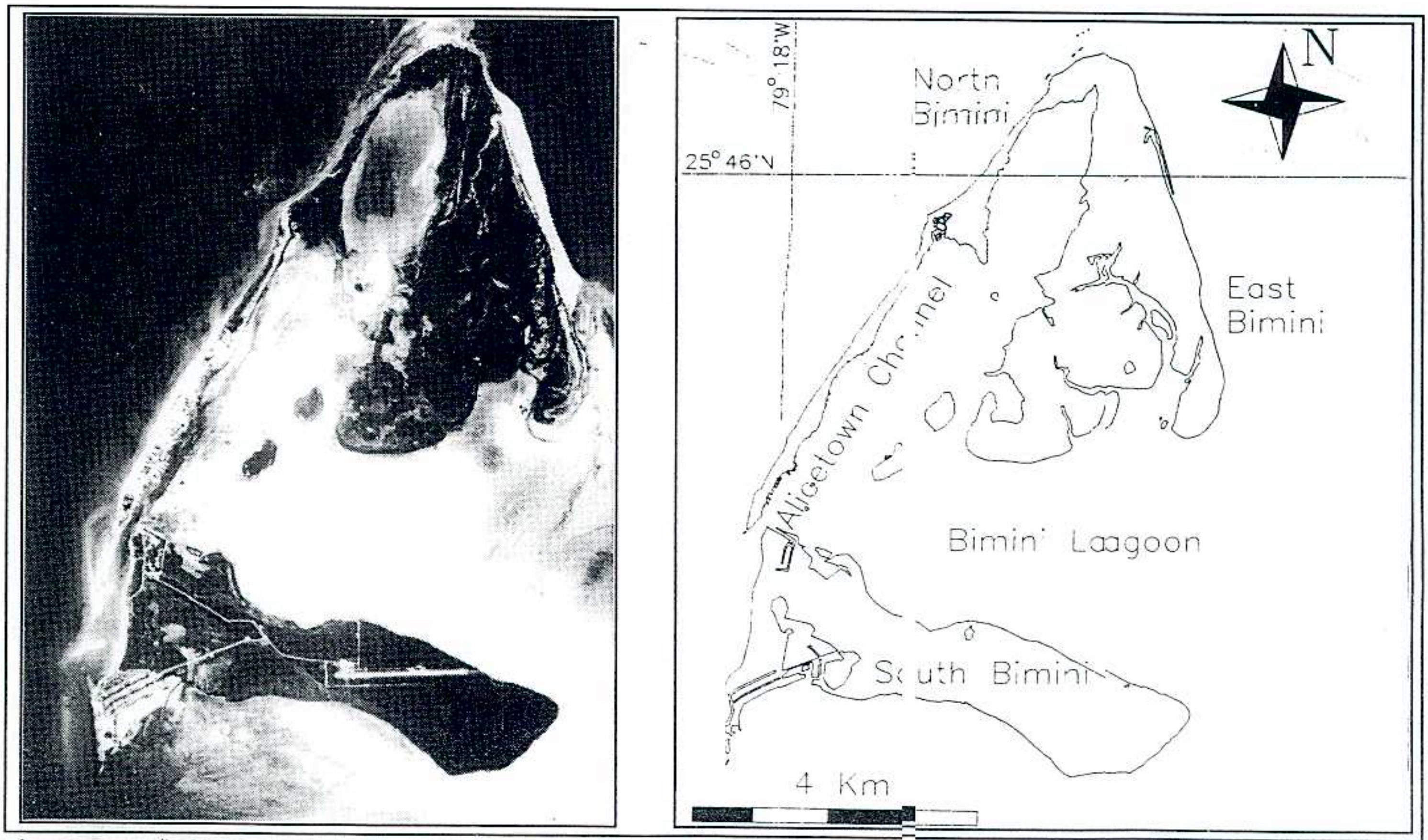


Figure 2. Aerial photograph (a) and Graphical representation (b) of th Bimini Islands c tmplex, Bahamas. ı Location of study area where subadult lemon sharks were fitted with ultrasonic transmitters and traked during Wintr 1994.

Figure 3. Tracking a subadult lemon shark in Bimini Lagoon, Bahamas during Winter 1994. The tracking boat has a crew of two, driver and tracker. The driver is responsible for both driving according to the tracker's directions and also saving and recording positions every fifteen minutes. The tracker uses the telemetry equipment to continuously follow the shark. Photograph by Tim Calver.

the darts, threaded through the ends of the transmitters and secured close to the skin with steel press sleeves.

Table 1. Subadult lemon sharks captured on bottom longlines in the Alice Town Channel during Winter 1994. These four sharks were fitted with ultrasonic transmitters. Pre-caudal length (PCL; cm), fork length (FL; cm), Total length (TL; cm).

Shark name	Date of capture	Sex	PCL	FL	TL
Bacardi	19-jan-94	M	110.0	-	150.5
Ursula	21-jan-94	F	135.5	150.0	173.0
Junkanoo	24-jan-94	M	132.5	145.5	169.0
Tootsie	25-jan-94	F	141.0	154.0	186.0

To track the sharks we used crystal-controlled ultrasonic transmitters (model XTAL 87, Sonotronics, Tucson, AZ, USA) which were 10 x 100 mm plastic cylinders weighing 40 g in air. The transmitters generated a 10 ms pulse of either 76.8 or 78.1 KHz. The interval between pulses varied between 748 and 1053 ms and provided the individual identification codes. The nominal battery life of a transmitter was three months.

Location and Tracking Method

Ultrasonic pulses were detected using ultrasonic receivers (model USR-D, Sonotronics) to which were attached a set of headphones and a directional hydrophone (model DH-2, Sonotronics) mounted on a 110 cm long plastic handle. The person monitoring the shark's activity listened to the transmitted signals with the headphones while holding the end of the handle with the hydrophone submerged. The receiver units were powered by small 12 volt, 20 ampere-hours lead-acid batteries (model 4L-B, GNB Inc., St. Paul ,MN, USA).

Three 4 m skiffs with 15 Hp outboard motors (Mariner Inc., Fond-du-Lac, WI, USA) served as tracking boats. These flat-bottom boats were chosen because they can be operated in depths shallower than 30 cm which is typical of the Lagoon at Bimini (Figure 3). In the first phase of the tracking, two boats were sent out to locate a shark. This involved an active search of the area, covering all of the lagoon, with frequent stops to monitor for ultrasonic signals. After having found a shark, one fully equipped boat with a crew of two remained with the shark for as long as possible, continuously tracking it throughout day and night. Crews then took turns tracking the shark for 8 hour periods. Whenever possible sharks were tracked for a period of 24 hours. After 24 hours the shark was tracked only until a new shark was detected.

Positioning

Every fifteen minutes the crew recorded the position of the boat using a hand-held Global Positioning System (GPS) unit (model Ensign, Trimble Navigation, Austin, TX, USA). The tracker attempted to remain less than 100 m from the shark based on signal intensity. Depth and temperature of the water were recorded with the position. The fifteen minute interval carries no biological significance and was chosen for convenience. In addition, other authors doing this type of study such as Holland *et al.* (1993), Klimley (1993) and McKibben & Nelson (1986), have chosen the same time interval.

Statistical Analysis

The data were separated into tracks of individual sharks which ranged from 1 to 24 hours. Each track was then analyzed and graphed with computer softwares (Excel 5.0, Microsoft Corporation, USA; and Autocad 11, Autodesk Inc., USA). Because we hypothesized that these sharks exhibited a repeatable daily pattern, an analysis was performed on each track. Most statistical analyses of animal movements are based on the assumption that the different locations are independent of one another (i.e. not correlated) although this assumption is often neglected in ecological studies of spatial dynamics (Anderson, 1982). Our data were therefore tested for independence using Schoener's Ratio (SR, Swihart & Slade, 1985). The SR is a statistical test to determine whether a set of successive positions are dependent or independent and is defined as t^2, the mean squared distance between successive positions, over r^2, the mean squared distance between each position and the center of activity (COA).

(1) COA =($(\overline{X}/(\overline{Y})$

where $(\overline{X}$ = the mean of all X-coordinates and $(\overline{Y}$ = The mean of all Y-coordinates for all locations of a particular track

$$(2)\quad t^2 = \frac{1}{m}\sum_{i=1}^{m}(X_{i+1} - X_i)^2 + \frac{1}{m}\sum_{i=1}^{m}(Y_{i+1} - Y_i)^2$$

$$(3)\quad r^2 = \frac{1}{n-1}\sum_{i=1}^{n}(X_i - \overline{X})^2 + \frac{1}{n-1}\sum_{i=1}^{n}(Y_i - \overline{Y})^2$$

(4) $SR = t^2/r^2$

The SR was calculated for each track and compared to critical values given by Swihart & Slade (1985). All tracks had to undergo a statistical method referred to as *time-to-independence* by Swihart & Slade (1985). Determining time to independence is an iterative procedure which consists of eliminating positions (i.e. increasing the time interval between two successive positions) and re-calculating SR after each iteration. Using the time-to-independence interval between fixes enabled us to perform parametric statistics to test our hypotheses. The diel (daily) cycle was calculated by analyzing individual tracks. Each day was divided in four periods: day, night, sunrise and sunset. A preliminary observation of the tracks showed obvious diel changes in the relationship between longitude and time-of-day. The statistical analysis was done using Student's t-test ($p < 0.05$) and focused on validating the following null hypotheses:

Ho(1); the difference between the mean of day longitudes and night longitudes equals zero;

Ho(2): the difference between the mean of sunrise longitudes and sunset longitudes equals zero.

We thus tested the difference between the mean longitudinal position of each shark during the day and that at night. This was also done between sunset and sunrise.

RESULTS

The four telemetered sharks were followed over a period of three months, yielding 1659 geographic fixes (Table 2) but data from only three sharks were used because shark Junkanoo shed its transmitter within ten days after capture. Once organized and processed with respect to independence the data yielded 34 individual tracks.

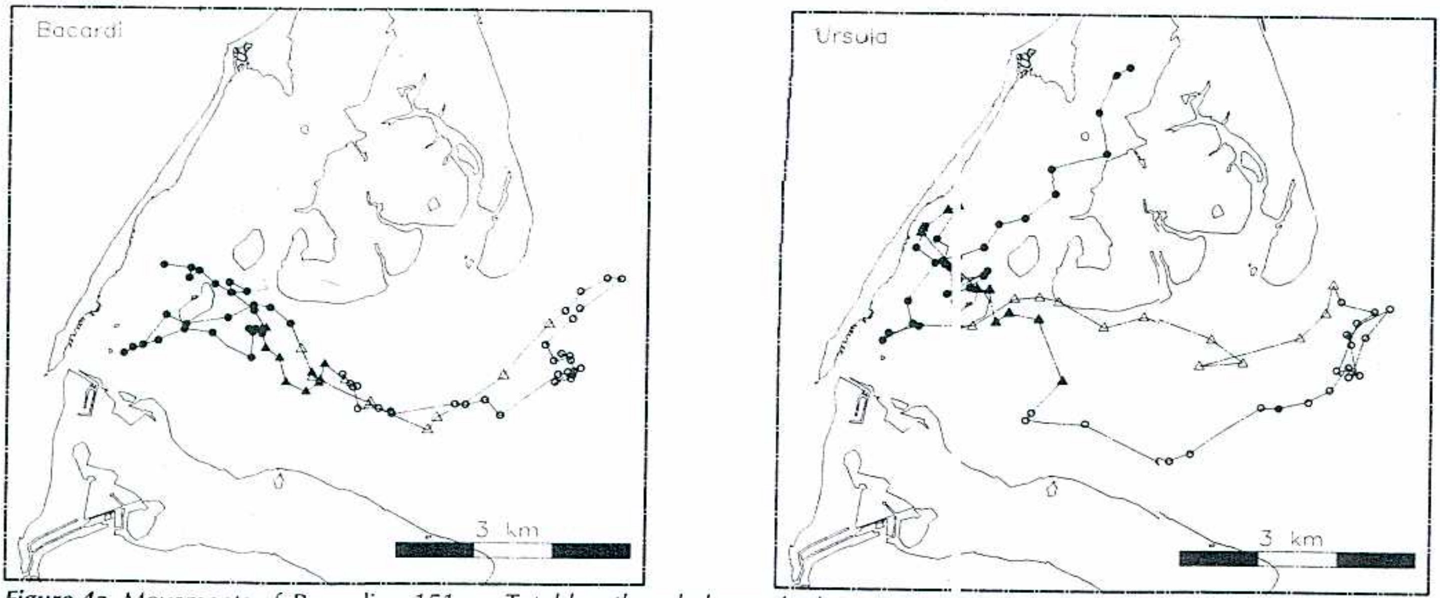


***Figure 4a.** Movements of* Bacardi, *a 151 cm Total length male lemon shark, on 21-22 February 94 in Bimini lagoon, Bahamas. n = 90 positions. Day (empty circle), night (full circle); sunrise (empty trianges) and sunset (full triangles).*
***4b.** Movements of* Ursula, *a 173 cm long female lemon shark, on 7 March 94 in Bimini lagoon, Bahamas. n = 82 positions. Day (empty circle), night (full circle); sunrise (empty triangles) and sunset (full triangles).*

Table 2. Tracks of the four subadult lemon sharks in Bimini lagoon, Bahamas during Winter 1994.

Shark name	No. Fixes	% of total individual fixes	First day of tracking	Last day of tracking	No.of days of contact
Bacardi	657	39.6%	2 Feb 94	19 Mar 94	15
Tootsie	528	31.8%	2 Feb 94	25 Mar 94	16
Ursula	395	23.8%	2 Feb 94	26 Mar 94	11
Junkanoo	79	4.8%	2 Feb 94	12 Feb 94	5 (*)
Total	1659				47

(*) Transmitter shed and found on the bottom of the lagoon.

Time-to-independence was determined to be three hours which yelded 208 independent fixes. Two of the more representative continuous tracks are shown in Figures 4a and 4b. These movement patterns suggested to us that the sharks were active on the western side of the Lagoon at night, on the eastern side at day and cross over from one side to the other during dusk (east to west) and dawn (west to east). This pattern was frequently observed in all of the four sharks.

To test our hypothesis that sharks occupied the eastern part of the lagoon during the daylight and the western part at night, we performed a Student's t-test on the day and night longitudinal coordinates (Figure 5a and b). The nighttime positions were significantly westward ($P<0.05$) of the daytime positions thus confirming our hypothesis. Likewise we compared the sunrise and sunset positions and determined that they did not differ, confirming our second hypothesis (Table 3).

***Table 3.** Individual results of Student's t-tests ($p < 0.05$) performed on independent data for validation of hypothesised movement patterns. The tested null hypotheses are:*
Ho(1): the difference between the mean of day longitudes and night longitudes equals zero;
Ho(2): the difference between the mean of sunrise longitudes and sunset longitudes equals zero.
Mean longitudes (79°W) in minutes.

Shark name	n	Ho(1): *Night= Day?*	Ho(2): *Sunset= Sunrise?*	Mean longitude daynight	Mean longitude sunrise	Mean longitude sunset	Mean longitude
Bacardi	93	No	Yes	15.92 ± 0.50, n=25	16.86 ± 1.34, n=52	16.54 ± 0.98, n=7	16.53 ± 0.82, n=9
Tootsie	62	No	Yes	14.80 ± 0.72, n=28	15.69 ± 1.18, n=22	15.75 ± 0.65 n=6	15.63 ± 0.98, n=6
Ursula	43	No	Yes	14.61 ± 0.52, n=19	16.51 ± 0.78, n=16	15.74 ± 0.83, n=3	15.82 ± 1.01, n=5

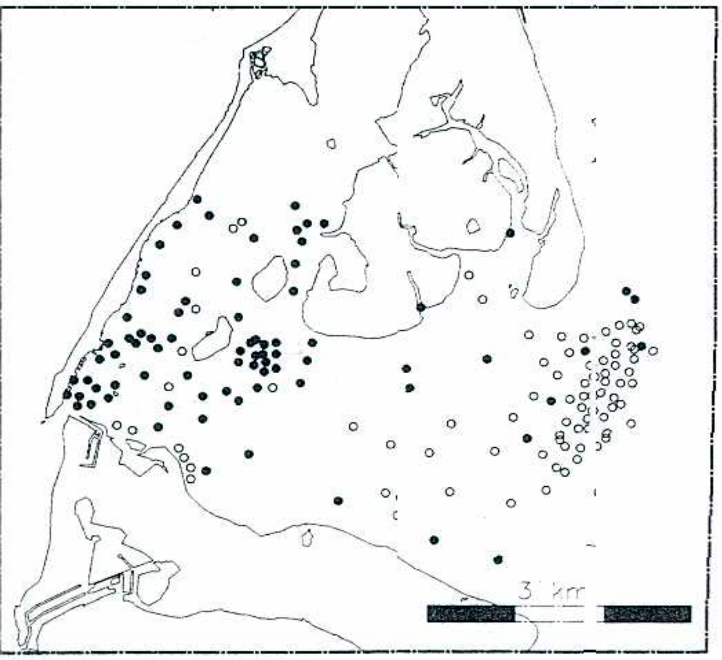


***Figure 5a.** Day and night activity spae as shown by the ndependent position plots of the four lemon shrks tracked in Birrsini lagoon during the Winter of 1994. Note th predominance tf western longitudes during night and eastern ongitudes during day.*

DISCUSSION

This study is the logical next step following the work of Morrissey & Gruber (1993a, 1993b) who investigated activity patterns of zero to three-year old lemon sharks. Their ecological and behavioral research was framed within the discipline of bioenergetics and attempted to understand the spatial requirements of lemon sharks. Another aim of their study was to estimate the metabolic requirements of young lemon sharks by combining laboratory results with their field observations. We are continuing and expanding their work by studying spatial requirements, habitat selection and diel activity patterns of the larger lemon sharks found throughout the year in Bimini lagoon.

We have suggested elsewhere (Gruber 1982) that lemon sharks born in the lagoon may remain closely associated with the island for up to 10 years. The sharks we selected were between 150 and 200 cm TL with an estimated age of six to nine years old (Brown & Gruber, 1988). One of the sharks captured during this study (Junkanoo) was tagged

1988 at 81.6 cm TL quivalent to about two ears old. He was recapred January 1994 with a otal length of 169 cm hich would indicate an ge of seven years and nine onths. This study shows at a variety of age classes emain for long periods at e island and that they tay in the lagoon for at east several months at a me. Whether they leave nd return is open to question and is one subject that ve will be looking into vith long-life (18 month) ransmitters.

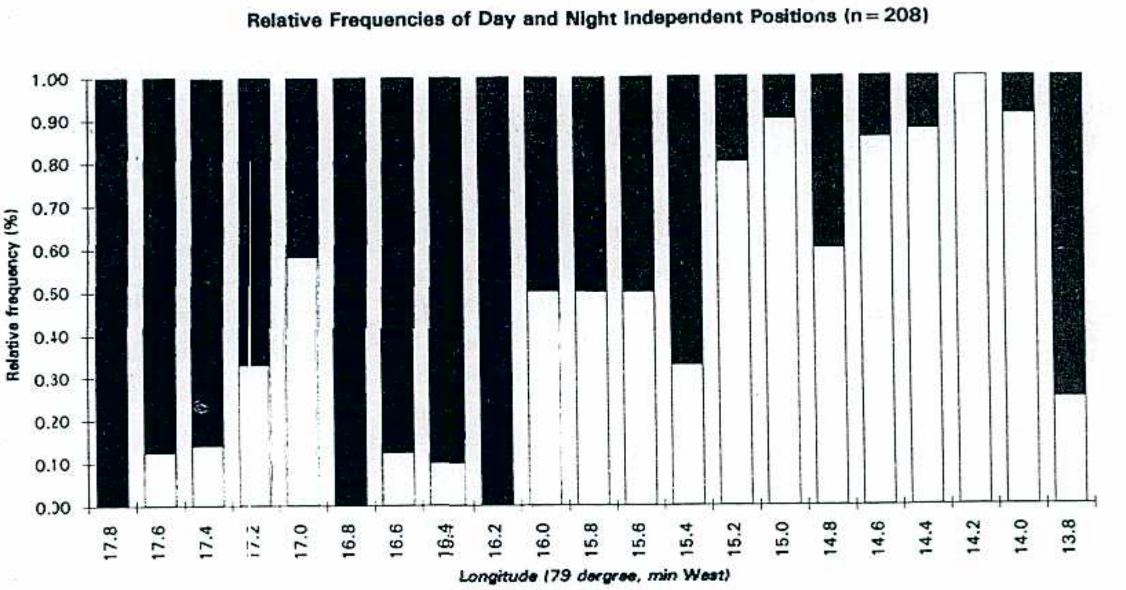


Figure 5b. Histogram with relative frequencies of day and night longitudinal positions of the four tracked sharks in Bimini lagoon. n = 208 independent positions. Observed night longitudinal positions (black bars); observed day longitudinal positions (white bars).

The tracks made from the our telemetered sharks definitely established a repeatable east-west movement pattern. Analysis of the 34 racks showed that all four sharks stayed near the western edge of the lagoon at night, traveled eastward (toward the sun) at sunrise and remained in a relatively localized area ust east of the southeastern point of east Bimini during he daylight hours. As the sun set, the sharks became more active and moved westward (toward the sun). Our data analyses demonstrated that this pattern is statistically valid and thus confirms the observations of Gruber *et al.* (1988).

A comparison of the home ranges of newborn versus seven year old lemon sharks revealed that the younger sharks are highly site-attached while the older sharks were more nomadic, using nearly all the lagoon in their daily activities and occasionally moving outside the confines of the lagoon at night. McNab (1963) proposed that the size of an animal's home range is proportional to body size. This relation is obvious and expected. McNab further suggested that proportionality is a general feature of all animals and that carnivores with spatially heterogenous food should have larger home ranges than herbivores of the same size.

We believe the difference of the observed east-west movement pattern lies in behavioral differences associated with foraging and refuging. Based on visual observations from both aircraft and boats, we regularly see groups of two to twenty-five lemon sharks at the southeastern edge of East Bimini. These sharks are either resting on the bottom or meandering slowly at one to two km/h. The aggregated sharks remain within an area smaller than one hectare. The tracking data show that sharks regularly return to the eastern flat after nocturnal activities several kilometers to the west. This behavior fits the pattern Hamilton and Watts (1970) termed refuging. In contrast, all these sharks which were originally captured in the Alicetown Channel move rapidly to the west at sunset and work their way up and down the channel until daybreak. We believe they are foraging and feeding in the channel and its vicinity. Part of this belief stems from our capturing experience: the Alicetown Channel appears to be the best area to capture six to nine-year old lemon sharks. In addition, telemetered sharks appear to be more active in the Alicetown Channel than on the eastern flats. From the four sharks tracked in Bimini during winter 1994 there was a clearly defined diel movement pattern which suggested to us that six to nine-year old lemon sharks may forage in the Alicetown Channel at night and refuge on the eastern flats during the day.

We are currently in the process of analyzing telemetry data of 28 six to nine year old lemon sharks captured in Bimini over four years. We are confident that the diel pattern will remain significant in all sharks. We are also investigating the hydrology of Bimini Lagoon to determine how tidal currents influence the sharks' movements. We will use speed-sensing transmitters to measure the absolute swimming velocity of the sharks and establish how it varies throughout the diel cycle. Lastly, we are planning to map the bottom saces of Bimini Lagoon to establish habitat preference of the lemon shark.

ACKNOWLEDGMENTS

This study was carried out under Bahamas Research Permit MAF/FIS/17 and received financial support from the University of Miami, University of Basel and the U.S. Office of Naval Research. We thank Dr. David Senn for his support and encouragement. The following corporations assisted with products and materials: Mariner (Brunswick Corporation), Kawasaki, Pelican Products, Davie

Marine of Florida and Trimble Navigation. We thank the following people for their help: graduate student Eva Nagy and volunteers Oliver Balmer, Tim Calver, Ian Campbell, Melissa Drake, Sonja Fahner, Marisa Gruber, Eddie McMannus, Nicole Ochsenbein, Heidi Paproth, Ronnie' Pfister, Christopher Saunders and Jonathan Schlosser. We are indebted to Colin Higgs, Director of Fisheries, Commonwealth of the Bahamas for his enthusiastic support of the overall shark research program.

REFERENCES CITED

Anderson, D. J. 1982. The Home Range: A New Nonparametric Estimation Technique. Ecology. 63(1): 103-112.
Bathurst, R. G. C. 1967. Oölitic Films on Low Energy Carbonate Sand Grains, Bimini Lagoon, Bahamas. Marine Geol. 5: 89-109.
Brattström, H. 1992. Littoral Zonation at Three Bahamian Beachrock Localities. Sarsia 77: 81-109.
Brown, C. A. and S. H. Gruber. 1988. An Assessment of the lemon shark age *Negaprion brevirostris* using tetracycline validated centra. Copeia 1988: 747-753.
Compagno, L. J. V. 1984. Sharks of the World. FAO Fisherie Synopsis No. 125, 4(2), 655 p.
Cortés, E.and S. H. Gruber 1990. Diet, Feeding Habits and Estimates of Daily Ration of Young Lemon Sharks, *Negaprion brevirostris* (Poey). Copeia, 1990(1): 204-218.
Garrick, J. A. F. and L. P. Schultz. 1963. A Guide to the Kinds of Potentially Dangerous Sharks. In P. W. Gilbert (ed.). Sharks and Survival. Boston, D.C. Heath, pp. 3-60.
Gruber, S. H. 1982. Role of the Lemon Shark, *Negaprion brevirostris* (Poey) as a Predator in the Tropical Marine Environment: A Multidisciplinay Study. Florida Sci., 45(1): 46-75.
Gruber, S. H., Nelson, D .R. and J. F. Morrissey, 1988. Patterns Of Activity And Space Utilization Of Lemon Sharks, *Negaprion brevirostris*, In A Shallow Bahamian Lagoon. Bulletin of Marine Science, 43(1): 61-76.
Hamilton, W. J. and K. E. Watt. 1970. Refuging. Ann. Rev. Ecol. Systemat. 1:263-287.
Harrison, W. Byrne, R. J., Boon III, J. D. and R. W Moncure, 1970. Field Study of a Tidal Inlet, Bimini, Bahamas. In Proceedings of the Twelfth Coastal Engineering Conference, Washington D.C., 2: 1201-1222.
Holland, K. N., Lowe, C. G. and Peterson, J.D.and A. Gill, 1992. Tracking Coastal Sharks with Small Boats: Hammerhead Shark Pups as a Case Study. Aust. J. Mar. Freshwater Res., 43: 61-66.
Holland, K. N., Wetherbee, B. M., Peterson, J. D.; Lowe, C. G. 1993. Movements and Distribution of Hammerhead Shark Pups on Their Natal Grounds. Copeia, 1993(2): 495-502.
Jacobsen, T. 1987. An ecosystem-level study of a shallow, subtropical, marine lagoon, North Sound, Bimini, Bahamas. Athen: university of Georgia. Dissertation.
Klimley, A. P. 1993. Highly directional swimming by scalloped hammerhead sharks, *Sphyrna lewini*, and subsurface irradiance, temperature, bathymetry, and geomagnetic field. Marine Biology, 117: 1-22.
McKibben, J. N. and D R. Nelson, 1986. Patterns of Movement and Grouping of Gray Reef Sharks, Carcharhinus amblyrhynchos, at Enewetak, Marshall Islands. Bulletin of Marine Science, 38(1): 89-110.
McNab, B. K. 1963. Bioenergetic and the determination of home-range size. Am. Nat. 98(894):133-140.
Morrissey, J. F. and S. H. Gruber, 1993a). Habitat selection by juvenile lemon sharks, *Negaprion brevirostris*. Environmental Biology of Fishes 38: 311-319.
Morrissey, J. F. and S. H. Gruber, 1993b). Home Range of Juvenile Lemon Sharks, *Negaprion brevirostris*. Copeia, 1993(2): 425-434.
Newell, N.D. and J. Imbrie. 1955. Biological reconnaissance in the Bimini area, Great Bahama Bank. Trans. NY Acad. Sci., Ser. II 18:3-14.
Swihart, R. K. and N. A. Slade. 1985. Testing for Independence of Observations in Animal Movements. Ecology, 66(4): 1176-1184.
Turekian, K. K. 1957. Salinity Variations in Sea Water in the Vicinity of Bimini, Bahamas, British West Indies. American Museum Novitates, 1822: 1-12.

João Correia, Unidade das Ciências e Tecnologias de Recursos Aquáticos., Campus de Gambelas, Universidade do Algarve, 8000 Faro, Portugal (c/o Sadat Muzavor)
Jean de Marignac, Bimini Biological Field Station, 15 Elizabeth Dr., Bimini, Bahamas
Samuel Gruber, Rosenstiel School of Marine and Atmospheric Science., University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149, USA

The original title of this article was ***Diel Activity Patterns of the 6 to 9 year old Lemon Shark* (Negaprion brevirostris, *Poey 1868) in Bimini Lagoon, Bahamas: A Progress Report*.**