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The Diet and Feeding Habits of the Southern Stingray, Dasyatis americana, in Tropical Shallow Marine Habitats

David S. Gilliam
Nova Southeastern University

THE DIET AND FEEDING HABITS OF THE SOUTHERN STINGRAY, DASYATIS AMERICANA, IN TROPICAL SHALLOW MARINE HABITATS

By

David S. Gilliam

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DAVID S. GILLIAM

Approved:

THESIS COMMITTEE

MAJOR PROFESSOR ____________________

Dr. Curtis Burney
Nova University

____

Dr. Charles Messing
Nova University

____

Dr. Kathleen Sullivan
University of Miami

NOVA UNIVERSITY

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ABSTRACT

The diet and feeding habits of the southern stingray, Dasyatis americana, were investigated through aerial surveys, land-based observations, and quantitative analysis of stomach contents. The field research was conducted in the Exuma Cays Land and Sea Park, central Bahamas. Systematic aerial surveys and the land-based observations were made to determine population density and feeding periodicity in terms of time or tidal phase. In August, 1989, systematic surveys were flown over two cays in the Park; a 12 km^2 area around Waderick Wells Cay and a 21km^2 area around Shroud Cay. Both survey areas were flown three times over different times of the day. Over the large area covered by the aerial surveys the population varied over time of day. A significantly higher density occurred in the morning for both grids and was lowest in the afternoon for both grids suggesting that the stingrays prefer to feed early in the day in the summer. The peak density was 2.07 stingrays per km^2 for the Waderick Wells survey area and 1.87 per km^2 for the Shroud survey area. A total of 117 hours of land-based observations were made over 4 months; with 28 to 31 hours of observations in April and May 1990 and January and July, 1991. The land-based observations indicated that the stingrays were actively feeding throughout the day , but showed some increase in feeding activity during the high tidal phase. The habitat utilization was recorded during the land-based observations and showed that the stingrays spent most of their time feeding in the soft sediment habitats, thus taking advantage of the soft sediment algal turf and sandy shoal habitats that dominate the shallow marine environments within the Park. Eighteen stingrays were collected in January, 1991 for stomach content analysis. Decapod crustaceans were the most important prey category, but the large number of prey types found in all of the stomachs indicates that the southern stingray is a generalist feeder. There were no empty stomachs and 77% of the stomachs had more than 20 prey items. Stomach fullness measures did not indicate any feeding periodicity. The southern stingray is a generalist feeder taking advantage of a broad range of prey types and opportunistic in its feeding habits, showing no strong feeding periodicity.

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PREFACE

This thesis consists of four chapters, three of which are in manuscript form. Chapter one is an introduction on feeding theories, stingray biology, and the Exuma Cays. Chapter two consists of the manuscript AERIAL SURVEYS AND LAND-BASED OBSERVATIONS OF SOUTHERN STINGRAY FEEDING HABITS and chapter three consists of the manuscript DESCRIPTION OF THE DIET AND FEEDING HABITS OF THE SOUTHERN STINGRAY USING QUANTITATIVE STOMACH CONTENT ANALYSIS. Both of these chapters have been written according to the editorial format of the BULLETIN OF MARINE SCIENCE. The fourth chapter is a summary and the conclusions from chapters two and three.

CHAPTER 1

INTRODUCTION

Feeding and food preference studies provide vital information on how an individual animal interacts with its environment. The prey of most predators are not available at all times, randomly scattered throughout its environment, but occur aggregate at particular times in particular habitats (Taylor, 1961). In order to survive, a predator must make choices as to when to feed, where to feed, and what to feed on. Optimal foraging models have been developed by many investigators to explain and to predict the foraging behavior of animals (Emlen, 1966; MacArthur and Pianka, 1966; Schoener, 1971; Pyke et al., 1977). When describing food preferences, the relationships between selectivity versus non-selectivity and specialization versus generalization are of great interest (MacArthur and Pianka, 1966).

A generalist feeder can be described as an individual that consumes a broad range of food types throughout its lifetime, in contrast, a specialist feeder consumes a highly restricted number of food types (Alcock, 1975; Gray, 1990). Schoener (1971) states that a generalist feeder can switch from one food type to another in response to the relative abundance of the food types and that generalists are favored in areas where a single food type is rarely consistently present in large numbers. Theoretical models on the role of time and energy predict that when food is scarce, selectivity in food preference should decrease (Emlen, 1966; Pyke et al., 1977). Similarly, MacArthur and Pianka (1966) state that a more productive environment will promote selectivity in food preference.

MacArthur (1972) defines organisms as being "searchers" or "pursuers" in how they gather their food. A "searcher" is an animal that spends more time searching for its food than pursuing it, while a "pursuer" always has its food in sight making search time almost negligible. MacArthur states that a "searcher" should be a generalist feeder. He continues by stating that an unproductive environment would increase search time, thus being more suitable for a generalist feeder.

There have been many food preference and foraging studies on fish and fish communities. An early experiment by Ivlev (1961) gave evidence with the carp, Carassius auratus, that selectivity decreases under conditions of low food abundance. More recent studies by Ringler (1979) on the brown trout and Anderson (1984) on the largemouth bass have confirmed Ivlev's findings that prey selectivity should decrease with decreasing prey abundance. Cowen (1986) describes the California sheephead, Semicossyphus pulcher, as being a food generalist because of the large number of different prey items it consumes. This fish makes site specific prey choices and its diet reflects prey availability. Studies on tropical or subtropical fish species have mostly dealt with teleosts. The diet and foraging habits of tropical reef bony fishes have been described quantitatively by Randall (1967) in the Virgin Islands, by Polunin and Klump (1989) in the Coral Sea, and by Parrish et al (1986) in the Hawaiian Islands. All of these studies use diet and feeding habits to describe the trophic role of the fish and how they interact in the tropical community.

Elasmobranchs are numerically abundant large predators in subtropical and tropical marine environments (Bigelow and Schroeder 1953; Gruber, 1982). Many feeding studies on elasmobranchs indicate that they are opportunistic (i.e. generalist) feeders and occupy the higher trophic levels. Springer (1960) considers the diet of the sandbar shark, Eulia milberti, primarily as a general piscivore because of the wide range of fish species it eats. Schmidt (1986) states that the lemon shark, Negaprion brevirostris, is near the top of the food web because it feeds on fish and small shrimp that occupy middle levels of the food web. The diets of many elasmobranchs found in a variety of waters including Scymnorhinus licha (Matallanas, 1982), the dogfish, Scyliorhinus canicula, (Lyle, 1983), the leopard shark, Triakis semifasciata, (Talent, 1976), young sandbar sharks, Carcharhinus plumbeus, (Medved and Marshal, 1981), and young lemon sharks, Negaprion brevirostris, (Cortes, 1987) have all been described as being opportunistic feeders because of the broad number of prey types and habitats they utilize.

The lemon shark, believes that this elasmobranch is an abundant, large, top predator in tropical marine ecosystems (Gruber, 1982) . To this end, it must have evolved a way to exploit this tropical environment. Brown and Gruber (1988) found that the lemon shark grows more slowly, lives longer, and matures later than teleost predators of similar size, even though the bioenergetics of the shark are similar to those of predatory teleosts (Gruber, 1985). Wetherbee (1988) concluded that slow growth rates are not a consequence of inefficient absorption of energy from food but may be a consequence of low rates of food consumption coupled with prolonged gut passage times. Diet and feeding habits also contribute. Cortes (1987), using quantitative measures of stomach contents, found that these sharks are opportunistic feeders that feed on the most available prey items. Cortes' study revealed no feeding patterns relative to time of day or tidal phase.

Stingrays of the family Dasyatidae are another group of abundant, large elasmobranchs found in shallow tropical and subtropical marine environments (Bigelow and Schroeder, 1953), where they may also be important top predators. Knowledge of the diet and feeding habits of Dasyatid stingrays is limited. It is the purpose of this study to quantitatively describe the diet and detail the feeding habits of the most abundant stingrays, the southern stingray, Dasyatis americana.

1.1 BIOLOGY OF DASYATID STINGRAYS

The southern stingray, Dasyatis americana, is one of the largest and most abundant stingrays of the family Dasyatidae found in sub-tropical and tropical waters. Earliest accounts of the species are by Garman in 1883 as Dasibatus hastatus (Funicelli, 1975). Hildebrand and Schroeder (1928) later renamed the species Dasyatis americana. D. americana has a range extending throughout the coastal waters of the subtropical and tropical western Atlantic including the Gulf of Mexico and the Caribbean (Bigelow and Schroeder, 1953).

Dasyatis americana is ovoviparous; its embryos lie in the uterus without any direct connection to the mother (Bigelow and Schroeder, 1953). The breeding habits of D. americana are not fully understood. Males are thought to reach maturity when at a disc width of 460 mm while females reach maturity at about 700-800 mm (Bigelow and Schroeder, 1953; Funicelli, 1975). Radcliffe (1916) and Fowler (1944) both found gravid females in the summer in Beaufort, North Carolina. In the central Bahamas, gravid females were found in January (pers. obs.) suggesting that individuals in different areas may have different breeding cycles.

Dasyatid stingrays are "searchers" as defined by MacArthur and Pianka (1966), actively searching for their prey rather than sitting and waiting. They feed mainly by excavating the bottom by undulating their pectoral fins. They then suck in their prey and swallow it whole or crush it in their pharyngeal cavity.

Elasmobranchs are able to locate their prey visually, mechanically, chemically, or electrically. Gilbert (1963) found that the lemon shark, Negaprion brevirostris, uses primarily vision when locating prey closer than 3 meters although Banner (1972) found that sound alone can alert N. brevirostris to the presence and location of prey. The dogfish, Mustelus canis, uses olfactory stimuli to locate prey (Hara, 1971). Weak, low-frequency electric fields are detected by the ampullae of Lorenzini located on the heads of some elasmobranchs (Kalmijn, 1978). Experiments on the stingrays, Urolophus halleri, Dasyatis sabina, and Raja clavata, indicate that they can locate prey using only electroreception (Kalmijn, 1971 and 1978; Blander and Alevision, 1988). An experiment by Hodgson and Mathewson (1971) indicates that the nurse shark, Ginglymostoma cirratum, can use true gradient searching, moving slowly with a S-shaped path towards a chemical stimulus.

The only predators of adult Dasyatid stingrays are large sharks. The hammerhead, Shryna mokarron, has been seen attacking and eating stingrays (Stronge et al., 1990). Stingrays have also been found in the stomachs of large lemon sharks (Cortes, 1987). The only protection the stingrays have is their large size and a dorsal cartilagenous spine located midway down their tail (Bigelow and Schroeder, 1953). Predation on adult stingrays is probably low because of the limited number of very large sharks.

Funicelli (1975) reported that the National Marine Fisheries Service collection data indicates a marked decrease in Dasyatid numbers in rocky or coral bottom habitats as compared to soft sediment habitats. These hard bottoms would make prey capture and visual predator avoidance difficult because the stingrays would not be able to excavate the substrate.

Most work on the diet of stingrays has been descriptive, without enumerating the importance of the prey items (Table 1.1). Bigelow and Schroeder (1953) found stomatopods, shrimp, crabs, worms, and fish in D.

TABLE 1.1: Previous studies describing the major prey categories in the diet of Dasyatid stingrays.

SPECIES	LOCATION	PREY CATEGORIES				REFERENCE
		TELEOSTS	CRUSTACEANS	ANNELIDS	MOLLUSCS	
D. americana	BIMINI, BAHAMAS	YES	YES	YES	NO	BIGELOW AND SCHROEDER, 195
D. americana	VIRGIN ISLANDS	YES	YES	YES	NO	RANDALL, 1967
D. americana	GULF OF MEXICO	YES	YES	YES	YES	FUNICELLI, 1975
D. americana	INDIAN RIVER, FL.	YES	YES	YES	NO	SNELSON AND WILLIAMS, 1981
D. centroura	WOODS HOLE, MASS.	YES	YES	NO	YES	BIGELOW AND SCHROEDER, 195
D. centroura	S.E ATL., U.S.	NO	YES	YES	YES	STRUSAKER, 1969
D. guttata	S. AMERICA	YES	NO	NO	YES	THORSON, 1983
D. sabina	DELAWARE BAY	YES	YES	YES	YES	HESS, 1961
D. sabina	GULF OF MEXICO	YES	YES	YES	YES	FUNICELLI, 1975
D. sabina	INDIAN RIVER, FL.	YES	YES	YES	NO	SNELSON AND WILLIAMS, 1981
D. sayi	BEAUFORT, N.C.	YES	YES	YES	YES	BIGELOW AND SCHROEDER, 195
D. sayi	DELAWARE BAY	YES	YES	YES	NO	HESS, 1961
D. sayi	GULF OF MEXICO	YES	YES	YES	YES	FUNICELLI, 1975
D. sayi	INDIAN RIVER, FL.	YES	YES	YES	NO	SNELSON AND WILLIAMS, 1981

americana collected near Bimini, Bahamas. Crabs, clams, gastropods, squid, and fish were found in stomachs from D.centroura collected near Woods Hole, Massachusetts; annelid worms, bivalves, gastropods, amphipods, shrimps, crabs, and fish were found in stomachs of D. sayi near Beaufort, North Carolina (Bigelow and Schroeder, 1953). Hess (1961) found that D. sayi and D. sabina from Delaware Bay, a shallow temperate estuary, share similar diets of crustaceans, molluscs, annelids, and teleosts. D. guttata from the coast of South America were found to eat mainly teleosts and molluscs (Thorson, 1983). Snelson and Williams (1981) found crustaceans, polychaetes, and small fish in the stomachs of D. sabina, D. sayi, and D. americana from the Indian River Lagoon System, Florida. D. centroura from the southeastern United States is described by Struhsaker (1969) as having a broad diet of crustaceans, molluscs, nemerteans, and polychaetes

Several studies have measured the diet of stingrays quantitatively. Babel (1964) studied the food and feeding habits of the round stingray, Urolophus halleri, off the coast of California. These stingrays fed mainly on bivalves (42% by volume), polychaetes (30%), and crustaceans (21%). Babel felt that they fed on the most available items throughout the day.

A more quantitative study was performed by Funicelli (1975) on the feeding habits of D. sabina, D. sayi, and D. americana from the Gulf of Mexico. Funicelli (1975) used an index of abundance, calculated by multiplying the abundance of a prey item by the number of individuals that contained that item. For D. sabina, crustaceans and bony fishes were the most important food items. Decapod crustaceans were the most important food items for D. americana, and both decapod and stomatopod crustaceans were important food items of D. sayi. Funicelli concludes that D. sabina is an opportunistic feeder and has a more diversified diet than D. americana or D. sayi. This may be due to the fact that D. sabina was found more in shallow estuarine waters than either D. americana or D. sayi.

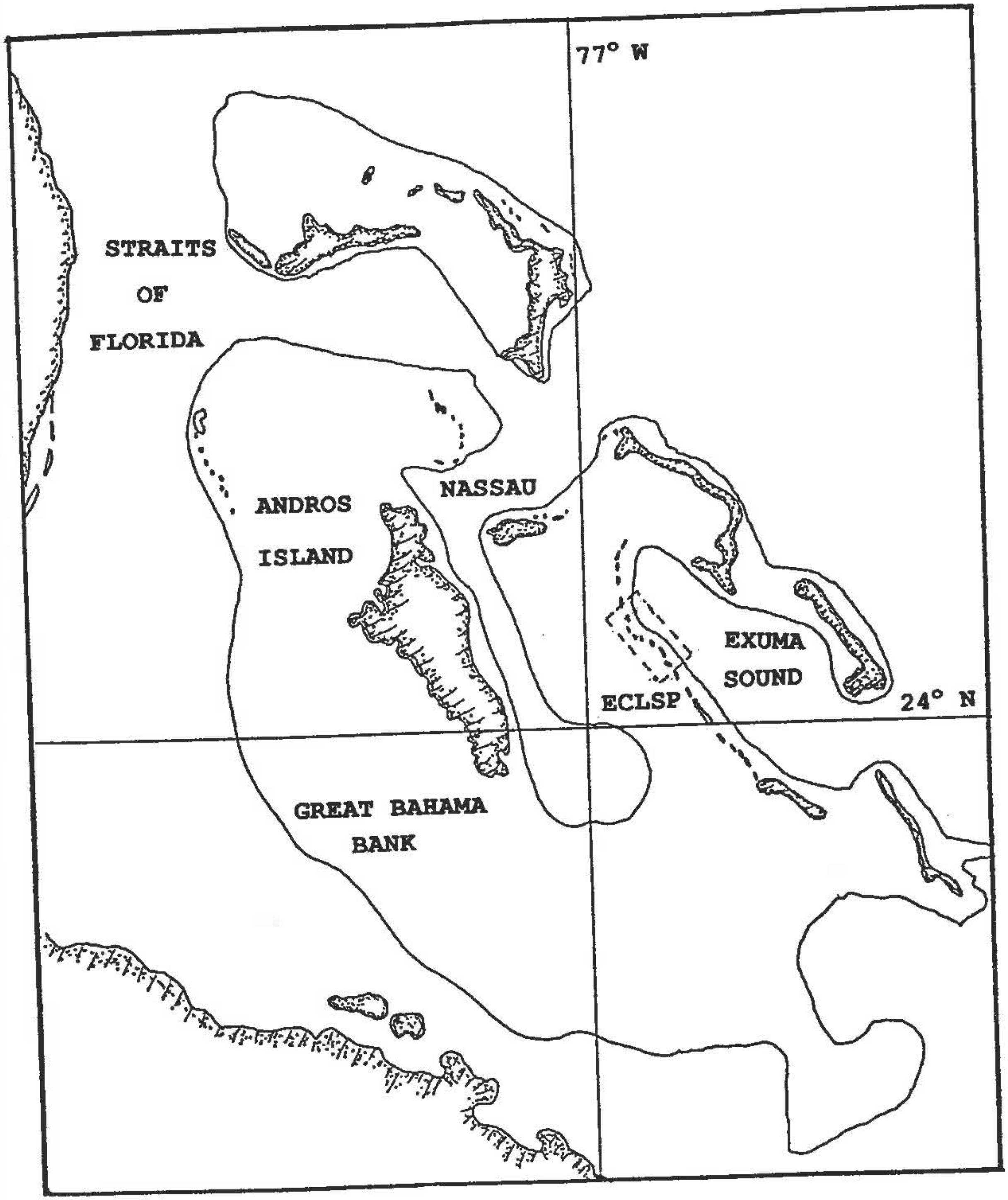
A quantitative study done on D. americana from tropical waters was conducted by Randall (1967) in the Virgin Islands, but he only looked at the percent volume major food groups contributed to total diet and said nothing of their feeding habits. Randall found that fish (22% by volume), sipunculids (21%), crabs (18%), and polychaetes (17%) were the most important food items.

1.2 MARINE ECOLOGY OF THE EXUMA CAYS

The Exuma Cays Land and Sea Park was the location of this study. The park encompasses 22 miles of the Exuma Island chain ($24^{o}22'$ N to $77^{o}30'$ W) in the central Bahamas (Figure 1.1). This park was chosen for this study for two reasons. First, the governing bodies of the park, the Bahamas National Trust and the Department of Fisheries (Bahamian government), have established laws protecting all organisms found in the water and on land. Second, no permanent settlements exist in the park and most of the cays are uninhabited. The marine habitats of the park are nearly pristine, enabling field studies to be accomplished with little human interference.

The marine habitats found in the interior banks of the park can be characterized by two substrate types (Sealey, 1985; Sullivan, 1991). Soft sediment habitats dominate, covering over 80% of the banks. These calcium carbonate sediments are in constant production via lithogenic and biogenic processes

FIGURE 1.1: Map of the Bahamas indicating the site of this study in the Exuma Cays Land and Sea Park (ECLSP).


77° W
STRAITS
OF
FLORIDA
NASSAU
ANDROS
ISLAND
EXUMA
SOUND
ECLSP
24° N
GREAT BAHAMA
BANK

(Sealey, 1985). The habitats found in the soft sediments include sandy shoals, algal turfs, and seagrass beds (Table 1.2). Sandy shoals are found in shallow water and may be partly exposed at low tides while algal turfs and seagrass beds are found in deeper water. The mixed algal turf habitats are characterized by sparse populations of calcareous algae. These soft sediment habitats have low epifaunal densities but remain important in overall organic production of the banks because of the large area they cover (Sullivan, 1991).

Hard substrate communities include hard coral reefs, sponge and soft coral reefs, and rocky platforms (Table 1.2). The hard and soft coral reefs occur most frequently in the tidal channels that flow between the cays and the rocky platform occurs along the shores of the cays near tidal channels. These habitats have high species diversity but cover less than 20% of the banks (Sullivan, 1991). Local tides in the park are mixed semidiurnal with a vertical range of 1.7 meters.

1.3 RESEARCH GOALS

The purpose of this study was to 1) use aerial and land-based observations to determine habitat use and feeding periodicities of D. americana and 2) use quantitative measures of stomach contents to describe the diet of D. americana. This study also gives some insight on how large, tropical top predators have successfully adapted to food limited marine environments.

TABLE 1.2: The shallow water habitats found in the Exuma Cays Land and Sea Park. Descriptions taken from Sullivan, 1991.

HABITAT	DESCRIPTIONS
SANDY SHOAL	SOFT SEDIMENT MOBILE BANKS COMPOSED OF COARSE-GRAINED SAND, WITH VERY LITTLE CONSPICUOUS BENTHOS; SOME EXPOSED AT LOW TIDES
ALGAL TURF	SOFT SEDIMENTS COMPOSED OF MODERATELY COARSE SAND; SPARSELY POPULATED WITH CALCAREOUS GREEN ALGAE, AND RED ALGAE AND IN SOME AREAS, SPARSE SEAGRASS.
SEAGRASS BED	SOFT SEDIMENT BEDS COMPOSED OF SMALLER-SIZED SEDIMENTS OF SAND-MUD. SEAGRASSES PREDOMINATE AND MAY COVER LESS THAN 10% TO ALMOST 100% OF THE BOTTOM; IN DEEPER WATER THAN ALGAL TURFS
DEEP CHANNEL	HARD SUBSTRATE COMMUNITIES IN TIDAL CHANNELS BETWEEN CAYS WITH SOFT CORAL/SPONGE AND HARD CORAL PATCH REEFS ANCHORED TO THE CARBONATE PLATFORM.
ROCKY PLATFORM	HARD SUBSTRATE COMMUNITIES FOUND ALONG THE SHORE IN HIGH ENERGY AREAS, DOMINATED BY SPONGES AND SMALL SOFT AND HARD CORALS; SOMETIMES WITH A THIN LAYER OF SAND ABOVE THE CARBONATE PLATFORM.

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CHAPTER 2

AERIAL SURVEYS AND LAND-BASED OBSERVATIONS OF STINGRAY FEEDING HABITS

2.1 INTRODUCTION

Some animals must actively search, capture, and consume many prey items in order to survive; therefore, their foraging strategy must include choices about what to eat, when to eat, and where to eat (Pyke et al., 1977). The searching behavior of an animal involves temporal organization and habitat choice (Bell, 1991). Diana (1979) describes two types of feeding patterns: 1) a synchronous and 2) an asynchronous feeding pattern. The former is one in which the entire population feeds at one time. The latter is one in which members of the population feed at different times. These feeding patterns can be affected by climatic factors, food abundance, and predator abundance (Schoener, 1971). Schoener (1971) theorizes that animals should expand their feeding periods and habitat choice when food is scarce, energy requirements increase, and when food can be best converted into offspring. In an area where available food is proportional to foraging area, the animal should forage in an area just large enough to fulfill its energetic requirements (Schoener, 1971).

Diana (1979) believes that for top predators the feeding interval is short relative to total digestion time. Jones and Green (1977) found that the spiny dogfish, Squalus acanthias, ceases to feed until digestion is complete. Cortes (1987) work on the lemon shark also indicates that, in most cases, feeding ceases until digestion is complete. However, due to their opportunistic feeding behavior, lemon sharks may take another meal prior to complete digestion. Gruber (1984) reported increased activity and metabolic rate for lemon sharks at dusk indicating that they may feed more at this time, but Cortes' (1987) found no such diel feeding behavior.

Habitat choice may depend upon the time and energy available for searching, the probability that continued search will improve the eventual choice, and whether the animal's fitness would benefit from continued search (Bell, 1991). Very little work has been done on feeding periodicity and habitat choice in stingrays. Funicelli (1975) states that the National Marine Fisheries Service collection data indicates a decrease in stingray numbers found on rocky or coral bottom relative to soft bottom habitats. Bigelow and Schroeder (1953) observed that stingrays prefer to feed in soft sediment habitats where they can easily excavate the bottom for their prey.

The Bahama banks are dominated by oolitic soft sediment habitats which are continually being produced biogenically and chemically (Sealy, 1985). The sediment type determines the biological communities in the banks. On the Exuma platform margin, soft sediment communities cover over 80% of the bank area while hard substrate communities cover less than 20%. Soft sediment communities include seagrass beds, mixed algal turfs, and sandy shoals (Table 1.2). Hard substrate habitats include deep channel and rocky platform communities (Table 1.2). The sandy shoals cover the greatest area followed by algal turfs and seagrass beds (Sullivan, 1991).

Seagrass beds in the tropics have been shown to have lower macroinvertebrate abundances than those found in temperate areas (Heck, 1977), but still have greater faunal densities than the more barren sandy shoals (Virnstein, 1987). The shallow soft sediment habitats in the Bahamian banks can be characterized by having low abundances of macroinvertebrates (> 1 cm body length). In these habitats food may be limiting for large predators. Gruber (1982) characterized elasmobranchs as important to the trophic ecology of tropical ecosystems because they are abundant large predators. He also states that food may be a limiting factor for one large tropical elasmobranch, the lemon shark.

The southern stingray, Dasyatis americana, is another large predatory elasmobranch and is among the most abundant in the Bahamas. Understanding the feeding periodicity and habitat utilization of this species will provide valuable information on the trophic ecology of and the role large predators play in shallow tropical marine habitats.

This study uses systematic aerial sampling and land-based observations to describe the feeding periodicity, habitat use, and the density of D. americana in the shallow marine habitats of the Exuma Cays Land and Sea Park in the central Bahamas.

2.2 MATERIALS AND METHODS

All aerial surveys and land-based observations were conducted in the Exuma Cays Land and Sea Park (Figure 1.1). The marine habitats in which stingray feeding was observed included sandy shoals, algal turfs, seagrass beds, and deep channels, and rocky platform. All habitats were characterized from both photo-interpretation of high and low altitude aerial photos (1:48,000 B/W and 1:5000 natural color) and from field surveys (Sullivan, 1991).

2.2.1 Aerial Observations

Aerial observations were flown at two locations in the park during August 1989. A total of six aerial surveys were completed, three at each site. The geometry of the observations made from a high-wing, fixed-gear aircraft is described in Pennycuick and Western (1972) and Pennycuick et al. (1977). The aerial survey methodology used to census large mammal populations in Kenya was modified to observe stingrays in shallow water habitats of the Exumas. Using both island landmarks and LORAN-C, the aircraft was navigated along flight paths at an altitude of 92 meters (maintained by altimeter).

Observers were trained to detect active stingrays that contrasted as dark rhomboids against the light color of the sediment by observing life-sized plastic models. In most cases, the minimum disc width detected by aerial observers was 60 cm. Although smaller actively swimming stingrays may be detected, 60 cm was taken as the lower limit of detection. Thus, the survey detected only large adults.

Two sites were chosen for censusing based on extensive shallow water habitats and previous sightings of stingrays: 1.) a 12 km^2 area around Waderick Wells and White Bay Cays with flight paths covering chiefly the leeward side of the cays (Figure 2.1). Of the 12 km^2, 10.1 km^2 was suitable stingray marine habitat. The remainder was above the high tide mark. This survey area included the area used in the land-based observations. 2.) A 21 km^2 area around Shroud Cay at the north end of the park, selected because of the the large area of shallow marine habitats around the cay (Figure 2.2). Of the 21 km^2, 17.6 km^2 was marine. Morning, midday, and late afternoon censuses were flown over each area. The sampling pattern for both study areas was based on a grid of 1 km by 1 km squares divided into 250m by 250m squares. Each of these smaller squares was covered by one flight path. Both grids were oriented northwest/southeast, parallel to the axis of the islands to maximize the coverage of the shallow shoreline waters.

The locations of stingrays sighted were recorded on maps of the study areas together with the time and flight line number. Marine habitats within the sample grids were previously identified and mapped (Sullivan, 1991). Soft sediment habitats covered over 85% of the survey areas, and provided a light field for easy detection of stingrays from the air. These areas were more conducive to stingray sightings compared with darker seagrass beds, soft coral-sponge reefs or channel areas. A recognized bias exists against detection of stingrays in deeper water or in spatially heterogeneous habitats (i.e., reefs).

Population size estimates were calculated for each survey as done by Pennycuick et al. (1977). Sightings in the survey grids were analyzed as stratified random samples. The larger squares were treated as the strata and the four smaller sampling units within each large square were treated as if randomly positioned.

FIGURE 2.1: The survey grid around Waderick Wells Cay and White Bay Cay. The total area is 12 km^2 and each square is 1 km^2. Arrows indicate directions of flight paths.

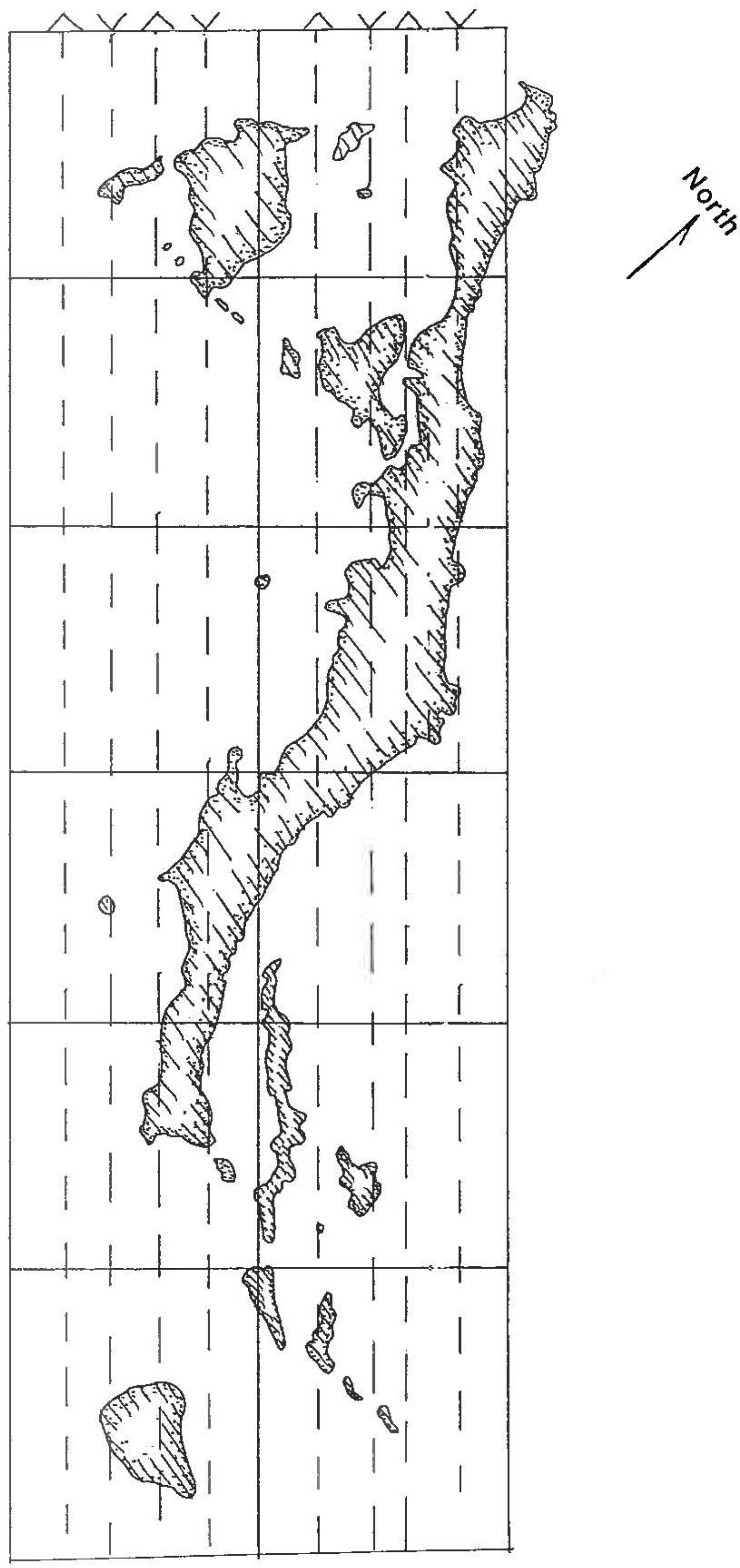
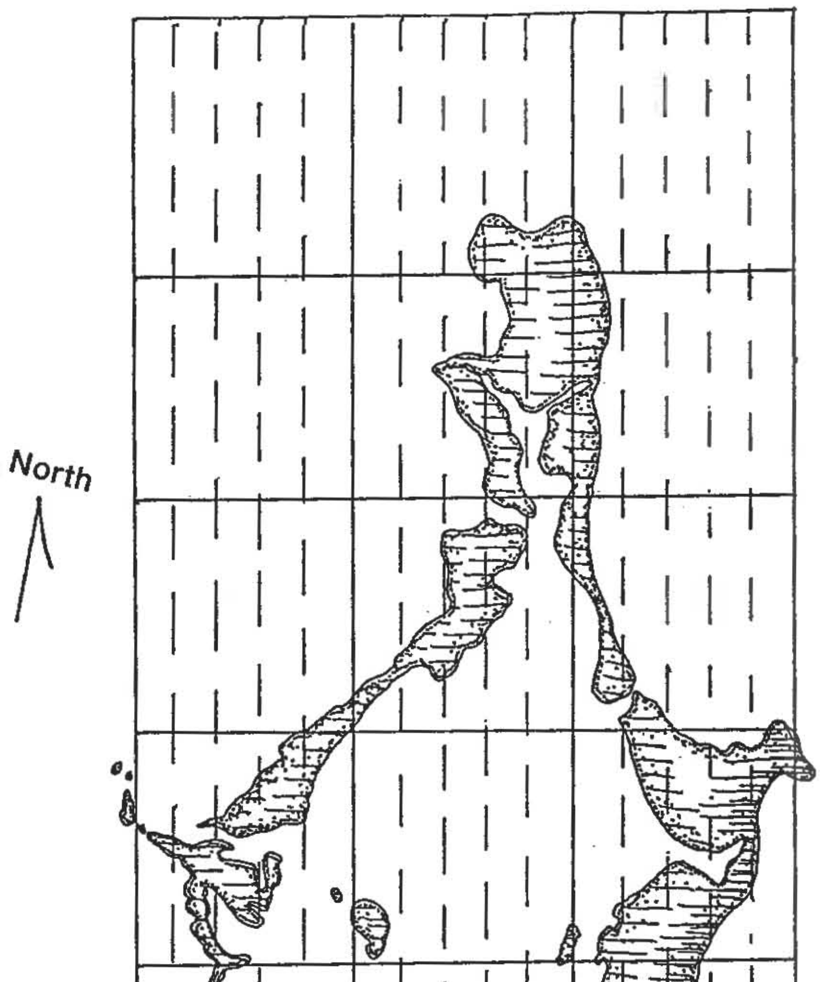

North

FIGURE 2.2: The survey grid around Shroud Cay. The survey area is 21 km^2 and each square is 1 km^2. Arrows indicate directions of flight paths.


North

The population (Y) was estimated using the equation:

$$Y = N * y, \tag{1}$$

where N is the total number of km^2 sample units in the survey grid and y is the mean number of stingrays seen per km^2 during each survey (Pennycuick et al., 1977). The population variance (Var(Y)) was calculated using the equation:

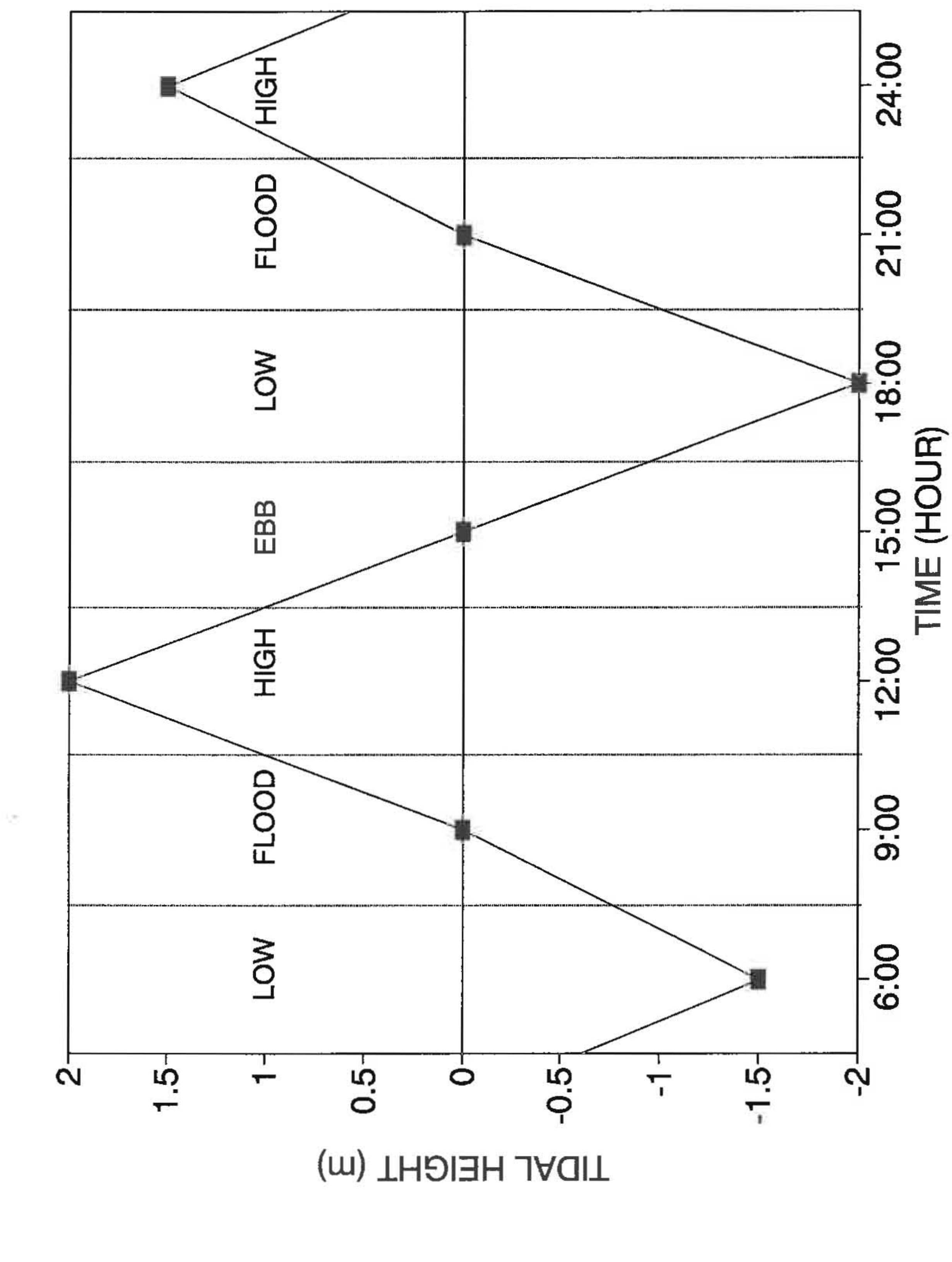
$$Var(Y) = \frac{N(N-n)}{n} s^2, \tag{2}$$

where n is the number of sampling units in the sample and s^2 is the variance within each km^2 block (Pennycuick et al., 1977). The population size for each survey was compared with a student t-test to describe any periodicity in activity relative to time of day (Sokal and Rohlf, 1969).

2.2.2 LAND-BASED OBSERVATIONS

Land-based observations were made from the cupola on top of the park headquarters building on Waderick Wells Cay in April and May 1990 and in January and July 1991. The cupola is 10 meters above the mean tide level and all habitats mentioned above can be clearly seen from this point. A random schedule of hour-long observational periods was used during daylight hours permitting comparison of stingray activity to be with time of day and tidal phase. The day was divided into six 2-hour segments from sunrise to sunset when sufficient light was available to see the study area. The tide was divided into four 3-hour phases: high, ebb, low, and flood (Figure 2.3).

FIGURE 2.3: Graphical representation of the tidal phases in the central Bahamas. Tides are mixed semidiurnal and each tidal phase lasts 3 hours. The high tidal phase runs 1.5 hours before and after the high tide. The ebb tidal phase starts 1.5 hours after the high tide and ends 1.5 hours before the low tide. The low tide runs 1.5 hours before and after the low tide. The flood tide starts 1.5 hours after the low tide and ends 1.5 hours before the high tide.


TIDAL HEIGHT (m)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
LOW
FLOOD
HIGH
EBB
LOW
FLOOD
HIGH
6:00
9:00
12:00
15:00
18:00
21:00
24:00
TIME (HOUR)

Total numbers of stingrays seen were recorded during each observational period. Total ray-minutes were recorded during each observation hour; ray-minutes equal the sum of the total number of minutes each stingray was seen during one observational period, and provided an index of activity. This value could exceed 60 if more than one stingray was seen during the observation period. The sum of the total number of minutes that stingrays were seen in each habitat type was also recorded.

Two assumptions were made to complete this study. First, active stingrays are feeding. Second, all stingrays seen were Dasyatis americana. The second assumption is not entirely correct because at least 5 species of stingrays exist in the Bahamas (Bigelow and Schroeder, 1953), but identification to species during the observations was not possible. Ground truthing was performed over a three year period. During this time as many stingrays as possible were identified by boat patrols with underwater inspection. Of 118 stingrays identified, 107 (or 91%) were D. americana.

Statistical analyses tested for feeding periodicity and habitat preferences as follows. Mean number of stingrays and ray-minutes per observation hour were tested against time of day and tidal phase using a two way ANOVA (Sokal and Rohlf, 1975). Total ray-minutes for each habitat type was compared using an one-way ANOVA. A student-Newman-Kuels test was performed to predict the habitat preferences. Mean numbers of stingrays seen per observation hour for each sampling month were tested with an one-way ANOVA and used to compare seasonal abundances.

2.3 RESULTS

2.3.1 Aerial surveys

Results of the six aerial surveys from the two study sites are shown in Table 2.1. Both survey areas, Waderick Wells and Shroud Cays, had a maximum number of observed stingrays, with similar estimates of population density, in the early morning surveys followed by the late afternoon, then midday surveys. A significant difference exists between densities of stingrays recorded in the morning survey versus the midday survey for both the Waderick Wells area ($t = 4.07$, $P < .05$) and the Shroud area ($t = 3.43$, $P < .05$). Stingray densities also differ significantly between the late afternoon and midday surveys at both Waderick Wells Cay ($t = 2.83$, $P < .05$) and Shroud Cay ($t = 3.84$, P, .05). No significant differences exists between stingrays densities in morning and late afternoon surveys at either the Waderick Wells Cay ($t = 1.76$, $P < .05$) or Shroud Cay ($t = 1.92$, $P < .05$).

The tide was the lowest during the morning survey times and the highest during the late afternoon survey times for both sites. Unequal semidiurnal tides in the central Bahamas experience some lag in bank areas and in mangrove creeks. The exact tidal phase/time of day combination is duplicated only twice a year. These aerial surveys were carried out over three days and represent one tide/time combination, thus, no periodicity in the foraging population size can be estimated for tidal phase.

TABLE 2.1: The information from the six surveys of the two sites. The population estimates are shown for each survey area (Waderick = 10.1 km2 and Shroud = 17.7 km2). The population density is the mean number of stingrays per km2.

SURVEY NUMBER	SURVEY SITE	DATE	TIME	TIDAL PHASE	POPULATION ESTIMATE	POPULATION DENSITY
1	WADERICK	10 AUG 89	0820-0900	LOW	20.9 +/- 5.6	2.07
2	WADERICK	10 AUG 89	1450-1520	HIGH	12.2 +/- 2.7	1.21
3	SHROUD	10 AUG 89	1527-1608	HIGH	11.6 +/- 2.0	1.16
4	SHROUD	11 AUG 89	1126-1200	FLOOD	3.6 +/- 1.23	0.43
5	WADERICK	11 AUG 89	1220-1300	FLOOD	7.6 +/- 2.0	0.36
6	SHROUD	12 AUG 89	0717-0800	EBB	33.1 +/- 13.1	1.87

2.3.2 Land-based observations

A total of 117 hours of land-based observations were made during four sampling periods of 8-12 days: 30 hours in April 1990, 28 hours in May 1990, 28 hours in January 1991, and 31 hours in July 1991. Table 2.2 presents the mean number of stingrays seen and the mean number of ray-minutes per hour of observation for each sampling month. The mean number of stingrays seen per observational hour was used to recognize variations in population size among sampled months. No significant variation in observed population size was found (ANOVA, $F = 2.47$, $P > .05$) suggesting that the population of stingrays remains constant throughout the year (Figure 2.4).

Table 2.3 gives the mean number of stingrays seen and the mean number of ray-minutes per observation hour for each time period during each sampling month, as well as totals for all months. Stingray feeding activity is a function of the number of stingrays seen or the number of ray-minutes per observation period. The greater the number of stingrays or ray-minutes observed per hour, the greater the feeding activity of the population.

Figure 2.5 shows the relationship between feeding activity (total mean number of stingrays seen per observation hour) and time of day. Feeding activity appears to increase during the morning and late afternoon and decrease during midday, but neither mean numbers of stingrays observed (ANOVA, $F = 1.69$, $P > .05$) nor mean numbers of ray-minutes (ANOVA, $F = 1.32$, $P > .05$) differed significantly relative to time of day.

Table 2.4 gives mean number of stingrays and ray-minutes per observation hour for each tidal phase. Figure 2.6 shows the relationship between feeding activity (total mean number of stingrays seen per observation hour) and tidal

TABLE 2.2: Number of observation hours, mean numbers of stingrays and ray-minutes per observation hour during each sampling month and totals for all months

	JANUARY	APRIL	MAY	JULY	TOTAL
NO. OF HOURS	28	30	28	31	117
MEAN NUMBER OF STINGRAYS / HOUR	1.64	1.93	2.47	1.42	1.84
MEAN NUMBER OF RAY-MINUTES / HOUR	12.79	21.68	18.80	18.35	17.50

FIGURE 2.4: Population variance between sampling months based on the mean number of stingrays seen per observation hour. Error bars indicate ± 1 S.E. from the mean.

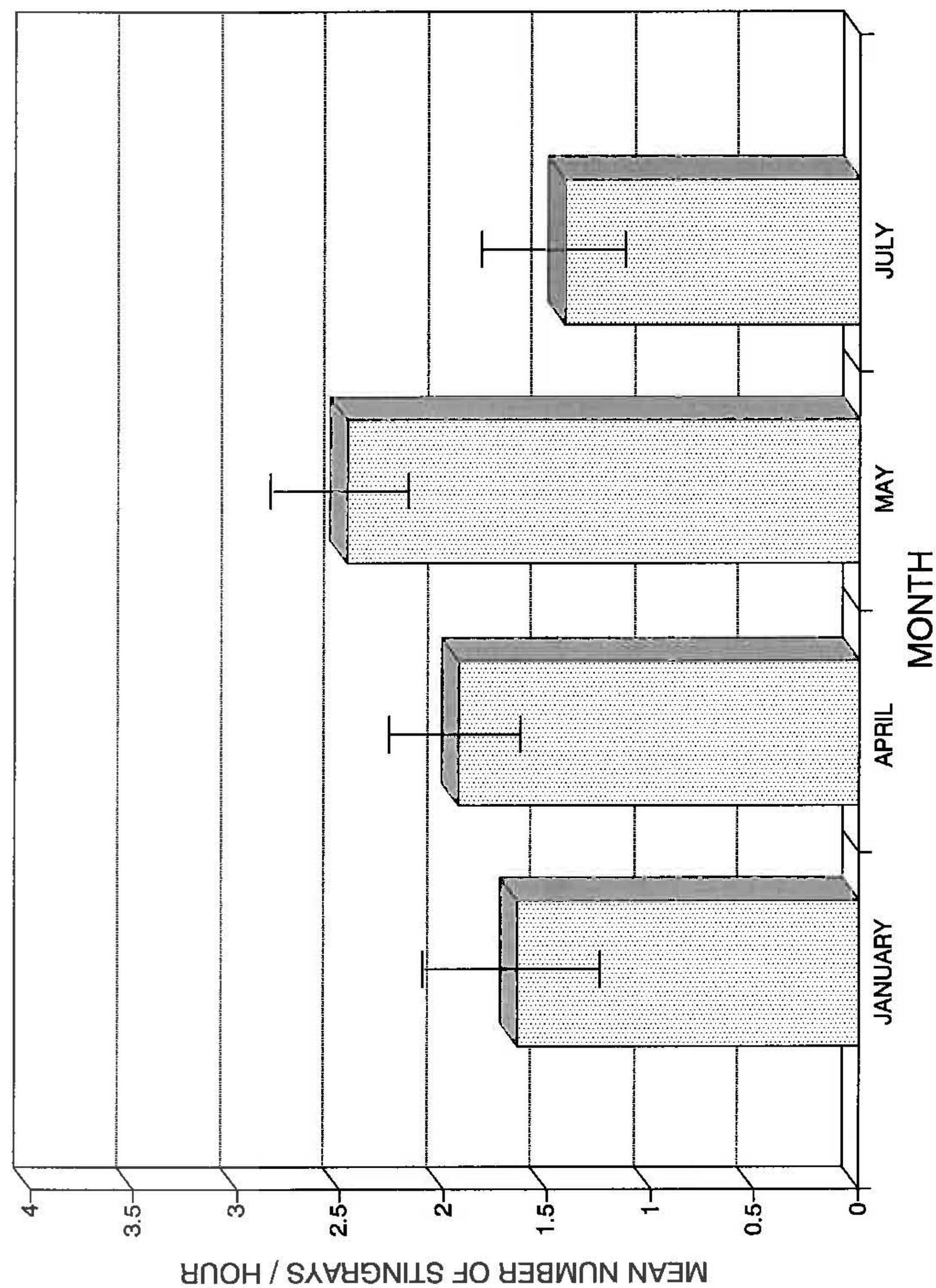
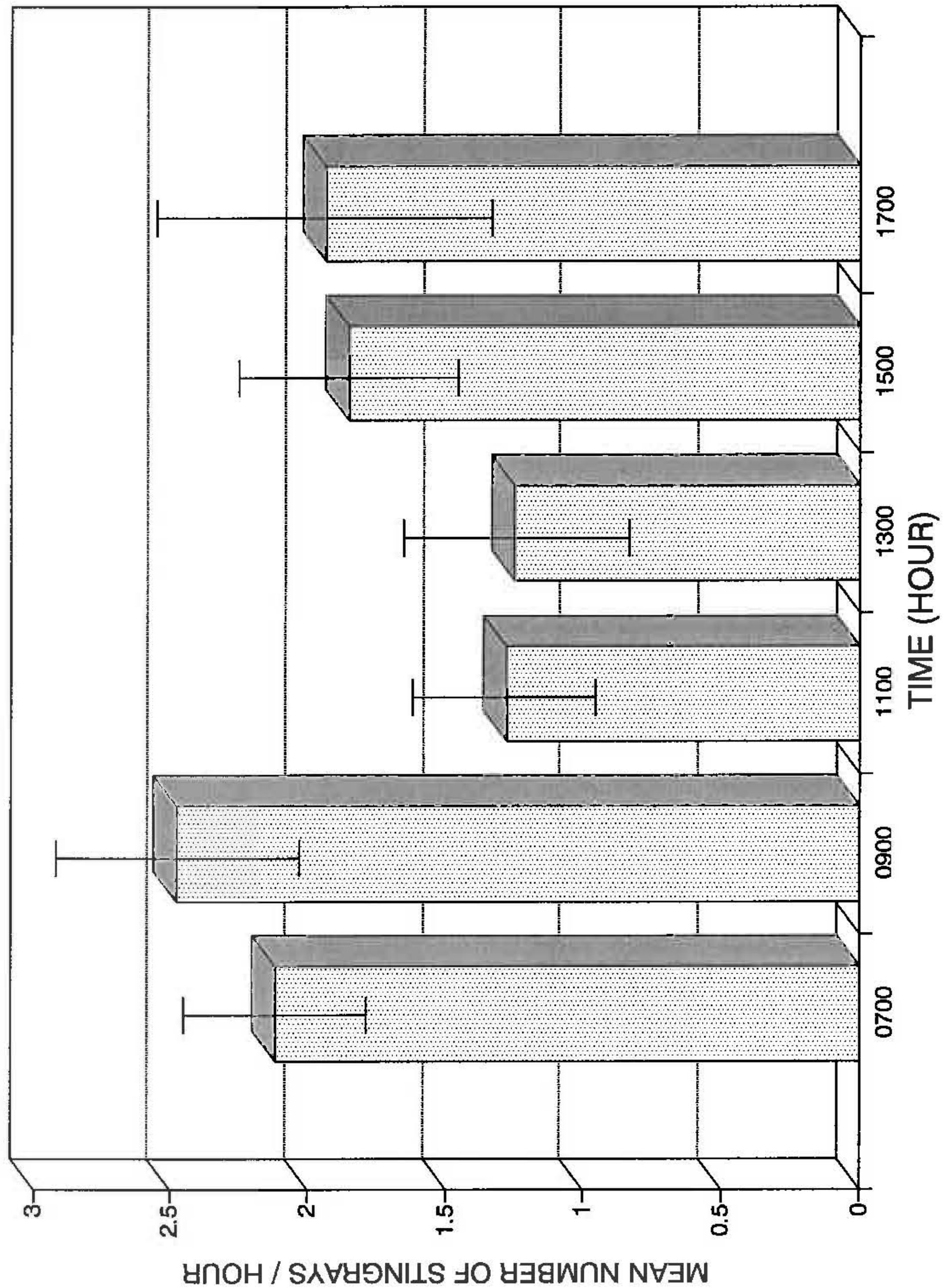

MEAN NUMBER OF STINGRAYS / HOUR
0
0.5
1
1.5
2
2.5
3
3.5
4
JANUARY
APRIL
MAY
JULY
MONTH

TABLE 2.3: Mean number of stingrays (NO.) and ray-minutes (R-M) per observation hour during each time period for each sampling month and totals for all months.

TIME	JANUARY		APRIL		MAY		JULY		TOTAL	
	NO.	R-M	NO.	R-M	NO.	R-M	NO.	R-M	NO.	R-M
0700-0900	1.00	7.00	3.33	41.00	2.33	23.33	1.33	10.50	2.12	21.88
0900-1100	2.28	18.28	2.00	12.33	2.33	20.33	3.20	50.80	2.48	25.76
1100-1300	0.50	1.00	1.60	9.80	2.00	15.00	1.00	11.40	1.28	9.44
1300-1500	1.00	13.66	0.50	9.17	3.50	12.50	1.40	23.20	1.25	14.81
1500-1700	2.71	21.28	0.25	1.75	2.60	18.60	1.00	13.00	1.85	15.05
1700-1900	2.00	2.67	4.00	53.25	2.75	15.25	0.80	2.40	1.94	18.38

FIGURE 2.5: Feeding activity based on the total mean number of stingrays seen per observation hour for each time period. Error bars indicate ± 1 S.E. from the mean.

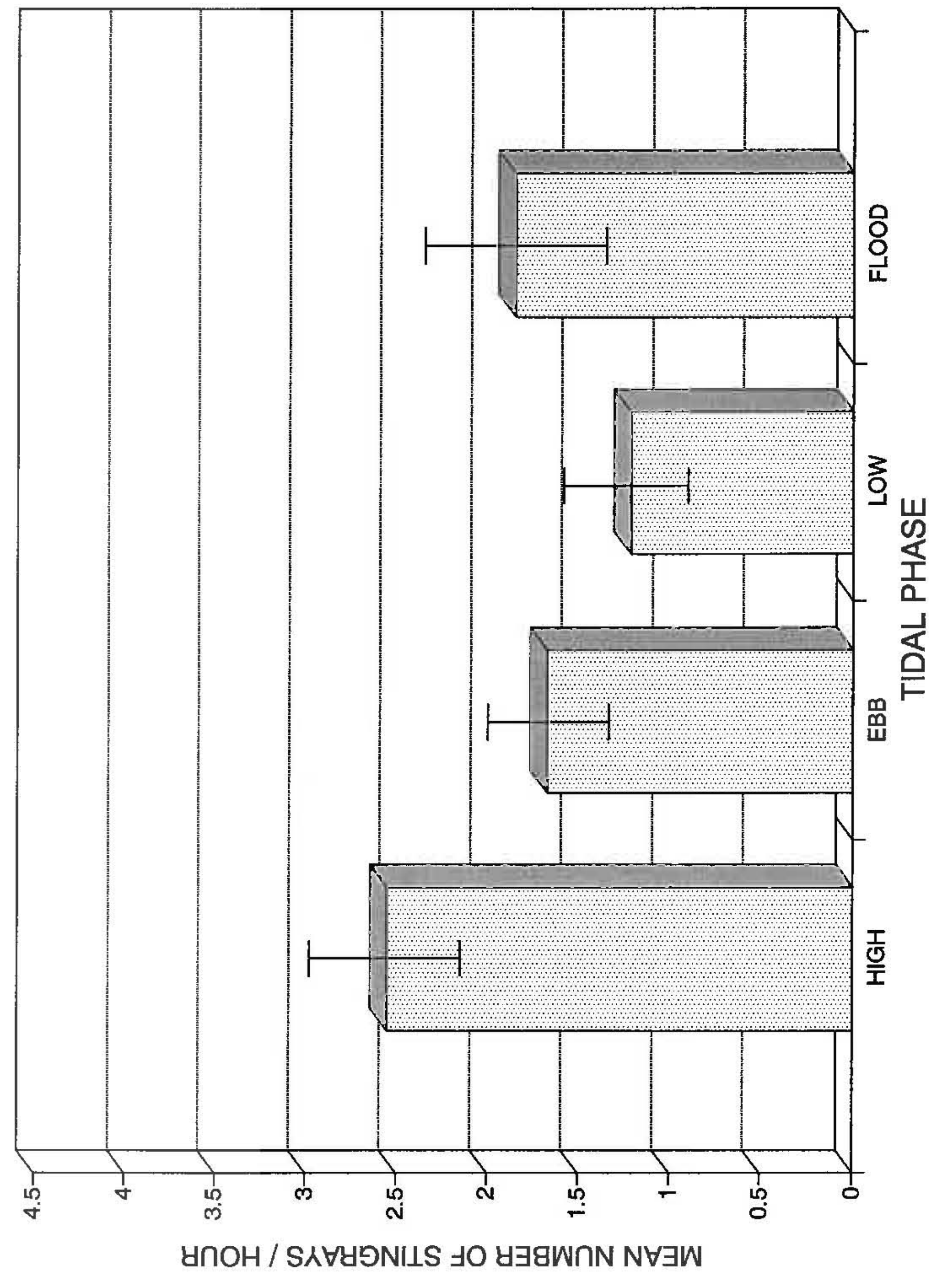


MEAN NUMBER OF STINGRAYS / HOUR
0
0.5
1
1.5
2
2.5
3
TIME (HOUR)
0700
0900
1100
1300
1500
1700

TABLE 2.4: Mean numbers of stingrays seen (NO.) and ray-minutes (R-M) per observation hour during each tidal phase for each sampling month and totals for all months.

TIDE	JANUARY		APRIL		MAY		JULY		TOTAL	
	NO.	R-M	NO.	R-M	NO.	R-M	NO.	R-M	NO.	R-M
HIGH	2.57	22.00	3.83	44.17	3.00	22.88	1.00	17.50	2.55	24.86
EBB	2.17	12.33	1.33	11.22	1.57	17.00	1.83	16.17	1.67	14.80
LOW	0.89	7.00	1.00	8.60	2.60	22.40	0.83	10.83	1.21	10.82
FLOOD	1.17	11.17	1.75	24.75	2.33	17.00	2.17	35.83	1.85	22.38

FIGURE 2.6: Feeding activity based on the total mean number of stingrays seen per observation hour for each tidal phase. Error bars indicate $\pm$ 1 S.E. from the mean.



MEAN NUMBER OF STINGRAYS / HOUR
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
HIGH
EBB
LOW
FLOOD
TIDAL PHASE

phase. The greatest feeding activity occurred during the high tidal phase while the lowest feeding activity occurred during the low tides. Mean numbers of stingrays observed differed significantly relative to tidal phase (ANOVA, $F = 3.62$, $P < .05$), but no significant differences were found relating the mean number of ray-minutes at different tidal phases (ANOVA, $F = 1.14$, $P > .05$).

Effects of time of day and tidal phase on feeding activity were determined for each sampling month. No sampling month was shown to have any significant difference in the activity versus time of day except April. In April, a significant difference was found between the higher feeding activities during the early morning (0700 -0900) and late afternoon (1700 -1900), relative to the lower midday activities for both the mean number of stingrays observed (ANOVA, $F = 3.97$, $P < .05$) and mean number of ray-minutes (ANOVA, $F = 5.01$, $P < .05$). This may reflect a sampling bias because both time periods contained observations from periods of high or flood tides only, which were shown to have the highest numbers of stingray observed (Figure 2.6).

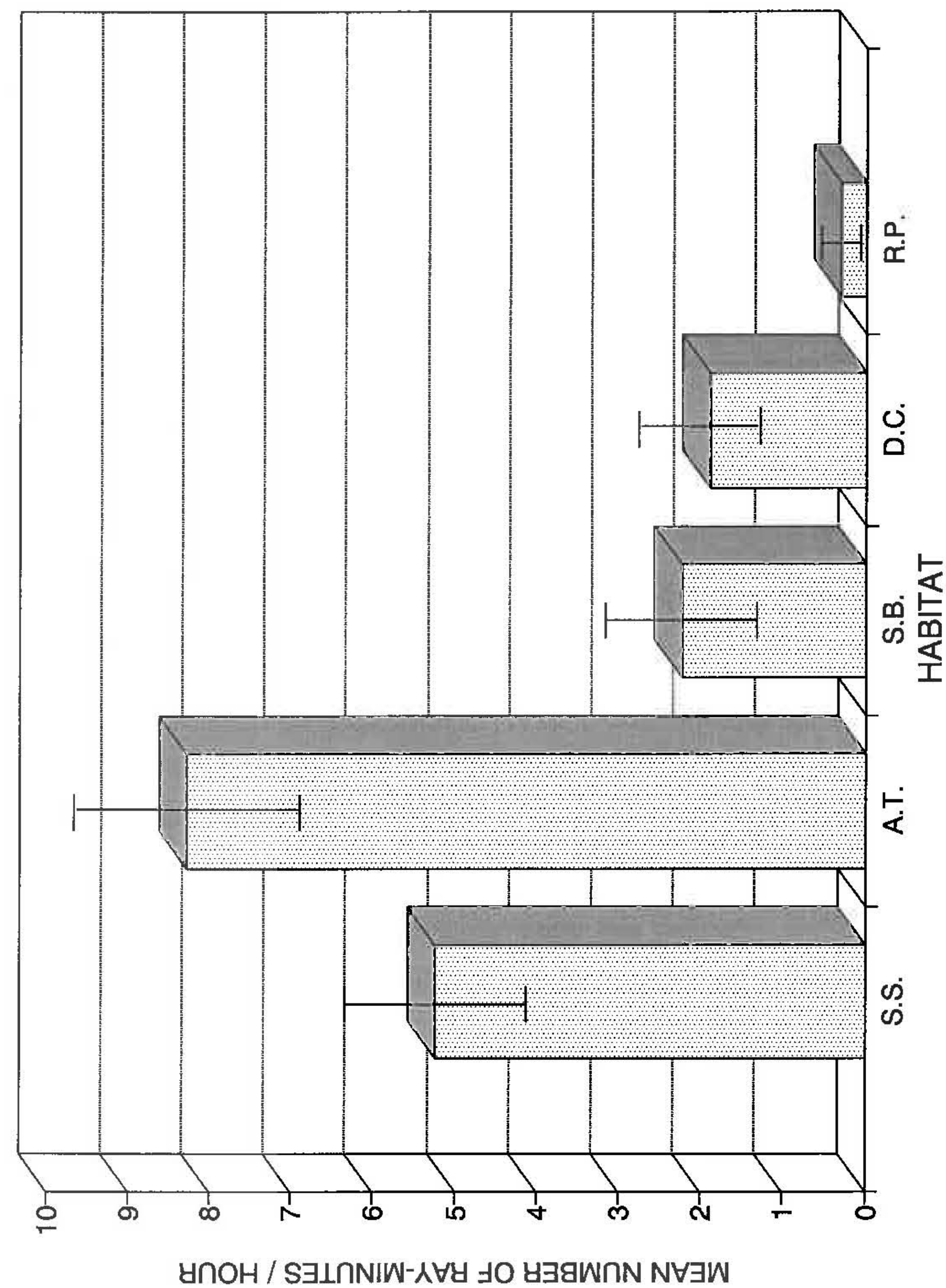
Even though feeding activity (total mean numbers of stingrays seen) was significantly higher during the high tidal phase for the total of all the sampling months, no relation of tidal phase and feeding activity was found for any individual month. For April and January, there was weak correlation between feeding activity (mean number of stingrays seen and ray-minutes) and tidal phase, with increased feeding activity at high tide (ANOVA, April: $F = 2.87$, $P < .10$ and $F = 2.98$, $P < .10$; January: $F = 2.68$, $P < .10$ and $F = 2.60$, $P < .10$).

Table 2.5 gives the mean number of ray-minutes per observation period relative to each habitat type. Figure 2.7 indicates that the southern stingray spends more time feeding in the soft sediment algal turf and sandy shoal habitats.

TABLE 2.5: Mean number of ray-minutes per observation period and the percentage of the total foraging time spent in each habitat for each sampling month and the total for all months.

HABITAT	JANUARY		APRIL		MAY		JULY		TOTAL	
	R-M	%	R-M	%	R-M	%	R-M	%	R-M	%
ALGAL TURF	8.11	63.40	12.14	58.20	7.40	38.60	5.77	31.30	8.27	46.30
SANDY SHOAL	2.68	20.90	3.14	15.10	9.20	48.00	5.58	30.30	5.23	29.30
SEAGRASS	0.50	3.90	2.86	13.70	1.50	7.80	3.71	20.10	2.22	12.20
ROCKY PLATFORM	0.21	1.70	0.14	0.68	0.37	1.90	0.42	2.30	0.29	1.60
DEEP CHANNEL	1.29	10.00	2.57	12.30	0.70	3.60	2.94	15.90	1.90	10.50

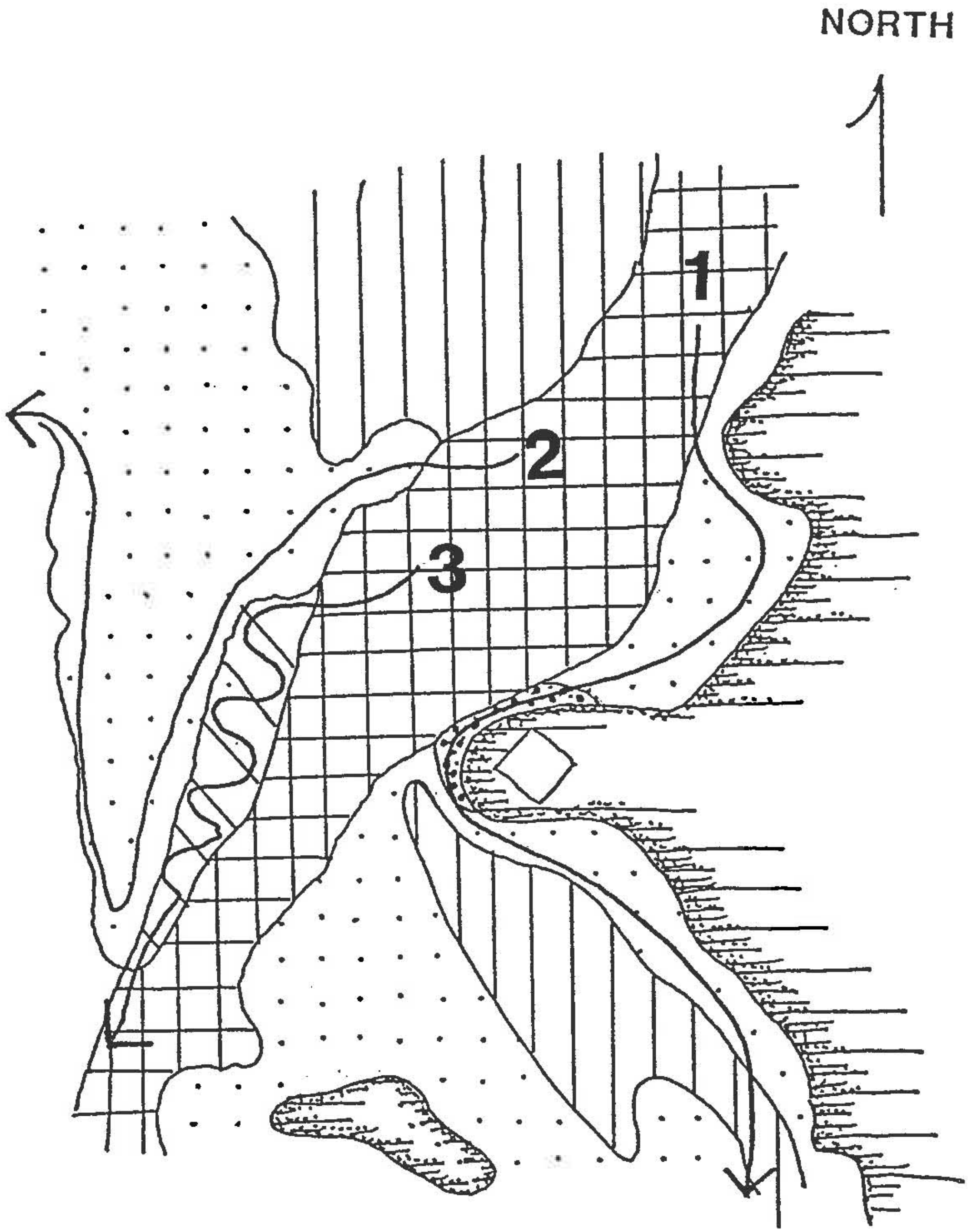
FIGURE 2.7: Habitat utilization based on the total mean number of ray-minutes per observation hour for each habitat type. Error bars indicate ± 1 S.E. from the mean. (Algal turf = A.T., Sandy shoal = S.S, Seagrass bed = S.B., Deep channel = D.C., Rock platform = R.P.)


MEAN NUMBER OF RAY-MINUTES / HOUR
0
1
2
3
4
5
6
7
8
9
10
S.S.
A.T.
S.B.
D.C.
R.P.
HABITAT

A one-way ANOVA showed significant differences between the amount of time spent feeding in each habitat ($F = 9.70$, $P < .05$). A student-Newman-Kuels (SNK) test determined that the mean number of ray-minutes spent in algal turf habitats was significantly greater than the ray-minutes spent in the other habitat types. The SNK test also showed that the time spent in the sandy shoal habitats was significantly greater than in the seagrass bed, deep channel, or rocky platform habitats. The seagrass, deep channel, and rocky platform habitats were not shown (SNK) to differ significantly in ray-minutes. No significant difference was determined in habitat utilization between the sampling months (ANOVA, $F = 0.58$, $P > .05$).

Search patterns of feeding stingrays were recorded by mapping the movement of the stingrays among habitats during the observation periods. Figure 2.8 shows the map of the land-based observation area and the common swimming paths taken by foraging stingrays. The most common foraging paths included: 1) stingrays that traced the outline of a soft sediment habitat, 2) stingrays that swam along the shoreline of the islands near the water's edge, or 3) stingrays that made alternating passes through a soft sediment habitat. Time spent in deep channel (hard substrate) habitats was primarily for travel to another soft sediment habitat. Rarely were stingrays seen sitting inactive lying on the bottom; stingrays seen during the observations were actively foraging.

FIGURE 2.8: Map of the land-based observation area showing the habitats and common foraging paths (see text 1, 2, and 3) used by the feeding stingrays. (Habitat Legend: Light Dots = Algal Turf, Vertical Lines = Sandy Shoal, Diagonal Lines = Seagrass Bed, Cross Hatch = Deep Channel, Heavy dots = Rocky Platform)


NORTH
1
2
3

2.4 DISCUSSION

Aerial observations made during three days in the summer at both survey areas indicate that greater numbers of stingrays feed in the morning and late afternoon hours and fewest feed at midday. Land-based observations throughout the year also show a general trend towards greater feeding activity in the morning followed by late afternoon, but the differences were not significant. The aerial surveys provide a count of stingrays feeding at one time and cover a large area (combined area of 32 km^2) dominated by shallow, soft sediment habitats. The land observations provide a long term look at numbers of feeding stingrays in a much smaller area (0.25 km^2).

Differences may exist between stingrays populations sampled during land-based observations and those surveyed by plane for several reasons. More stingrays were seen per hour (x = 1.85 individuals) in the smaller land observation area (0.25 km^2) than were expected from the aerially estimated population densities (2.00 individuals/km^2). More smaller stingrays were recorded during the land-based observations than during the aerial surveys. The land observation area is located in the Park headquarters anchorage where human activity is more concentrated than in the large aerial survey areas. The land observation area was chosen because it had a variety of habitats that were close together in a small area between cays, thus providing an ideal place to map stingray movements. The proximity of these habitats to the two cays and the presence of a deep tidal channel through the area may also concentrate stingrays in the area. The deep channel habitats covered a greater percentage of the land observation area than in the aerial survey areas. Short term movements of the stingrays from the deep channels onto the shallow habitats were recorded by the land-based observations but were not for the aerial surveys.

The aerial survey showed that during a short period of time or in some seasons, the stingrays can show time of day feeding periodicity. The time of the aerial surveys was in the summer when the water temperatures in the shallow habitats during the middle of the day may be in excess of 34°C, likely near the thermal limit of stingrays. The lack of significant feeding periodicity shown by the land-based observations indicates that in the long term, through all seasons, many factors in combination with time can influence when a stingray feeds (i.e. temperature, tide, movement of prey).

No information was obtained on nocturnal activity, but capture data on the bluntnose stingray, D. sayi, and D. americana suggests that they are active at night (Snelson et al., 1981; Snelson et al., 1989). Both aerial surveys and land-based observations illustrate that some portion of the southern stingray population in the Exumas is feeding at all times during the day. Their population, therefore, exhibits an asynchronous feeding behavior.

Studies on the tropical lemon shark, Negaprion brevirostris, also showed no feeding periodicity (Cortes, 1987). Cortes found that populations of young lemon sharks in Bimini, Bahamas and, in the Florida Keys were also asynchronous feeders with no diel feeding preference. Laboratory studies on the metabolism of the lemon shark predicts that they may start to feed more actively at dusk (Gruber, 1984), but Cortes (1987) found that they would feed at any time and attributed this to their opportunistic behavior.

Stingrays were seen feeding during all tidal phases with a preference to forage during the high tidal phase (Table 2.4). Stingrays may increase their feeding activity during the high tide when more prey items are exposed in shallow habitats. Cortes (1987) found no find any tidal preference for the lemon shark, but it does not feed on benthos as do the stingrays.

The southern stingray spends most of its foraging time in soft sediment algal turf and sandy shoal habitats. Snelson et al. (1988) reported that the Atlantic stingray, D. sabina, was observed most often in soft sediment sand and silt habitats in the Indian River Lagoon system, Florida. Both of these soft sediment habitats have lower abundances of macroinvertebrates than the seagrass habitats (Abele, 1974; Virnstein, 1987), but cover the greatest area of the shallow banks in the Exuma Cays (Sullivan, 1991). The observed deliberate foraging patterns through the soft sediment habitats further support the finding that the southern stingray has a preference for feeding in the soft sediment habitats. The southern stingray is able take advantage of the most abundant habitat.

Stingrays were observed in all available habitats (Table 2.5). Stingrays are active searchers and must transit through less attractive habitats to get to preferred habitats. Animals must also sample alternative habitats in order to make a choice and, therefore, must spend some time in habitats which may prove less profitable (Goss-Custard, 1990).

Recording observations during 4 different months allowed for an estimate of seasonal population variance. Greatest numbers were seen in the spring months of April and May, but abundances did not differ significantly. Several dasyatid exhibit seasonal migrations. Struhsaker (1969) states that the roughtail stingray, D. centroura, migrates to the waters off the southeastern states from the middle Atlantic states and New England in the winter. Snelson et al. (1988) found seasonal movement of D. sabina during the winter months in the Indian River Lagoon system. D. sayi to migrates seasonally in the northern part of it's range (Bigelow and Schroeder, 1953; Funicelli, 1975), but was not shown to migrate in the Indian River Lagoon (Snelson, 1989). Struhsaker (1969), Schwartz and Dahlberg (1978), and Snelson et al. (1988) all found that water temperature was the critical factor governing stingrays migrations; all found that stingrays preferred a water temperature greater than 15^{o}C. Funicelli (1975) found that D. americana occurred most often in waters that were warmer than 15^{o}C in the Gulf of Mexico. In the Exuma Cays the water temperature never approaches 15^{o}C and averages 25^{o}C in January and 29^{o}C in July (Park records). Such lack of strong seasonal fluctuations in water temperature may explain the absence of seasonal abundance patterns.

As an opportunistic feeder, D. americana does not show any strong feeding periodicity in terms of time of time of day. D. americana is able to utilize the habitats that dominate the shallow waters of the Exumas. It is this opportunistic behavior that allows D. americana to be the largest, and apparently most abundant predator in the shallow marine habitats of the central Bahamas.

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CHAPTER 3

DESCRIPTION OF THE DIET AND FEEDING HABITS OF THE SOUTHERN STINGRAY USING QUANTITATIVE STOMACH CONTENT ANALYSIS

3.1 INTRODUCTION

Trophic dynamics of an ecosystem can be better understood by studying the diet and feeding habits of its large predators (Ivlev, 1961; Gruber, 1982). The elasmobranchs are one of the most abundant and ubiquitous groups of large predators in marine tropical environments; studies on the trophic ecology of this environment must take this group into account (Gruber, 1982).

Study of the diet from stomach content analysis is a common way of investigating fish ecology (Berg, 1979; Hyslop, 1980). Many studies have used stomach content analysis to determine food and feeding habits of fish in regards to community trophic relationships (Blaber and Bulman, 1987; Parrish et al., 1986; Edwards and Bowman, 1979). Other studies have used stomach content analysis to describe the foraging strategy of a fish in its environment (Scrimgeour and Winterbourn, 1987; Greenberg and Holtzman, 1987; Pinkas et al., 1971; George and Hadley, 1979; Cowen, 1986).

Through analysis of stomach contents, quantitative measurements of the importance individual food types contribute to overall diet can be calculated. Numerical, volumetric, gravimeteric, and occurrence methods are available to quantify stomach contents (Berg, 1979; Hyslop, 1980). Each of these methods has its own advantages and disadvantages. The numerical method records the number of individuals in each food category as a percentage of the total number of food categories (Berg, 1979; Hyslop, 1980). This method provides no biomass estimates and can over estimate the importance of numerous small items (Pinkas et al., 1971; Hyslop, 1980).

Volumetric and gravimetric methods use the percent volume and weight that each food category contributes to the total volume and weight of all food categories. These methods do give an estimate of the biomass importance of the food categories, but measurement difficulties may introduce errors (Hyslop, 1980). The gravimetric method can also be used to determine the fullness of the digestive tract (Berg, 1979; Hyslop, 1980). Total weight of stomach contents is divided by total weight of the fish. This value, when related to the time or tide of capture, can be used to determine feeding periodicity (Berg, 1979; Hyslop, 1980).

One of the simplest methods of dietary analysis is to record the percent of stomachs that contain a particular food category (Berg, 1979; Hyslop, 1980). This occurrence method is quick, but gives little information on the relative amount or bulk each food category contributes (Hyslop, 1980). The occurrence method used alone may also introduce sampling errors (Pinkas et al., 1971).

Because of the problems associated with using any of the quantitative measures alone, several investigators have combined methods to give a more representative measure of the contribution of each food category to the diet. Pinkas et al. (1971) developed the index of relative importance (IRI) which incorporates percent number, volume, and occurrence of each food category. George and Hadley (1979) developed the relative importance index (RI) based on percent number, weight, and occurrence.

Quantitative measurements of stomach contents have frequently been used to describe feeding habits of elasmobranchs (Matallanas, 1982; Lyle, 1983; Talent, 1976; Medved and Marshal, 1982; Cortes, 1987) Lyle (1983) used numeric and gravimetric measures to describe the dogfish, Scyliorhinus canicula, as an opportunistic feeder. Talent (1976) used the index of relative importance (IRI) to describe the feeding habits of the leopard shark, Triakis semifasciata, which was characterized as an opportunistic feeder. Cortes (1987) used both the index of relative importance (IRI) and the relative importance index (RI) and found that lemon sharks, Negaprion brevirostris, are opportunistic feeders that prey on the most abundant and available organisms. He found no prey preference or feeding patterns relative to time of day or tidal phase.

Opportunistic or generalist feeders that do not limit themselves to certain prey or times of feeding may be more successful in food-limited environments (Emlen, 1966; MacArthur and Pianka, 1966; Schoener, 1971;). Stingrays of the family Dasyatidae are large, abundant elasmobranchs in tropical marine environments (Bigelow and Schroeder, 1953). Off the coast of Florida and in the Bahamas, the southern stingray, Dasyatis americana, is one of the largest and most abundant dasyatid stingrays.

Previous work on the biology and ecology of dasyatid rays includes seasonal distribution, reproduction, and movement of several species (Gunter, 1961; Struhsaker, 1969; Schwartz and Dahlberg, 1978; Snelson et al., 1988; Snelson et al., 1989;). Several studies briefly discuss the diet of stingrays, but give little quantitative information (Struhsaker, 1969; Snelson and Williams, 1981; Thorson, 1983;). Hess (1961) discusses the food habits of Dasyatis sayi and Dasyatis sabina in Delaware Bay and Babel (1969) gives quantitative information on the diet and feeding habits of the round stingray, Urolophus halleri, off the coast of California. A study on the food habits of Virgin Island reef fishes by Randall (1967) includes the only quantitative information on the diet of the southern stingray in the tropics; the most important food items were fish (22% by volume), sipunculans (21%), crabs (18%), and polychaetes (17%).

The purpose of this study is to quantitatively describe the diet and feeding habits of the southern stingray in a tropical environment via stomach content analysis. This analysis focuses on the quantitative contribution of fishes and invertebrates to stingray diet as related to time of day and tidal phase.

3.2 MATERIALS AND METHODS

3.2.1 Stingray Collection

Eighteen stingrays were collected in January 1991 by spearfishing. Sixteen individuals were collected within the park boundaries and two just south of the park. Scheduled patrols from a small boat were conducted throughout the daylight hours and tidal cycle. Patrols were also scheduled to permit the greatest coverage of the park. All stingrays were speared in the cranium; thus pithing accompanied by cervical dislocation served as the mode of euthanasia. Stingrays larger than 1.5m in disc width and those in water deeper than 2m were not sampled due to safety and handling considerations.

Time, location, sex, and habitat were recorded for each stingray at the time of capture. Disc width, total length and gape were measured to the nearest millimeter. Total body weight was measured to the nearest 250 grams on a hanging scale. The total digestive tract length was measured to the nearest millimeter. The stomach and intestine were removed and injected with Bouins' solution, then wrapped in cheese cloth and preserved in 10% buffered formalin for laboratory analysis.

3.2.2 Quantitative Measures

The following quantitative measurements were made in the laboratory: 1) Full stomach and intestine weights: all stomachs and intestines were blotted dry and weighed on an electronic scale to the nearest 0.01 gram, 2) Empty stomach and intestine weights: stomach and intestine were blotted dry and weighed after emptying them of their contents, 3) Stomach contents volume: volume of all the contents were measured to the nearest 0.1 ml by water displacement in a graduated cylinder, 4) Stomach contents weight: all content items were blotted dry and weighed to the nearest 0.01 gram, 5) Stomach fullness: relative fullness was measured by dividing the total stomach contents weight of each stingray by its total body weight (g/kg) (Berg, 1979).

To relate stomach fullness against time of day, a day was divided into five two-hour periods: 0700 to 0900, 0900 to 1100, 1100 to 1300, 1300 to 1500, and 1500 to 1700. The tidal cycle was divided into four, three-hour phases; high, ebb, low, and flood (Figure 2.3) and was used to relate stomach fullness against tide.

Stomach contents were separated and identified to the lowest possible taxonomic level. Published keys were used for the identification of crustaceans (Manning, 1969; and Abele and Kim, 1986). Teleosts were identified based on species descriptions in Robbins, et al (1986). Bivalve and gastropod molluscs and annelids were identified with the help of Dr. Charles Messing, Nova University.

The importance of different prey taxa in the diet of the stingrays was quantified by the following methods: 1) the numerical importance (%N) is the number of items of each taxon expressed as a percentage of the total number of content items, 2) the gravimetric importance (%W) is the percent weight of each taxon relative to the total weight of all stomach contents, 3) volumetric importance (%V) is the percent volume each taxon contributes to the total volume of all stomach contents, 4) the frequency of occurrence (%F) is the percentage of all stomachs that contain a certain content item (Pinkas et al., 1971; George and Hadley, 1979; Hyslop, 1980; Allen, 1982; and Cortes, 1987). The sum of the %F values for each stomach exceeded 100% because more than one item was found in each stomach. The above measurements were used to calculate indices which indicate selectivity in the diet of the stingrays. The relative importance index (RI) of each food type is calculated from the absolute importance index (AI):

$$AI = \%F + \%N + \%W \quad (1)$$

and

$$RI = 100 * AI / \Sigma\ AI \quad (2)$$

and is expressed as a percentage of the diet (George and Hadley, 1979). The index of relative importance (IRI) includes the volumetric importance and is calculated as:

$$IRI = (\%N + \%V) * \%F \quad (3)$$

where the importance of an item is directly related to the size of the value (Pinkas et al., 1971).

To test for feeding periodicity, stomach fullness was tested against time of day and tidal phase with a one-way analysis of variance (ANOVA). Regression analyses were performed on mean weight of the most important prey taxon against stingray body weight and gape width in order to test for food size preferences.

3.3 RESULTS

Twenty-six stingrays were observed during 30 hours of patrols and 20 were collected (Table 3.1). The size of the stingrays ranged from 2 to 23 kg and averaged 11.5 kg. The disc widths ranged from 37.0 cm to 101.5 cm with an average of 69.9 cm. Fourteen of the stingrays collected were female, three of which were immature (disc widths less than 70 cm). One of the males was immature having a disc width of 37 cm and a clasper length of 2.2cm. Two males, one with a disc width of 41.4 cm and the other 45 cm, were smaller than previously reported as being mature (Bigelow and Schroeder, 1953; Funicelli, 1975). These two males had clasper lengths of 9.6 cm and 11.3 cm, respectively, suggesting that they were mature. The remaining two were of a different genus (Himantura) and were not included in this study. The six additional stingrays that were sighted were not collected because of their large size. All the stingrays were collected from soft sediment habitats: 13 from algal turf, 4 from sandy shoal, and 1 from a seagrass bed.

Quantitative measurements of the stomach contents are shown in Table 3.2. A total of 65 prey categories belonging to 15 families in 4 phyla were identified. Figures 3.1 through 3.6 show the quantitative measures of the major prey categories. Crustaceans were the dominant food group by number (76.4%), wet weight (58.9%), and volume (59.7%), and occurred in 100% of the stomachs. Teleost were the next most important group in number (10.9 %), wet weight (18.3%), and volume (17.5%), and occurred in 83.3% of the stomachs. Molluscs, annelids, and plant material followed in importance. Indices of importance gave similar results, with crustaceans composing 39.5% (RI) of the stingrays diet and having an index of relative importance (IRI) of 14,393.5. Teleosts were next in importance followed by the molluscs, annelids,

TABLE 3.1: Collection information and morphometrics on the 18 southern stingrays collected in the Exuma Cays Land and Sea Park, central Bahamas, in January, 1991

STINGRAY NUMBER	TIME	TIDAL PHASE	HABITAT	SEX	CLASPER LENGTH (cm)	DISC WIDTH (cm)	BODY WEIGHT (kg)	MOUTH GAPE (cm)	STOMACH CONTENTS WEIGHT (g)	STOMACH FULLNESS (g/kg)
1	14:40	EBB	ALGAL TURF	FEMALE		101.50	N\A	8.10	25.35	N/A
2	08:05	LOW	ALGAL TURF	FEMALE		81.00	16.60	7.80	44.60	2.69
3	09:39	FLOOD	SANDY SHOAL	FEMALE		81.40	16.86	7.50	47.38	2.81
4	13:50	HIGH	ALGAL TURF	FEMALE		82.50	16.55	7.60	32.68	1.97
5	08:20	LOW	SANY SHOAL	FEMALE		83.00	17.59	7.30	11.23	0.64
6	11:30	FLOOD	ALGAL TURF	MALE	2.20	37.00	1.82	3.00	6.30	3.46
7	11:30	FLOOD	ALGAL TURF	FEMALE		42.00	2.73	4.30	3.04	1.11
8	15:00	HIGH	SEAGRASS	FEMALE		90.30	22.91	7.70	35.68	1.56
9	10:30	LOW	SANDY SHOAL	FEMALE		48.90	3.14	4.20	5.72	1.82
10	11:15	FLOOD	SANDY SHOAL	FEMALE		78.40	13.55	5.50	24.84	1.83
11	11:40	FLOOD	ALGAL TURF	MALE	11.30	45.00	2.77	4.20	5.68	2.05
12	11:40	FLOOD	ALGAL TURF	FEMALE		81.30	14.50	5.70	22.58	1.56
13	12:10	FLOOD	SANDY SHOAL	MALE	9.60	41.40	2.00	3.80	8.80	4.40
14	15:05	HIGH	ALGAL TURF	MALE	8.30	53.40	4.64	5.10	47.29	10.19
15	15:40	HIGH	SANDY SHOAL	FEMALE		83.50	16.91	6.60	83.00	4.91
16	08:13	EBB	ALGAL TURF	FEMALE		67.60	N/A	4.90	3.06	N/A
17	08:35	EBB	ALGAL TURF	FEMALE		88.90	20.18	7.30	4.95	0.25
18	08:55	EBB	ALGAL TURF	FEMALE		72.70	12.10	5.90	8.43	0.70

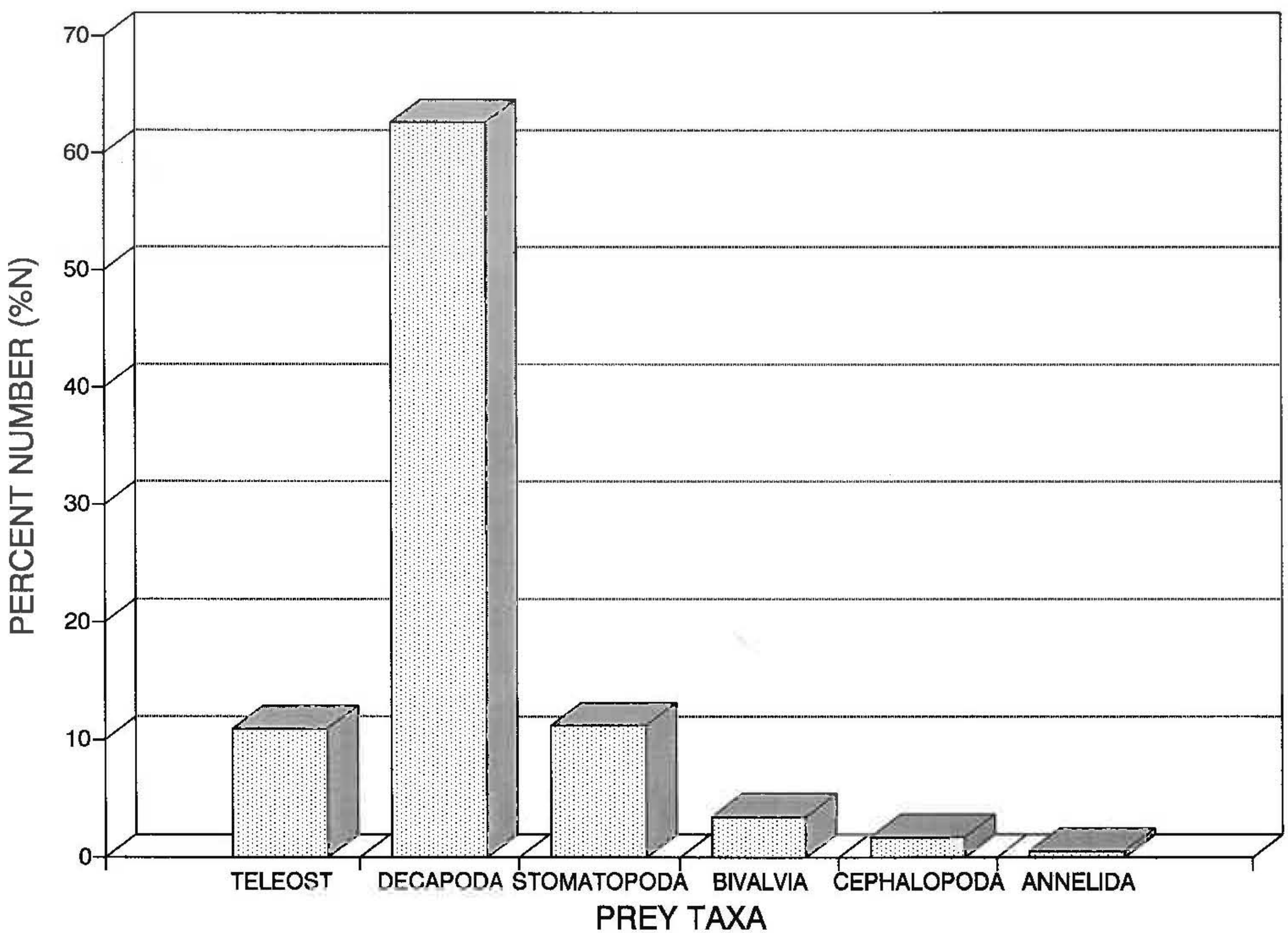
TABLE 3.2: Summary of prey taxa in the diet of collected stingrays as percent by number (%N), frequency of occurrence (%F), percent by weight (%W), and percent by volume (%V). Relative importance indices (RI), expressed as percent contribution to the diet, and the index of relative importance (IRI) are also shown.

PREY TAXA	NUMERICAL IMPORTANCE		FREQUENCY OF OCCURRENCE		GRAVIMETRIC IMPORTANCE		VOLUMETRIC IMPORTANCE		RI	IRI
	N	%N	F	%F	Wt.(g)	%W	Vol.(ml)	%V		
TELEOST	61	10.90	15	83.30	76.87	18.28	398.48	17.50	18.94	2364.08
LABRIDAE	12	2.20	6	33.30	30.89	7.34	158.80	7.20	7.21	312.08
GOBIIDAE	10	1.80	4	22.20	6.17	5.28	55.30	1.50	4.29	72.27
SCARIDAE	3	0.50	2	11.10	13.89	2.64	53.93	2.80	2.52	36.64
UNIDENTIFIED TELEOST	30	5.40	15	83.30	22.31	19.81	203.15	6.00	15.82	948.65
CRUSTACEA	427	76.40	18	100.00	247.55	23.78	1301.41	61.10	39.61	13603.38
PORTUNIDAE	231	41.30	14	77.80	119.46	18.50	707.20	30.90	24.84	5667.02
Portunus depressifrons	148	26.50	13	72.20	60.07	17.17	412.76	13.50	18.71	2887.20
Portunus ordwayi	57	10.20	10	55.50	60.13	13.20	290.32	13.20	13.47	1298.16
Portunus anceps	35	6.30	6	33.30	6.08	7.92	106.56	3.10	6.90	311.72
PENAEIDAE	81	14.50	16	88.80	32.01	21.11	295.70	7.60	18.67	1971.38
Metapenaeopsis goodei	71	12.70	13	72.20	31.06	17.17	259.70	7.40	15.53	1452.15
Trachypenaeus contrictus	6	1.10	2	11.10	0.87	2.64	23.09	0.20	2.08	14.23
ALPHEIDAE	22	3.90	5	27.80	4.37	6.61	71.46	1.00	5.52	138.47
Alpheus schmitti	21	3.80	4	22.20	4.34	5.28	63.10	1.00	4.55	106.11
PROCESSIDAE	3	0.50	3	16.70	0.09	3.97	25.17	0.10	2.91	10.79
Processa guyanae	1	0.20	1	5.50	0.16	1.31	8.39	0.02	0.96	1.22
HIPPOLYTIDAE	1	0.20	1	5.50	0.03	1.31	8.14	0.02	0.96	1.11
Tozeuma carolinense	2	0.40	2	11.10	0.03	2.64	16.25	0.02	1.93	4.23
PASIPHAEIDAE	1	0.20	1	5.50	0.06	1.31	8.17	0.02	0.96	1.10
Leptochela (Proboloura) carinata	1	0.20	1	5.50	0.06	1.31	8.17	1.80	0.96	1.11
ALBUNEIDAE	4	0.70	4	22.20	5.13	5.28	52.69	0.96	4.06	55.12
Albunea gibbesii	2	0.40	2	11.10	2.81	2.64	27.70	0.81	2.08	14.61
Albunea paretti	2	0.40	2	11.10	3.65	2.64	26.67	0.42	2.06	12.96
RANINOIDAE	2	0.40	1	5.50	1.91	1.31	15.50	0.42	1.06	4.32
Ranilia muricata	2	0.40	1	5.50	1.91	1.31	15.50	0.04	1.06	4.32
MAJIDAE	1	0.20	1	5.50	0.68	1.31	8.38	0.04	0.96	1.22
Mithrax hispidus	1	0.20	1	5.50	0.15	1.31	8.38	0.04	0.96	1.22

TABLE 3.2: Continued

PREY TAXA	NUMERICAL IMPORTANCE		FREQUENCY OF OCCURRENCE		GRAVIMETRIC IMPORTANCE		VOLUMETRIC IMPORTANCE		RI	IRI
	N	%N	F	% F	Wt. (g)	%W	Vol. (ml)	%V		
STOMATOPODA	62	11.10	12	66.70	40.02	15.86	262.41	9.30	14.70	1355.98
SQUILLIDAE	44	7.90	10	55.60	22.95	13.22	183.53	5.30	11.61	731.63
Alima hyalina	44	7.90	10	55.60	24.80	13.22	183.53	5.30	11.61	731.63
GONODACTYLIDAE	18	3.20	6	33.30	16.47	7.92	105.76	4.00	6.81	238.79
Gonodactylus oerstedi	7	1.30	3	16.70	2.72	3.97	35.01	0.60	3.13	30.45
Pseudosquilla ciliata	11	2.00	5	27.80	14.89	6.61	85.75	3.40	5.61	148.65
MOLLUSCA	36	6.40	13	72.20	27.72	17.17	216.20	7.10	14.35	975.64
BIVALVIA	19	3.40	6	33.30	10.03	7.92	90.63	2.40	6.57	193.15
GASTROPODA	1	0.20	1	5.50	13.52	1.31	50.45	3.20	1.50	18.28
STROMBIDAE	1	0.20	1	5.50	13.52	1.31	50.45	3.20	1.50	18.28
Strombus gigas	2	0.40	1	5.50	13.52	1.31	51.63	3.20	1.53	19.27
CEPHALOPODA	9	1.60	6	33.30	5.39	7.92	67.75	1.50	6.09	104.54
OCTOPUS	3	0.50	3	15.00	0.37	3.97	24.70	0.02	2.92	9.37
Octopus joubini	7	1.30	4	20.00	4.99	5.38	51.01	1.50	4.15	60.76
ANNELIDA	3	0.50	2	11.10	32.91	2.64	112.12	6.00	3.28	72.95
PLANT	5	0.90	5	27.80	0.99	0.24	37.64	0.40	4.87	36.55
UNIDENTIFIED MATERIAL	16	2.90	18	100.00	31.01	23.78	227.32	7.40	18.56	1023.04

FIGURE 3.1: Major prey taxa in the diet of the stingrays expressed by percent number (%N).



PERCENT NUMBER (%N)
0
10
20
30
40
50
60
70
TELEOST
DECAPODA
STOMATOPODA
BIVALVIA
CEPHALOPODA
ANNELIDA
PREY TAXA

FIGURE 3.2: Major prey taxa in the diet of the stingrays expressed by the frequency of occurrence (%F).

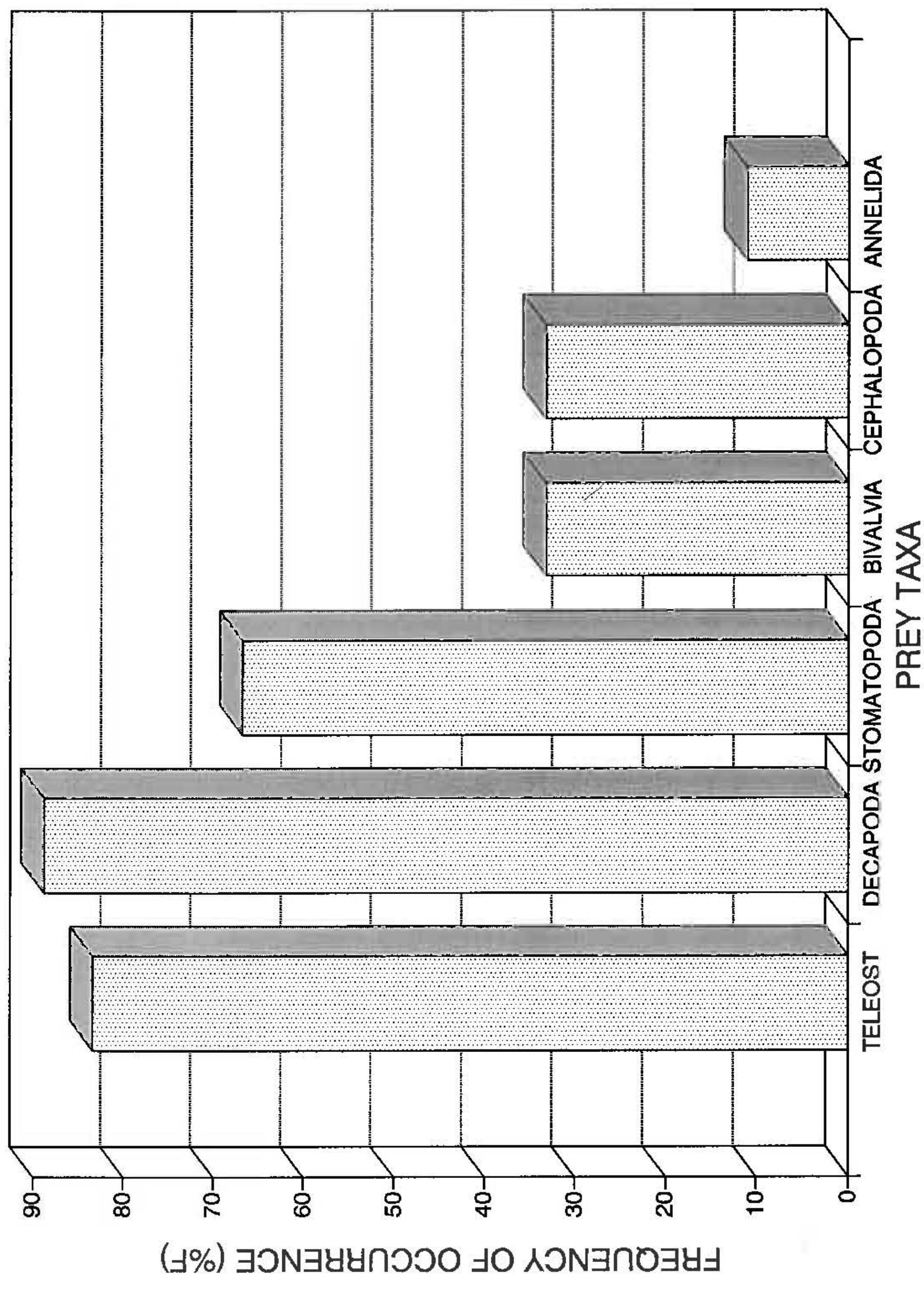

FREQUENCY OF OCCURRENCE (%F)
0
10
20
30
40
50
60
70
80
90
TELEOST
DECAPODA
STOMATOPODA
BIVALVIA
CEPHALOPODA
ANNELIDA
PREY TAXA

FIGURE 3.3: Major prey taxa in the diet of the stingrays expressed by percent weight (%W).

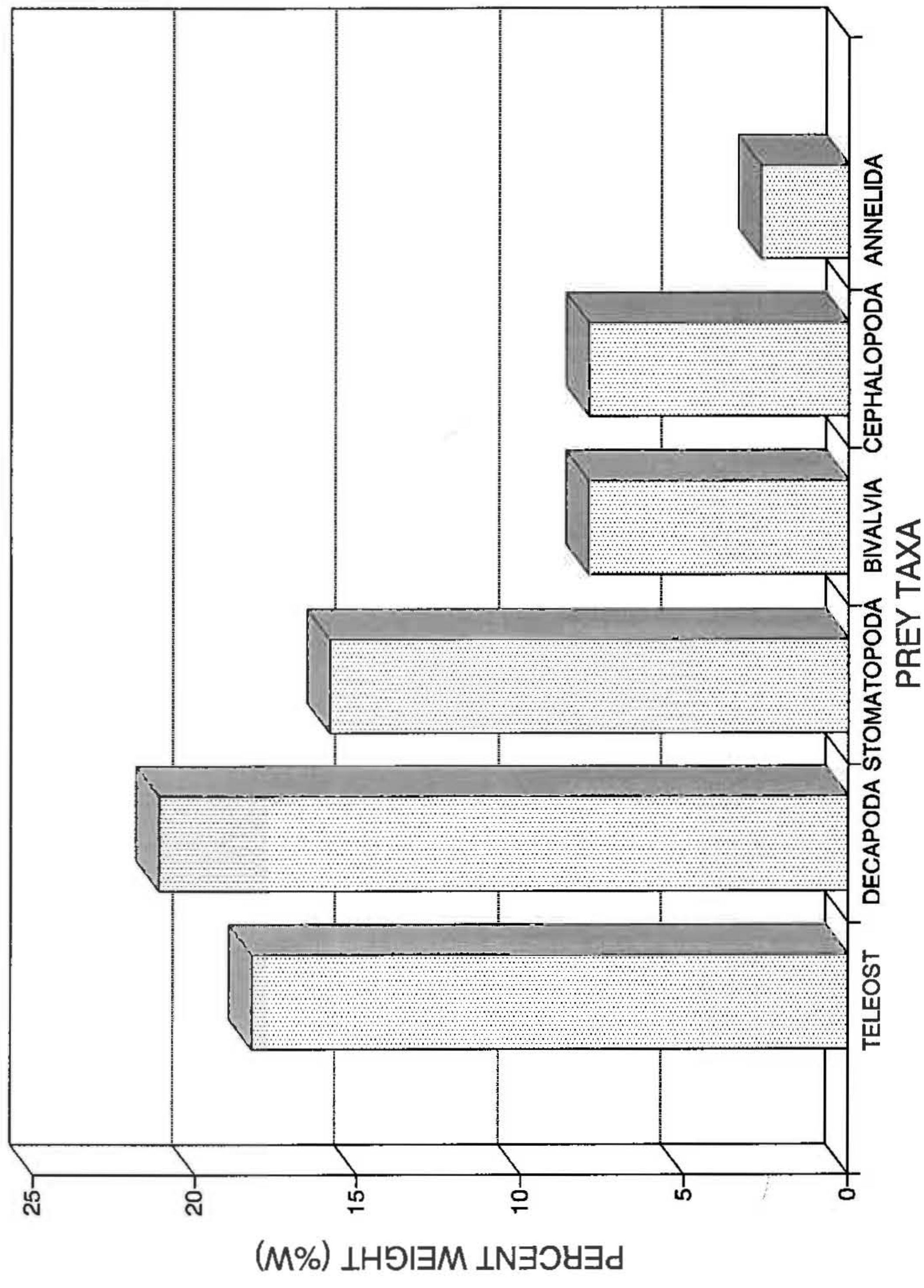
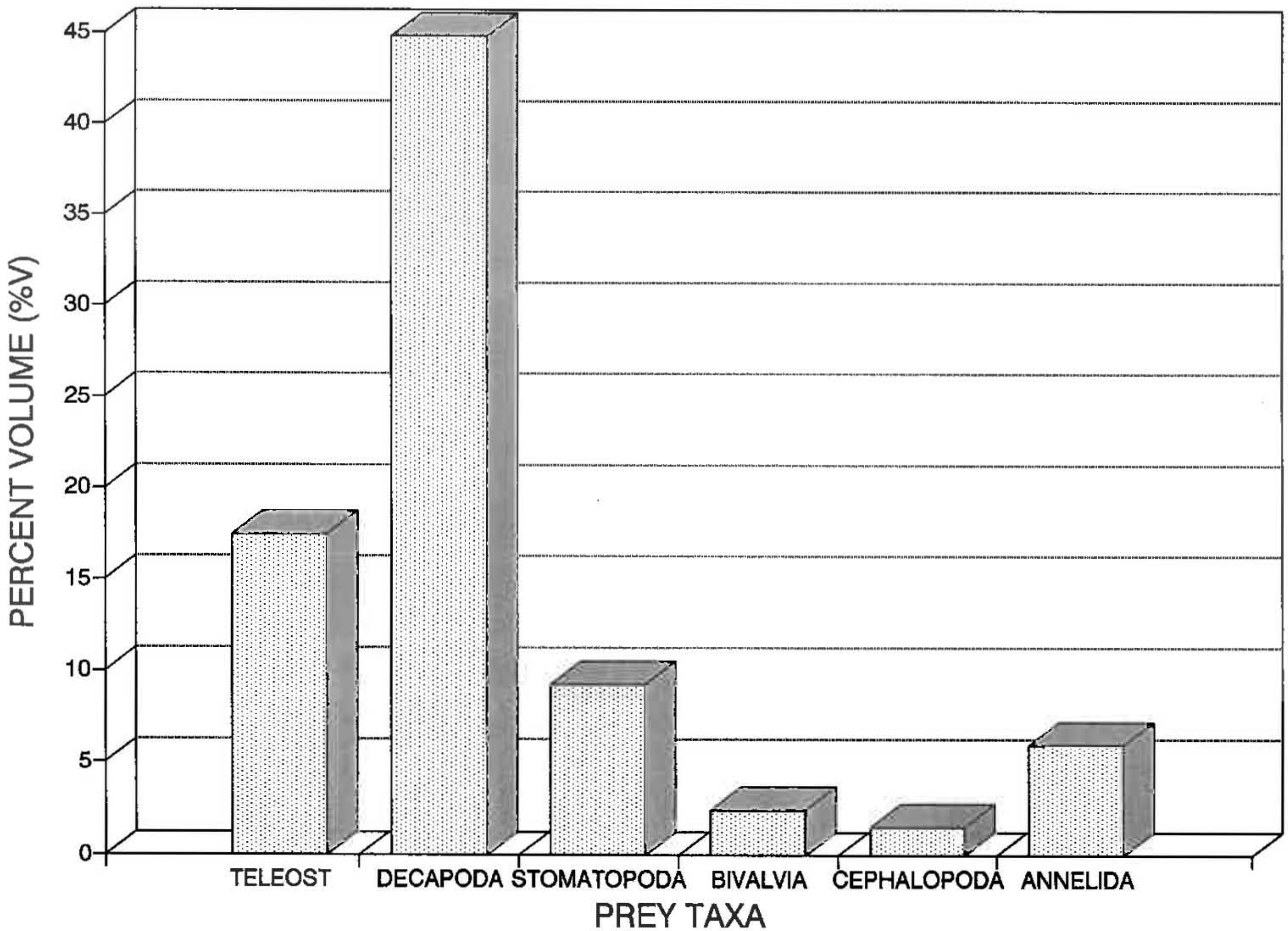

PERCENT WEIGHT (%W)
0
5
10
15
20
25
TELEOST
DECAPODA
STOMATOPODA
BIVALVIA
CEPHALOPODA
ANNELIDA
PREY TAXA

FIGURE 3.4: Major prey taxa in the diet of the stingrays expressed by percent volume (%V).



PERCENT VOLUME (%V)
0
5
10
15
20
25
30
35
40
45
TELEOST
DECAPODA
STOMATOPODA
BIVALVIA
CEPHALOPODA
ANNELIDA
PREY TAXA

FIGURE 3.5: Major prey taxa in the diet of the stingrays expressed by the relative importance index (%RI).

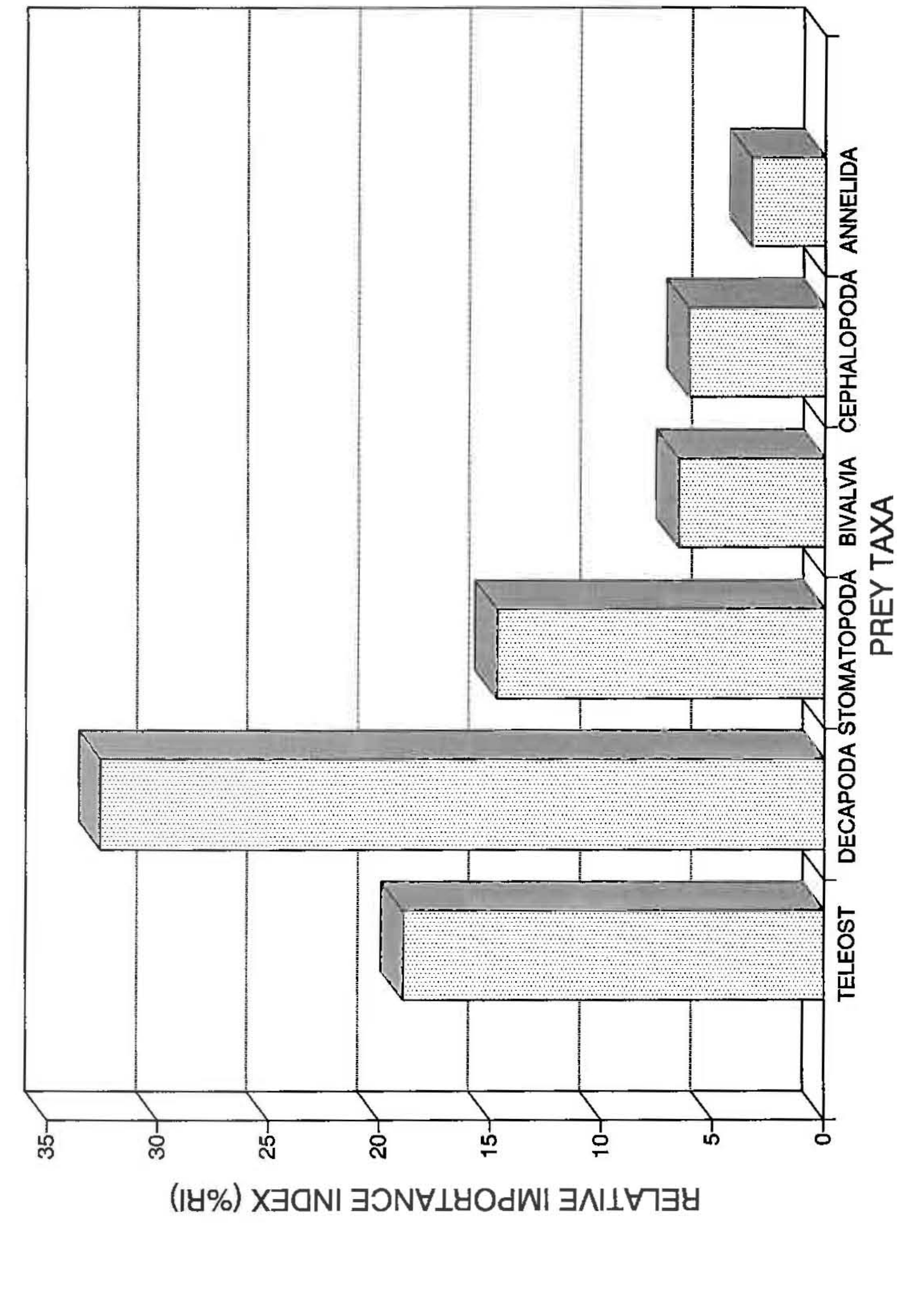
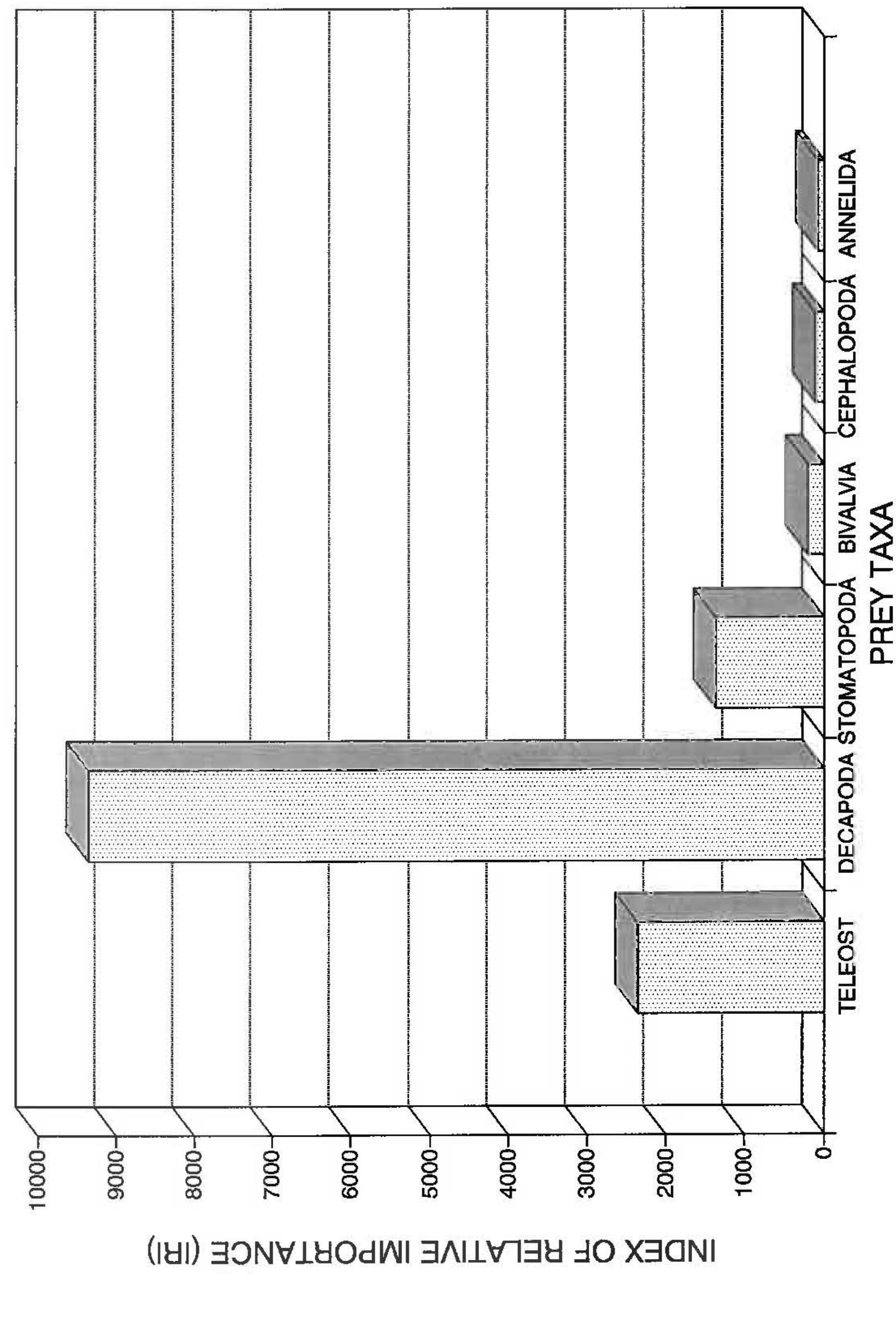

RELATIVE IMPORTANCE INDEX (%RI)
35
30
25
20
15
10
5
0
TELEOST
DECAPODA
STOMATOPODA
BIVALVIA
CEPHALOPODA
ANNELIDA
PREY TAXA

FIGURE 3.6: Major prey taxa in the diet of the stingray expressed by the index of relative importance (IRI).


INDEX OF RELATIVE IMPORTANCE (IRI)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
TELEOST
DECAPODA
STOMATOPODA
BIVALVIA
CEPHALOPODA
ANNELIDA
PREY TAXA

and plant material (Table 3.2).

Among the crustaceans, the most important (RI) families were the Portunidae (24.8%), Penaidae (18.7%), Alpheidae (5.5%), and Albuneidae (4.1%) (Decapoda), and the Squillidae (11.7%), and the Gonodactylidae (6.8%) (Stomatopoda). The important (RI) teleost families included the Labridae (7.2%), Gobiidae (4.3%), and Scaridae (2.5%). Unidentified teleosts represented (15.8%) of the relative importance (RI). The importance (RI) of the mollusc classes were: Bivalvia (6.5%), Gastropoda (1.5%), and the Cephalopoda (6.1%) (Table 3.2). Unidentified material represented 18.6% (RI) of the contents and was found in all the stomachs.

The number of items per stomach ranged from 3 to 65 with an average of 31. No empty stomachs were found. There were more than 20 items per stomach in 77% of the stomachs and 38% having between 20 and 30 items (Figure 3.7).

Figures 3.8 and 3.9 illustrate the relations of average decapod prey weight to stingray body weight ($R^2 = 0.39$) and gape width ($R^2 = 0.40$), respectively.

Stomach fullness measured against time and tidal phase at capture are shown in figures 3.10 and 3.11. Mean stomach fullness was lowest from 0700 to 0900 (1.07 g/kg) and highest between 15:00 and 17:00 (5.55 g/kg). Mean stomach fullness showed no significant difference between time of day (ANOVA, $F = 2.00$, $P > .05$) or tidal phase ($F = 1.96$, $P > .05$) (Sokal and Rohlf, 1969).

FIGURE 3.7: Frequency of occurrence of number of items per stomach.

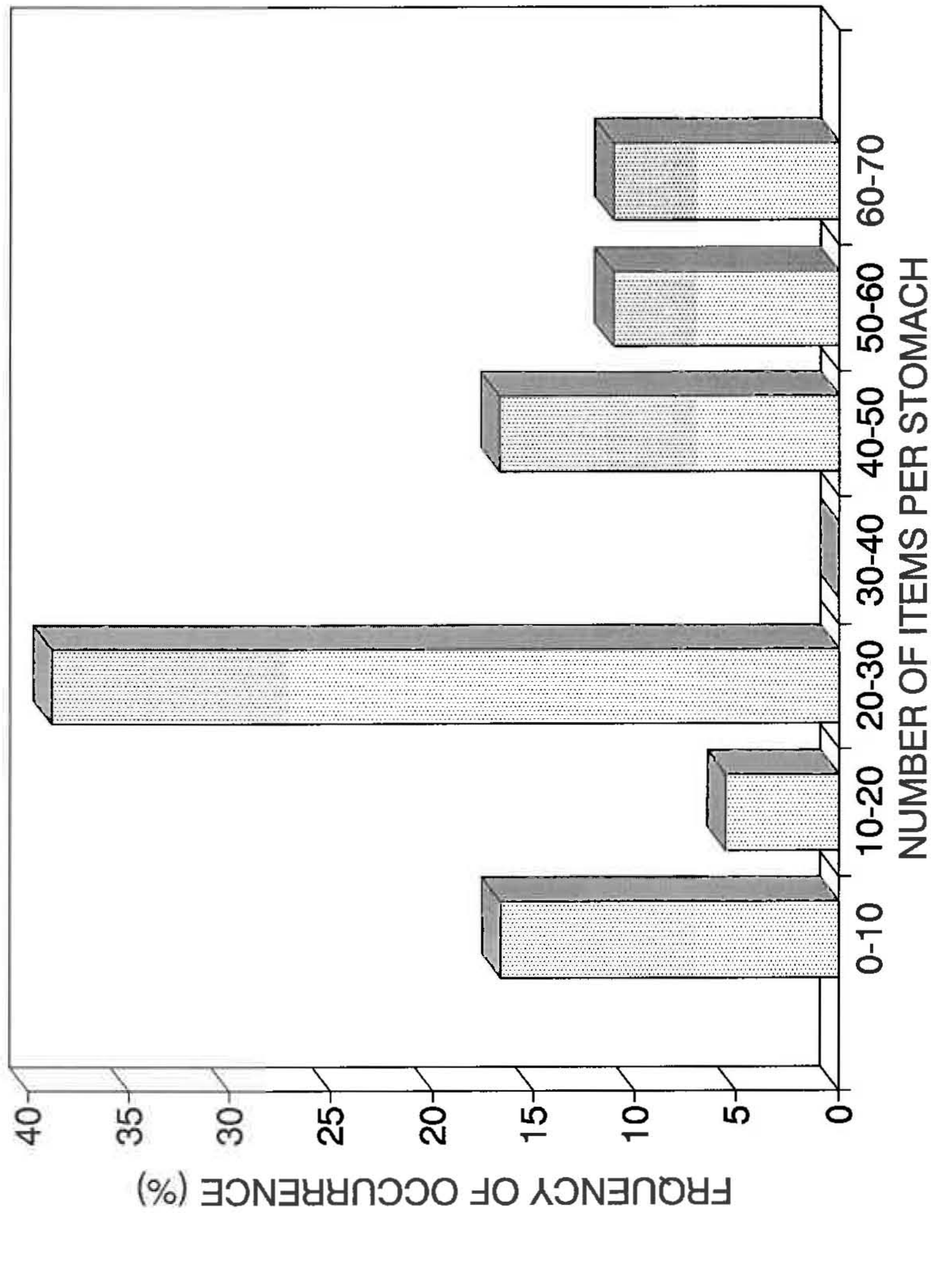

FRQUENCY OF OCCURRENCE (%)
0
5
10
15
20
25
30
35
40
0-10
10-20
20-30
30-40
40-50
50-60
60-70
NUMBER OF ITEMS PER STOMACH

FIGURE 3.8: Regression analysis of mean decapod weight on total stingray body weight (R^2 = 0.32).

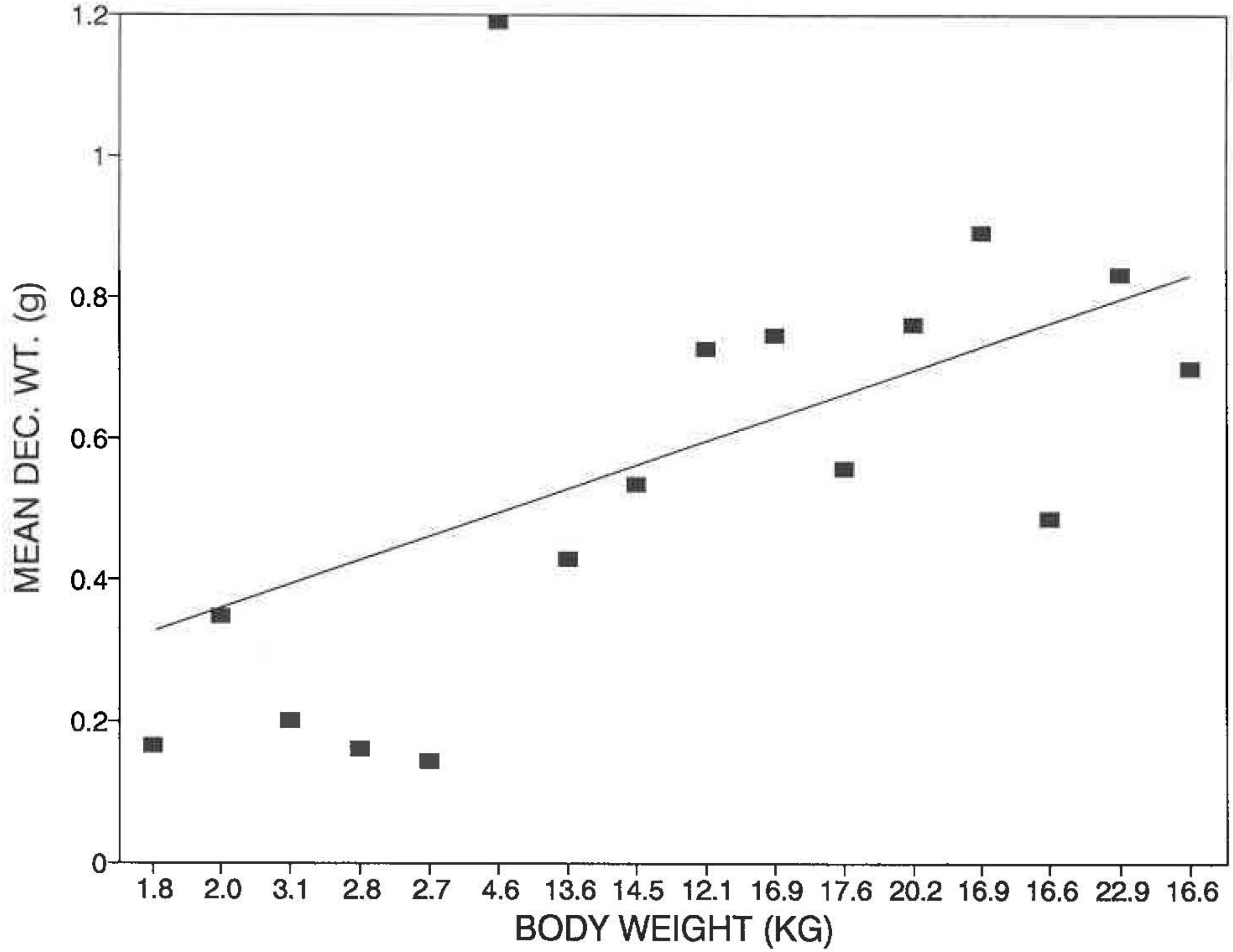

MEAN DEC. WT. (g)
0
0.2
0.4
0.6
0.8
1
1.2
1.8 2.0 3.1 2.8 2.7 4.6 13.6 14.5 12.1 16.9 17.6 20.2 16.9 16.6 22.9 16.6
BODY WEIGHT (KG)

FIGURE 3.9: Regression analysis of mean decapod weight on stingray mouth gape ($R^2 = 0.40$).

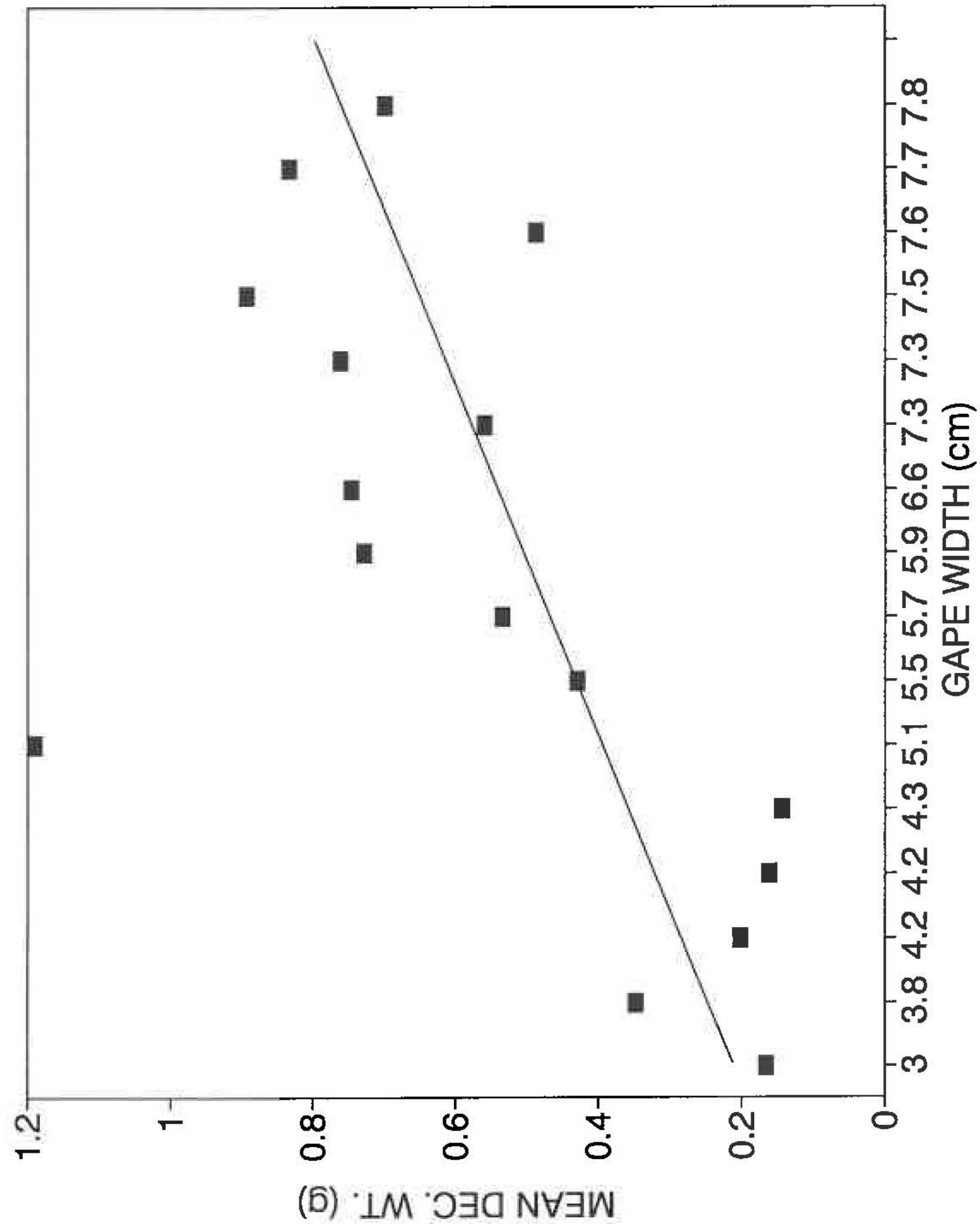

MEAN DEC. WT. (g)
0
0.2
0.4
0.6
0.8
1
1.2
GAPE WIDTH (cm)
3
3.8
4.2
4.2
4.3
5.1
5.5
5.7
5.9
6.6
7.3
7.3
7.5
7.6
7.7
7.8

FIGURE 3.10: Variation in mean stomach fullness (g/kg) with time of day. Error bars equal $\pm$ 1 SE.

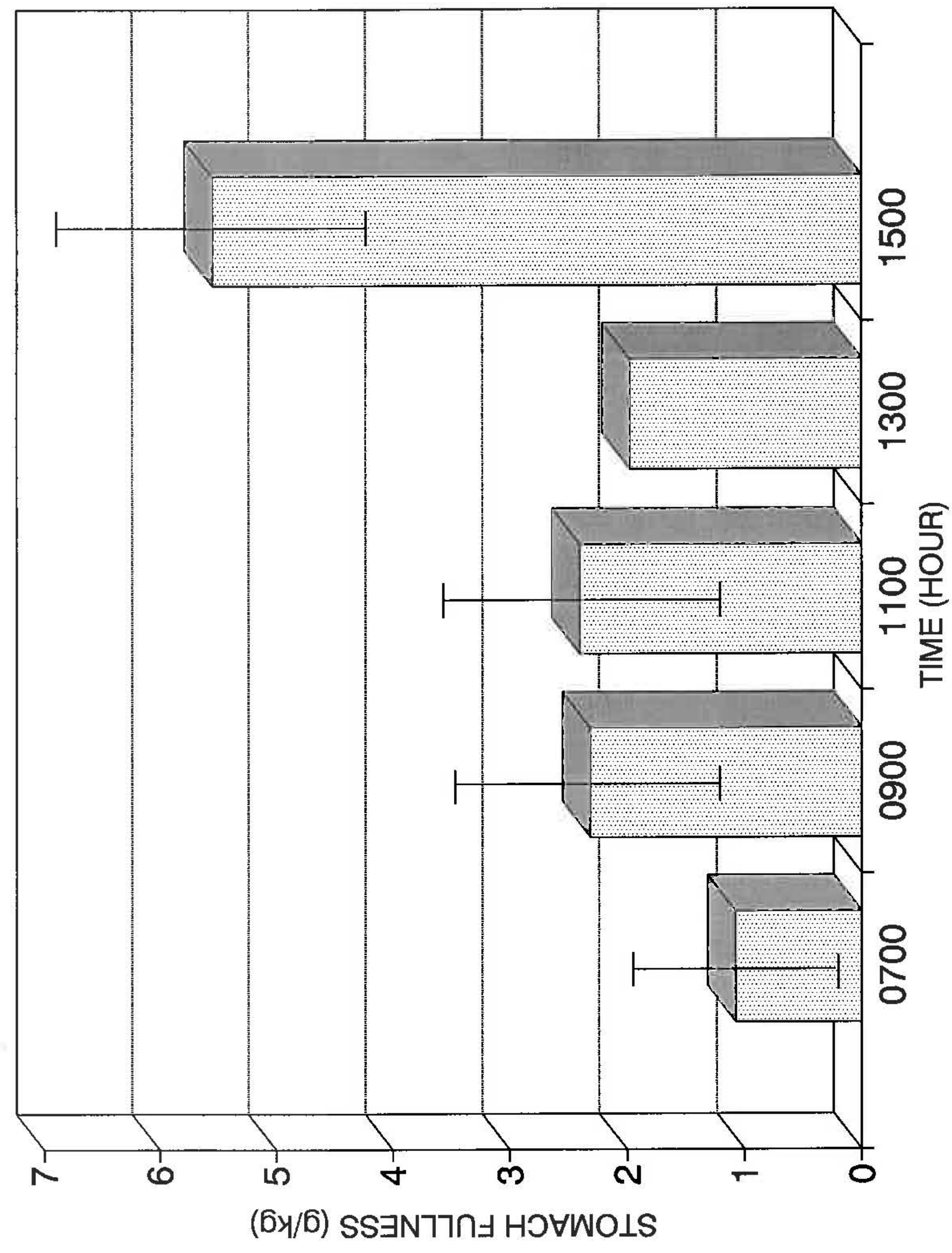
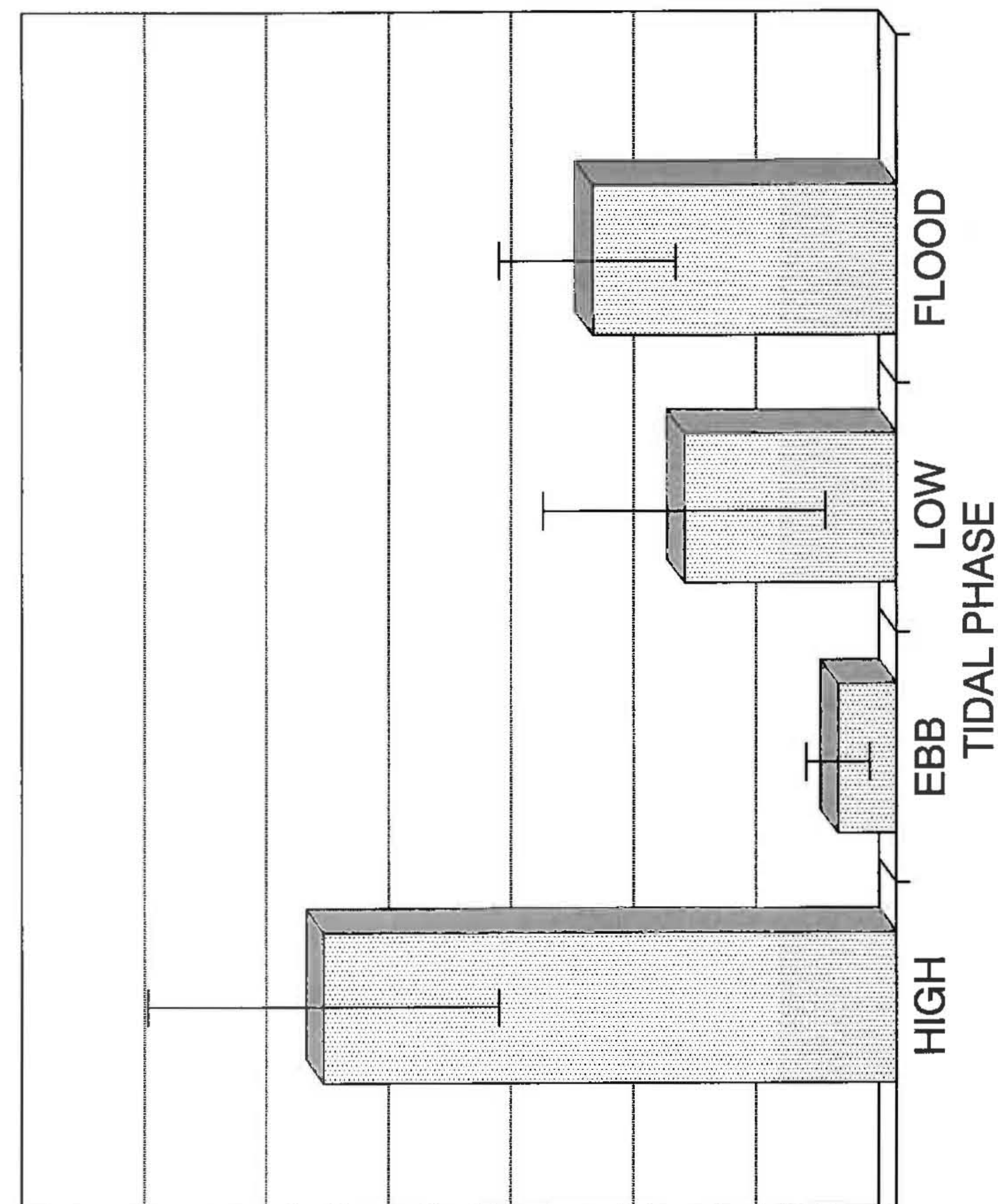

STOMACH FULLNESS (g/kg)
0
1
2
3
4
5
6
7
TIME (HOUR)
0700
0900
1100
1300
1500

FIGURE 3.11: Variation in mean stomach fullness (g/kg) with tidal phase. Error bars equal ± 1 SE.


STOMACH FULLNESS (g/kg)
0
1
2
3
4
5
6
7
HIGH
EBB
LOW
FLOOD
TIDAL PHASE

3.4 DISCUSSION

The results of this study generally agree with the limited existing reports on diet of southern stingrays. Bigelow and Schroeder (1953) found stomatopods, shrimp, crabs, worms, and fish in the stomachs of southern stingrays taken off Bimini, Bahamas. Snelson and Williams (1981) found portunid crabs, shrimp, and teleosts in three southern stingrays from the Indian River Lagoon, Florida. The current study indicates that southern stingrays in the central Bahamas utilize at least 13 decapod species with 3 species of Portunidae being the most important.

Studies on the diet of other dasyatid stingrays indicate that they have similar diets. Stomachs from Dasyatis sayi and Dasyatis sabina collected in the Indian River Lagoon contained crustaceans and polychaete worms (Snelson and Williams, 1981). Stomach contents from Dasyatis sayi and Dasyatis sabina from the Delaware Bay revealed similar diets of crustaceans, molluscs, annelids, and teleosts (Hess, 1961). Struhsaker (1969) found that the diet of Dasyatis centroura off the southeast United States was mostly crustaceans, molluscs, polychaetes, and nemerteans. Dasyatis guttata from the Atlantic coast of South America eats teleosts and molluscs (Thorson, 1983).

This study indicates that the southern stingray in the central Bahamas feed mainly on crustaceans, teleosts, and molluscs. The southern stingray is clearly capable of feeding on active prey; 58.4% (RI) of its diet comprises active epibenthic species (i.e. crustaceans and teleosts). The presence of many small prey items in all of the stomachs indicates that stingrays feed on small items throughout the day instead of feeding on larger items infrequently during the day.

The presence of such a large number of prey categories (Table 3.2) indicates that the southern stingray has a broad diet. Funicelli (1975) descibes D.

sabina as being a more opportunistic feeder than D. americana in the Gulf of Mexico because it feeds on 30 prey types versus 10 for D. americana. Dasyatus americana from the Exumas were found to eat 65 different prey types. Figure 3.3 shows the gravimetric importance each major prey taxon contributes to the diet. This gives an estimate of the total biomass and, therefore, caloric importance each category contributes and indicates that the major prey taxa are similar in importance. Teleosts and Stomatopods are within 5% of Decapod importance. The weak correlations of decapod prey size with disc width and gape (Figures 3.8 and 3.9) indicate that larger stingrays do not nesessarily feed upon larger prey. The distribution of prey items indicates that the southern stingray generally feeds in the soft sediment communities. Several studies have shown that crustaceans dominate macroinvertebrate biomass in tropical soft sediment habitats (Abele, 1974; Virnstein, 1987). Though no quantitative information is available on the biomass of the prey species in the Park, the results suggest that the stingray is a feeding generalist taking advantage of the most available prey species.

Diana (1979) states that feeding duration can be determined by examining the frequency of the number of items found in the stomachs. He found that the most common meal of the northern pike, Esox lucius, consisted of only one item suggesting that the meal was consumed over a short time period. Cortes (1987) found that most of the lemon shark stomachs he looked at contained only 1 or 2 items. Cortes concluded that the lemon shark feeds intermittently. Because 83% of the stingray stomachs contained over 10 items (Figure 3.7) and the average number of items was 31, it can be concluded that feeding is continuous for D. americana.

Mean stomach fullness increases through the day (Figure 3.10) indicating that the southern stingray feeds throughout the day. No empty stomachs were found in this study. Diana (1979) states that when fish with diel feeding cycles are collected at different times of the day, a percentage of their stomeachs should be empty. However, this may apply to fish that feed on prey that have hard parts that are difficult to digest, such as the crustaceans that D. americana feeds upon. The stomach fullness data indicate that D. americana may prefer to feed during the high tide (Figure 3.11), perhaps due to prey availability. High tide allows the stingrays to feed over a greater area. A larger sample size is needed to accurately asses subtle differences in feeding periodicity, however.

The feeding habits of the southern stingray seem to be similar to those of the lemon shark, Negaprion brevirostris. This tropical shark is an opportunistic feeder which feeds throughout the day and tidal cycle (Cortes (1987). In order to grow to a large size and be successful in shallow, tropical marine environments, a top predator must be a generalist in its diet and feeding habits. The southern stingray has a broad diet and is capable of taking advantage of abundant smaller epibenthic fishes and invertebrates.

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CHAPTER 4

SUMMARY AND CONCLUSIONS

4.1 SUMMARY

1. Population variations at different times of the day were determined for both aerial survey areas. Both survey areas had the greatest population of foraging stingrays during the morning surveys followed by the late afternoon surveys (Table 2.1). The lowest stingray population was seen during the midday surveys (Table 2.1).

2. A peak population of 2.07 individuals per km^2 was calculated for the Waderick Wells - White Bay Cay survey area. This compared favorably with the 1.87 stingrays per km^2 calculated for the Shroud Cay survey area.

3. No variations in seasonal abundance for D. americana in the central Bahamas was determined from the land-based observations (Figure 2.3).

4. No feeding periodicity was recognized for time of day either in terms of numbers of stingrays seen or number of ray-minutes from the land-based observations (Figure 2.5).

5. Feeding activity increased significantly during the high tidal phase for the number of stingrays seen from the land-based observations (Figure 2.6).

6. The land-based observations showed significantly more feeding in soft sediment algal turf and sandy shoal habitats relative to other shallow habitats (Figure 2.7).

7. A total of 65 prey categories belonging to 15 families in 4 phyla were identified from the stomach contents of 18 D. americana. No stomach contained only one type of prey.

8. Decapod crustaceans were the most important prey category followed by teleosts, stomatopod crustaceans, and molluscs (Figures 3.1 to 3.6).

9. The major decapod prey families were the Portunidae and Penaeidae (Table 3.2). The only identifiable teleost families were the Labridae, Gobiidae, and the Scaridae (Table 3.2). Three classes of molluscs (Bivalvia, Gastropoda, and Cephalopoda) were found in the diet; with bivalves most important (Table 3.2).

10. There were no empty stomachs and every stomach contained unidentifiable material. Stomachs averaged 31 items with more than 20 items found in 77% of stomachs (Figure 3.8).

11. A weak direct relationship was shown for mean decapod prey weight relative to both stingray body weight and mouth gape (Figures 3.8 and 3.9).

12. Stomach fullness increased during the day but did not vary significantly with time (Figure 3.10).

13. Stomach fullness was greatest during the high tidal phase but did not vary significantly from other tidal periods (Figure 3.11).

4.2 CONCLUSIONS

1) The population of southern stingrays in the central Bahamas does not show any strong time of day feeding periodicity and some portion of the population is feeding at all times (i.e. feeding is continuous and asynchronous).

2) The southern stingray feeds more intensively during the high tidal phase.

3) The southern stingray opportunistically forages a significantly greater amount of time in soft sediment algal turf and sandy shoal habitats.

4) The general diet of the southern stingray includes a wide variety of benthic macroinvertebrates and teleosts.

5) As an opportunistic feeder, the southern stingray feeds on the most available small prey items.