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MOVEMENT PATTERNS OF BONEFISH, *ALBULA VULPES*, IN BAHAMIAN WATERS

The regular daily movement patterns of fishes appear closely related to predictable changes in their environment. Factors such as tidal fluctuations (Dodson and Leggett 1973; Stasko et al. 1973), light levels (Yuen 1970; Collette and Talbot 1972; Standora et al. 1972; McFarland et al. 1979), and temperature (Coutant 1975; Kelso 1976; Haynes et al. 1978; Langford et al. 1979) have been found to influence the cyclic movement of fishes. Until recently, most information on such movement patterns has been obtained primarily through direct observation. However, there are many situations in which direct visual methods are not feasible. An alternate means of obtaining such information has been provided by recent advances in the use of ultrasonic telemetry as a research tool.

Ultrasonic telemetry has become a valuable technique both in freshwater and deep marine environments. However, the use of ultrasonics in coastal waters is still in the early developmental stages. Rapid signal attenuation occurs under such conditions because of combined effects of the high conductivity of the water, vegetative growth, turbulence, and bottom reflection (Stasko and Pincock 1977).

This research attempted to use ultrasonics to determine movements and daily activity patterns of the bonefish, *Albula vulpes*, in Bahamian waters. The only prior attempt at scientifically studying bonefish movements in the western Atlantic region was by Bruger,[1] who initiated a

[1]G. E. Bruger, Research Biologist, Florida Department of Natural Resources, Marine Research Laboratory, 100 Eighth Ave. SE., St. Petersburg, FL 33701, pers. commun. May 1980.

comprehensive conventional tagging program on Florida bonefish. He met with no success, however, presumably due to the failure of the dart tags used. This current research thus represents the first attempt to use ultrasonic telemetry for this purpose.

Methods and Study Sites

This investigation was conducted in waters around a series of small islands or "cays" at the East End of Grand Bahama Island. The general environment here consists of mangrove, sand flats, creeks, lagoons, and offshore reefs. The north shores of these cays border the shallow waters of the Little Bahama Bank, while their south shores merge with the waters of the Northwest Providence Channel. Areas in which bonefish populations were frequently observed were selected as tagging and tracking sites; these areas are locally known as McLean's Town, Big Harbor, Little Harbor, Thrift Harbor, and Big Creek (Fig. 1). Each site represents a somewhat different habitat type: Portions of several are situated in protected lagoon areas between Abaco Islands and Grand Bahama Islands, and portions of others are located in shallow backwaters of East End, Grand Bahama, while two other locations are adjacent to open ocean and coral reefs.

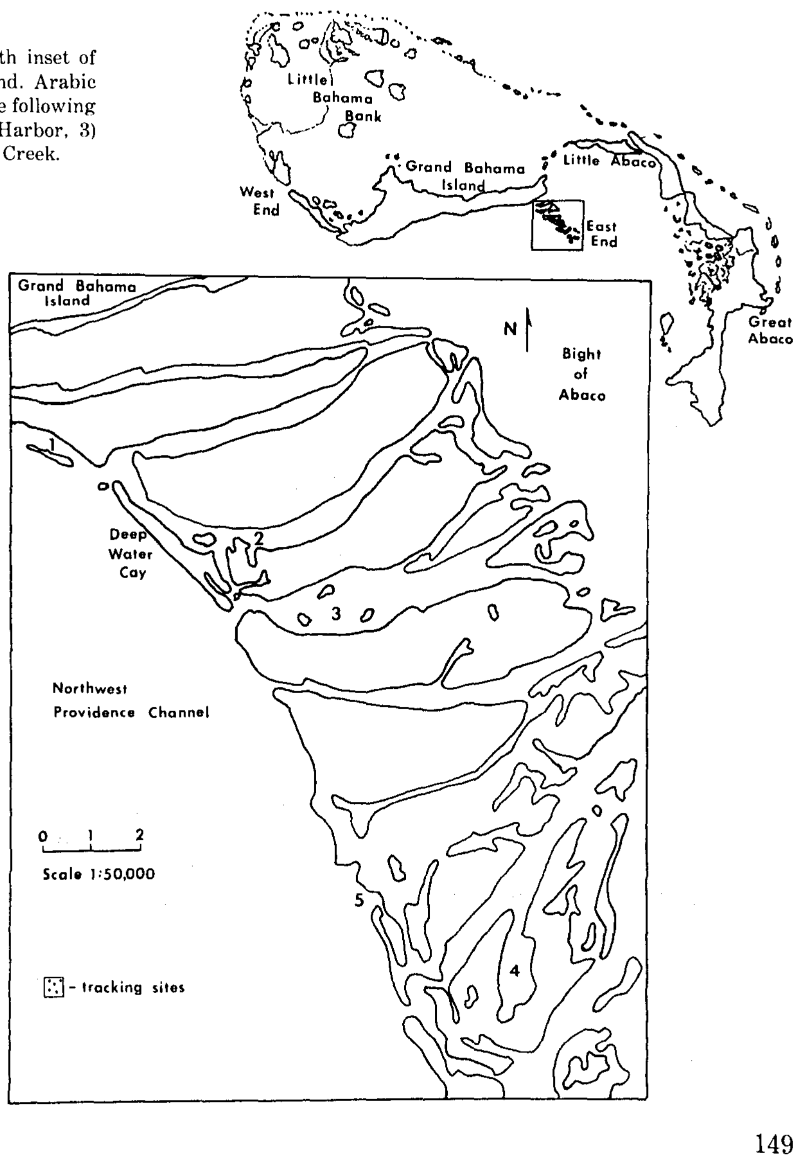

FIGURE 1.—Grand Bahama Island with inset of study areas in the vicinity of East End. Arabic numerals represent tracking sites at the following locations: 1) McLean's Town, 2) Big Harbor, 3) Little Harbor, 4) Thrift Harbor, 5) Big Creek.

The short-term (daily) movements of bonefish were monitored by an ultrasonic tracking system. Fish were captured by angling and gill nets. Bonefish were only minimally injured by the netting procedure, since the mesh size of 6.25 cm was chosen to restrain the fish without injury to the gills. Captured fish were removed by hand from the gill net and were held in a hand net for further treatment. Individuals, selected according to size (>2 kg) and physical condition, were equipped with ultrasonic transmitters. In tracking studies prior to 1981, the transmitter was placed in the stomach with a glass plunger (Henderson et al. 1966; Yuen 1970). During 1980, this technique often resulted, 3 out of 5 times, in disgorgement of the transmitter. Therefore, surgical implantation of the transmitter in the body cavity was used during 1981. Here, the fish was restrained ventral side up. Several scales were removed posterior to the pelvic fins and lateral to the midline, and an incision of 3-4 cm was made with a surgical scalpel. The transmitter was then inserted, and the incision sutured. This procedure is similar to that used by Hart and Summerfelt (1975). To aid in recovery, the fish was slowly worked forward and back in the water by hand to aerate the gills. The majority of the fish appeared to survive the implant and recovered without noticeable effect, provided predators of the bonefish were not in the immediate vicinity at time of release. Several individuals held in a saltwater holding tank for periods of 24-96 h showed no noticeable ill effects. Conclusions drawn from the observed movements of fish immediately after release are of questionable value, since behavior and movements may be strongly influenced by the process of capture and handling. Thus, only tracks initiated 24 h or more after release were considered to reflect normal behavior.

The transmitters were 58 mm long and 15 mm in diameter, weighed 3-4 g in water, and operated at a frequency range of 74-77 kHz. They were manufactured by either Smith Root Inc. or Sonotronics,[2] and were pulsed at different intervals (1-2 pulses/s), so that individual fish could be distinguished when several transmitters were operating in the same general area. Power for the pulse intervals was supplied by mercury batteries with a useful life of about 7-14 mo. Range was as wide as 0.5 km at times, but much narrower when the water was turbulent.

A Smith Root TA-50 and a Sonotronics digital (pulse/frequency display) receiver, with their respective hydrophones, were used to receive the signals. All tracking was conducted from a 4.5 m skiff equipped with two foot-controlled variable-speed electric motors. The hydrophones were mounted off the bow about 0.5 m below the surface, allowing the direction of a transmitting fish to be ascertained by pointing the bow in the direction of the strongest signal. Data recorded during tracking included location, water depth and temperature, tide state, time, and wind speed and direction. This information was generally recorded at about 30-min intervals, but more frequently when a tracked fish was moving rapidly. Location was accurately recorded on Bahamian land survey maps by using chartered landmarks in conjunction with depth.

To investigate long-term movements, a conventional tag and release program was initiated in February 1980. At the outset, Monel metal strap tags were crimped into the lower jaw. This method was replaced (January 1981) by the use of dart tags (FD 68B PVC) inserted adjacent to the dorsal fin, a procedure requiring less time and handling of the fish. These tags were of much heavier construction than those used by Bruger (1974). Tagging was concentrated in areas frequently fished and/or areas in which schools of bonefish were consistently seen.

Monthly collections of 20-30 bonefish were obtained from the study areas by nets and angling from June 1980 through December 1981, except September 1980. These data provided information on size distribution of captured individuals over the yearly cycle. Collections were obtained each month from the same general areas (indicated in Fig. 1).

Results

Between August 1980 and November 1981, 13 bonefish were implanted with ultrasonic transmitters and released. Of these, only three fish were relocated more than 24 h from time of release. Two of these fish, from McLean's Town Creek (50.5 and 53.5 cm FL (fork length)), were tracked for a period of 5 d each, with total tracking times of 16 and 30 h, respectively. The fish from Big Creek Lake (61.0 cm FL) was followed over a 100-d period for a total tracking time of 32 h (Fig. 2). Water depths in these areas ranged

[2]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

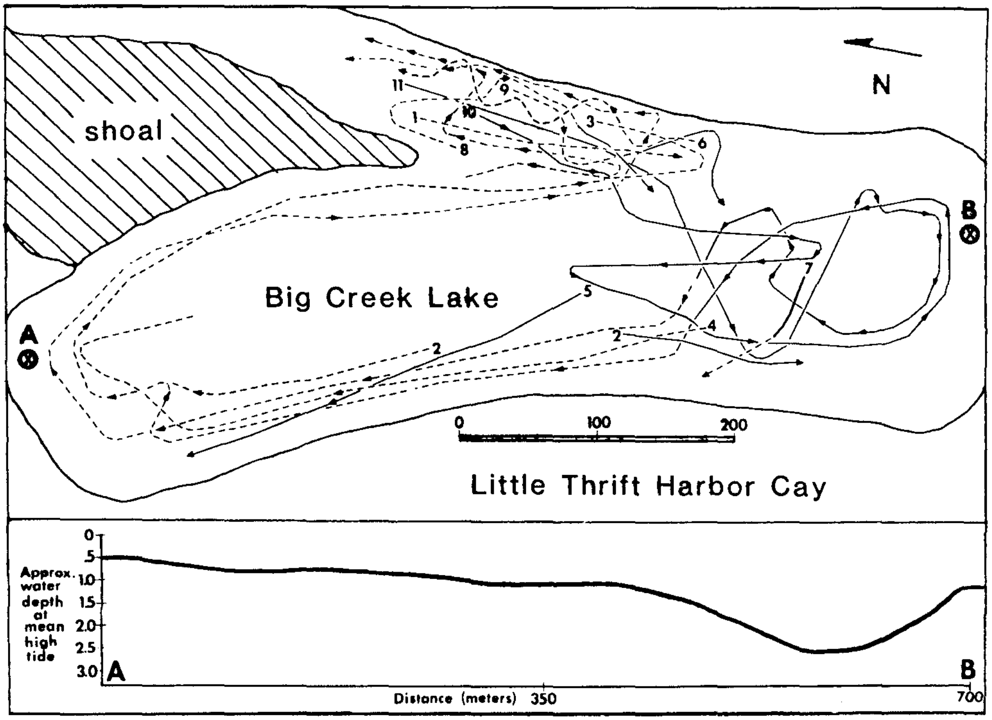

FIGURE 2.—Movements of a 61.0 cm FL bonefish in Big Creek Lake during 1981. The solid line denotes movement during falling tides, and the dashed line movement during a rising tide. The Arabic numerals denote the starting point and day of track, with ½-h intervals and direction of movement indicated by arrows. The time periods and dates of the individual tracks are: 1) 1630-1700, 14 April; 2) 0855-0925, 1615-1650, 15 April; 3) 1350-1435, 16 April; 4) 1557-1640, 18 April; 5) 1600-1700, 21 April; 6) 1200-1300, 22 April; 7) 1500-1530, 16 May; 8) 1200-1300, 20 May; 9) 0900-1000, 20 June; 10) 1200-2400, 23 June; 11) 1220-2420, 23 July.

from 0.1 to 4 m. Tracking occasionally extended into areas of <0.1 m depth, at which times movements were visually monitored by observing the exposed dorsal and caudal fins. Visual observations indicated that the fish generally remained near the substrate (<1 m). The range of water temperatures measured during a single track of any fish was no more than 8°C, with a low of 24°C and a high of 32°C.

The general pattern of daily movements was a retreat to deeper water on an ebbing tide and a movement into shallow water on a rising tide. This pattern can be clearly seen in the track of the fish from Big Creek monitored for 100 d (Fig. 2). A similar pattern was obtained by tracking the other two fish for 5 d each at McLean's Town. However, some variability was noted in the observed depth of fish movements as compared with the depth range available at the two locations. The fish at Big Creek was observed to move consistently into very shallow water (<1 m) with the rising tide. In contrast, the McLean's Town fish showed a variable response in depth-related movement. Also, "mudding" (a common term used to describe the turbidity resulting from fish feeding in bottom sediments) was observed only during low tide at Big Creek, but throughout the tidal cycle at McLean's Town. Nocturnal movements closely followed the same pattern.

From January 1980 through December 1981, 214 bonefish were tagged with Monel metal or dart tags and released in the same channels, bays, and flats of Deep Water Cay as they were captured. None of these fish were recaptured more than 24 h from time of release. Only a single collection resulted in recapture of tagged fish; this was made 4 h after the fish had been tagged.

Collection data provided a record of fish lengths and weights for each month (excluding September 1980) over a 19-mo period (June 1980-December 1981). The proportion of large fish (>55.5 cm FL) in these collections showed a pronounced regular seasonal change, with a strong inverse relation to inshore water temperature (Fig. 3). That this change represents a movement of large fish rather than small fish from the flats during summer is strongly supported by numerous conversations with the guides, managers, and avid anglers of the Deep Water Cay Club. All of these persons made it clear that the catching of large (>55.5 cm FL) bonefish on the flats, although not common in winter months, is extremely rare in summer. The measurement of 55.5 cm FL, used in this paper to distinguish large from small fish, corresponds to the division between the fifth and sixth age-class of bonefish from the Florida Keys (Bruger 1974).

Discussion

Information gained from extended ultrasonic tracking of three individuals in two different areas suggests that bonefish display a regular pattern in daily movements in response to tidal changes. These movement patterns, although monitored on individuals, are probably representative of school movement because transmitter-implanted fish generally returned and remained with schools of bonefish (3-20 individuals) within 24 h of release. The observed differences in daily movements of bonefish in the two different areas may indicate the effects of differences among the two locations in such factors as bottom topography, food resource distribution, and predation. However, this point is in need of further research.

Information derived from ultrasonic tracking, conventional tagging, and repetitive collecting effort in specific areas indicates that movements of bonefish on a long-term basis are highly variable and without apparent pattern. Ultrasonic tracking has indicated that individual fish usually remain in a given localized area for less than a week. The two fish tracked for 5 d apparently left the McLean's Town area after that time, since extensive searching on the sixth day, up to 2 km from the area last observed, resulted in no relocation of the fish or the transmitter. Subsequent searches of the same area weeks and months later also were unsuccessful. Six other fish equipped with transmitters and released in apparently good condition were never relocated 24 h after release.

Another strong indication of the transient nature of bonefish movements is the lack of return of conventionally tagged fish, although a concentrated tag and recapture effort was made

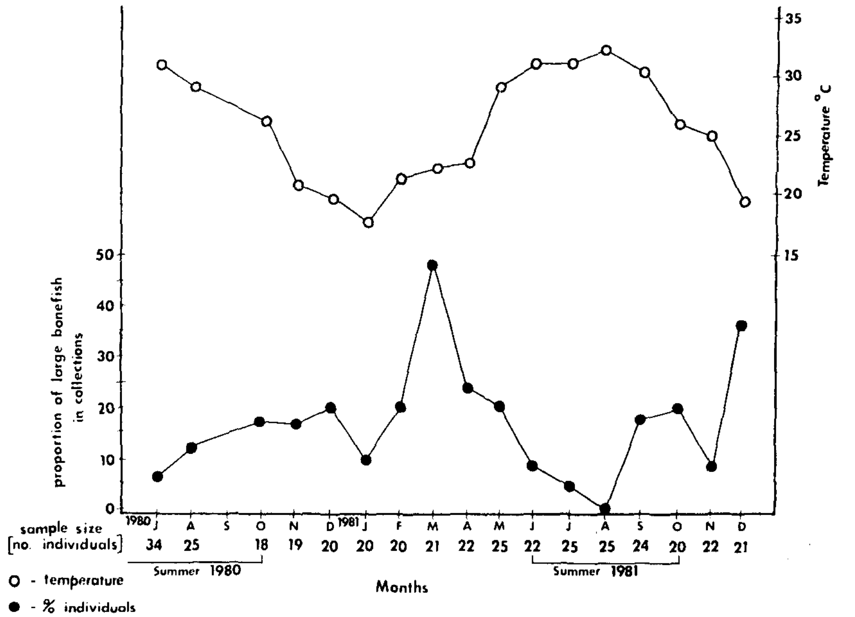

FIGURE 3.—Proportions of large individuals found in monthly collections of bonefish in the waters around Deep Water Cay, Grand Bahama. Each data point represents the percent of individuals collected each month exceeding 55.5 cm FL. No collection was obtained in September 1980. Open circles = temperature, solid circles = percent individuals.

in relatively restricted areas over a period of 18 mo. On one occasion only, fish (three individuals released 4 h prior to recapture) that had been previously tagged and released were recovered again. Failure to relocate fish conventionally tagged or fitted with transmitters could be the result of factors other than fish leaving the general area, such as mortality due to predation or shock of capture and handling, or tag failures. However, none of the evidence gained in this study suggests these factors were responsible.

The observed reduction in the proportion of large bonefish present on the flats during warm-water periods may correspond to a general offshore movement in preparation for spawning. Summer temperatures in the shallow areas of Thrift Harbor Creek have exceeded 34°C (Fig. 3). Although thermal requirements for *Albula vulpes* have not yet been experimentally determined, abnormally high temperatures are known to be deleterious to gamete formation among vertebrates (Guyton 1976; Langman 1981). Among fishes, it has been generally established that thermal requirements are even more restrictive for the reproductive process than for either growth or survival (Brett 1956). The hypothesis that large bonefish move offshore during summer is supported by the lore of the local Bahamian fishermen. They believe that larger individuals undergo a regular movement into deeper (15-25 m) waters at this time. During fall (October-November), these fish return inshore and aggregate in large numbers to spawn in shallow creeks. Erdman (1960[3]) reported a similar observation by commercial fishermen in Puerto Rico. At the time of this inshore movement, the fish are said to be lighter in color, with a highly silvery appearance. Personal examination by the senior author of fish collected by anglers from such aggregations revealed that nearly all individuals were sexually ripe. Additional evidence of seasonal offshore movements of bonefish comes from scuba divers in the Freeport area (pers. commun.), who have reported observing schools of thousands of bonefish suspended above the reefs. Böhlke and Chaplin (1968) cited a similar observation occurring off the Tongue of the Ocean, Green Cay, Bahamas.

[3]Erdman, D. S. 1960. Notes on the biology of the bonefish and its sports fishery in Puerto Rico. Paper prepared for the 5th Int. Game Fish Conf. Miami Beach, Fla., 11 p.

Summary

Bonefish appear to remain in a specific location (e.g., creek, small bay, channel, etc.) for a period usually not exceeding several days, and then move on to other locations. While at a given location, there is a distinct pattern to daily movements in response to tidal fluctuations, but long-term movements appear to be highly variable, with no definable pattern seen. In summer, larger individuals are rarely found on the flats. Their reappearance in the fall concurs with a rapid drop in water temperature at that time of the year.

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ANALYSES OF FEEDING IN TWO MARINE COPEPODS FROM SANTA MONICA BAY, CALIFORNIA

Understanding the feeding strategies of herbivorous, planktonic copepods is an important step in determining how primary production is partitioned in coastal marine food webs. The conditions under which selective feeding occurs among these animals vary, and are defined both by the species and the environment (Poulet 1974; Poulet and Marsot 1980; Donaghay 1980).

Although it is desirable to study feeding behavior in natural zooplankton assemblages, this is often difficult. Identification of phytoplankton in the gut by standard dissection and microscopic techniques is labor intensive, and usually qualitative. Furthermore, it is impossible to identify many of the soft-bodied organisms which might have been consumed. For this reason, much of the work on food selection in copepods has been restricted to the laboratory, where cultivated foods (Frost 1972) or natural particles (Poulet 1978) have been offered to the animals. While such studies have provided valuable information, they have been limited by the variety of foods which can be offered and by other technical problems (Mullin 1963; Harbison and McAlister 1980). Studies employing gut contents analysis of animals collected in the field using gut fullness (Hayward 1980; Huntley 1980) or chlorophyll a fluorescence as an estimate of total phytoplankton biomass in the gut (Mackas and Bohrer 1976; Boyd et al. 1980) have answered questions about when and where certain zooplankton feed, but usually provide only indirect data on the kinds of phytoplankton actually ingested. Dagg and Grill (1980) showed that the rate of particle ingestion is often not solely a function of concentration and suggested that food quality may be important in explaining the variability observed in the relation between feeding rate and particle concentration.

To understand the processes involved in food selection it is necessary to determine directly the types of materials in the guts of the copepods being studied. Such an analysis must be capable of detecting soft-bodied phytoplankton as well as diatoms and armored dinoflagellates, and of providing some indication of the relative importance of different taxa in the diet at a given time. We have been especially interested in the importance of the green algae to zooplankton feeding in coastal waters. Information in this area is rela-