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VIRGIN ISLANDS RESOURCE MANAGEMENT COOPERATIVE

BIOSPHERE RESERVE
RESEARCH REPORT NO. 25

ASSESSMENT OF ANCHOR DAMAGE AND CARRYING CAPACITY OF SEAGRASS BEDS IN FRANCIS AND MAHO BAYS FOR GREEN SEA TURTLES

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U.S. MAN AND THE BIOSPHERE PROGRAM

Virgin Islands National Park

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U.S. DEPARTMENT OF THE INTERIOR
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AND

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ABSTRACT

Over the past two decades, there has been a serious decline in the seagrass beds in Francis and Maho Bays, St. John, U.S. Virgin Islands. These beds provide habitat and food for one of the largest populations of the endangered species of sea turtles, Chelonia mydas L., the green sea turtle, in U.S. jurisdiction. The population size was estimated at 50 subadult turtles. These turtles exert heavy grazing pressure on the leaves of their preferred food, the seagrass Thalassia, in the bays. In addition to grazing pressure, the seagrass beds are seriously disturbed by the increasing number of boats that anchor in the seagrass, damaging roots and rhizomes. Up to 10% of the seagrass beds in the bays is presently damaged by anchors.

The effects of the grazing and anchor damage were evident in the extremely low productivity of the fragile, achlorotic, short and narrow Thalassia leaves. A carrying capacity for the turtle population was calculated based on this productivity and the feeding requirements of the turtles, estimated by observing turtles directly and remotely using radiotelemetry. The carrying capacity was estimated at 11-31 subadult turtles, indicating that the population may be in danger of decline. The grazing behavior of the turtles differed from the patterns reported previously in that the turtles fed throughout the day without taking characteristic midday breaks in feeding. This difference may be in response to the poor quality and quantity of food provided by the seagrasses in the bays.

Although anchor scars in the bay recovered little during the course of the study, some recovery of Thalassia occurred inside fences that excluded anchor damage and turtles. After 3 months, Thalassia blades inside the fences were significantly longer than outside and the productivity per shoot increased.

In order to protect the turtle population from further habitat degradation, it will be necessary to reduce the damage done by boats in anchoring the seagrass beds in the bays.

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ACKNOWLEDGMENTS

I am indebted to Dan Cooke who executed all phases of logistical, field, and laboratory work, often without assistance. We express our appreciation to the National Park Service, St. John, for its vital logistical support and interest; in particular, Dr. Caroline Rogers, Vonnie Zullo, and the numerous volunteers who assisted Dan Cooke. Rafe Boulon of the Department of Conservation and Cultural Affairs, Division of Fish & Wildlife Service cooperated by helping tag turtles and providing statistics on the turtle population. My interest in this research was initiated through Dr. John Ogden, who facilitated the work through support from the West Indies Laboratory and who offered advice, provided tracking gear, and assisted in a census of the turtle population. Helmut Gieben, Doug Kesling, and Lance Robinson also assisted in this census.

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INTRODUCTION

Seagrass beds are valuable natural resources that are easily disturbed by virtue of their coastal location. Once disturbed, seagrass beds can take decades to recover and important functions provided by seagrasses are lost. Such functions include: 1) provision of food, shelter, and nursery areas for many animals including commercially valuable and endangered species; 2) stabilization of sediments and thus protection of coastlines from storm damage; 3) active recycling of elements including heavy and trace metals; 4) ecological linkages with other ecosystems, including mangroves, coral reefs and the deep sea. Mitigation procedures that have been developed for disturbed seagrass beds are imperfect, costly, and labor intensive. This report will discuss disturbances to seagrass beds in Francis Bay and Maho Bay (hereafter referred to as FB and MB respectively) within the National Park on St. John, U.S. Virgin Islands. This study was undertaken to assess whether the seagrasses in FB and MB require protection in order to preserve their ecological functions and the large population of endangered green sea turtles which reside in the bays and utilize the seagrasses for food.

Caribbean seagrass beds growing in less than 15 m water depth, are typically mixed species assemblages of the seagrasses Thalassia testudinum Banks ex Konig, Syringodium filiforme, Kutzing, and Halodule wrightii Aschers. and various macroalgae. Thalassia (turtlegrass) is the dominant species in terms of plant size, leaf shoot density, biomass, and production. Thalassia is the climax species, able to outcompete other seagrasses in the habitat (Williams 1984, 1985, 1987). Various herbivores also prefer Thalassia to other seagrass species (Ogden and Lobel 1978). The ecological functions and biological diversity of seagrass beds in the Caribbean and southeast United States are expressed best in Thalassia beds (Zieman 1982). For such reasons, most seagrass research in the Caribbean and southeast U.S., including this study, has focused on Thalassia.

Stress to Thalassia

Stress or disturbance to seagrass beds can be categorized into two types having different severity: 1) disturbance to the above-ground photosynthetic portion of the plants, particularly the leaves, and 2) disturbance to the below-ground portion of the plants, i.e., the roots and rhizomes.

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Stress to leaves The less stressful type of disturbance is damage to the above-ground plant. The primary agents of this stress are animals that eat seagrass leaves, thus removing the photosynthetic organ of the plant, although hurricanes can also cause leaf removal. Repeated removal of leaves causes a decline in *Thalassia* productivity (Greenway 1974).

This report considers the chronic stress to *Thalassia* that green sea turtles (*Chelonia mydas*) cause by grazing on *Thalassia* leaves, their preferred food.

Green turtles do not crop *Thalassia* indiscriminately but create discrete grazing scars in the seagrass bed where they return every 7-10 days to crop new leaf growth almost to the substratum. It is hypothesized that this peculiar grazing strategy evolved in response to the poor nutritional quality of seagrass forage. Seagrass leaves are high in lignin, cellulose, and tannins and low in nitrogen; however, young newly-formed leaves have less fiber and almost twice as much protein. Repeated cropping of leaves would assure the turtles of a higher quality food in the regrown leaves.

Although initially repeated cropping stimulates leaf growth, eventually the ability of *Thalassia* to recover after leaf removal declines. Stress to the plant is indicated by slower growth and decreasing leaf shoot density, leaf width and rhizome diameter. The cause of the stress is hypothesized to be nutrient deprivation. Nutrients required for seagrass growth are supplied primarily by remineralization of organic matter from detritus in the sediments (Klug 1980). Leaf cropping by turtles greatly reduces accumulation of detritus within the seagrass bed (Thayer et al. 1985).

Stress to below-ground biomass The second type of stress to seagrasses is disturbance to the roots and rhizomes. This stress tends to be acute because the below-ground portion of the plants is largely responsible for the stability and resiliency of seagrass beds. The roots are the major organs for acquiring nutrients for growth and the rhizome acts as a storage organ, providing carbohydrates for regrowth when leaves are removed (Dawes and Lawrence 1979, Dawes et al. 1979). Areal extension of seagrass beds occurs primarily by vegetative propagation of the rhizome (Tomlinson 1974). The roots and rhizomes provide a stable specialized sedimentary environment for the complex microbial communities responsible for regenerating nutrients required by the seagrasses (Klug 1980, Kenworthy et al. 1982). Once the roots and rhizomes are disturbed, recovery of seagrasses is very slow, on the

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order of decades (Kelly et al. 1971, Patriquin 1975, Zieman 1976). Once damaged, a Thalassia rhizome takes at least one year to develop a new meristem (Fuss and Kelly 1969). Motor boat propellers, anchors, use of dynamite as a fishing practice, and dredge and fill operations are the principal causes of this type of seagrass disturbance although a minor amount can be caused by feeding activities of benthic fauna, such as rays (Williams et al. 1985).

The research problem

Francis and Maho Bays contain seagrass beds of Thalassia, Syringodium, Halodule, and various macroalgae (Fig. 1). The seagrasses there are subjected to both categories of stress described above. The bays are the habitat of a large population of green turtles. Grazing by these turtles is so extensive that no discrete grazing scars surrounded by uncropped Thalassia are found. Instead, the bays resemble one huge grazing scar. This observation suggests two points. One, seagrass may be in limited supply as turtle food. Two, all seagrass in the bays is under the stress of leaf removal by grazing turtles, leaving no uncropped plants for regeneration of leaves.

In addition to intensive grazing of leaves, the seagrass roots and rhizomes are being damaged by boat anchors. Over the past several years, the National Park Service (NPS) has documented a dramatic increase in boat usage in FB and MB.

Francis and Maho Bays are a refuge for the endangered green turtle and it is paramount that its habitat be preserved. Disturbance to the seagrasses in FB and MB thus is not limited to the potential subsequent loss of the valuable functions provided by seagrass vegetation but also may include impact on an endangered species. The objectives of this study were to assess the impact of grazing and anchor damage on the seagrass beds of FB and MB to determine the effect such damage has on the green turtle population, and to provide data necessary for resource management plans for the NPS.

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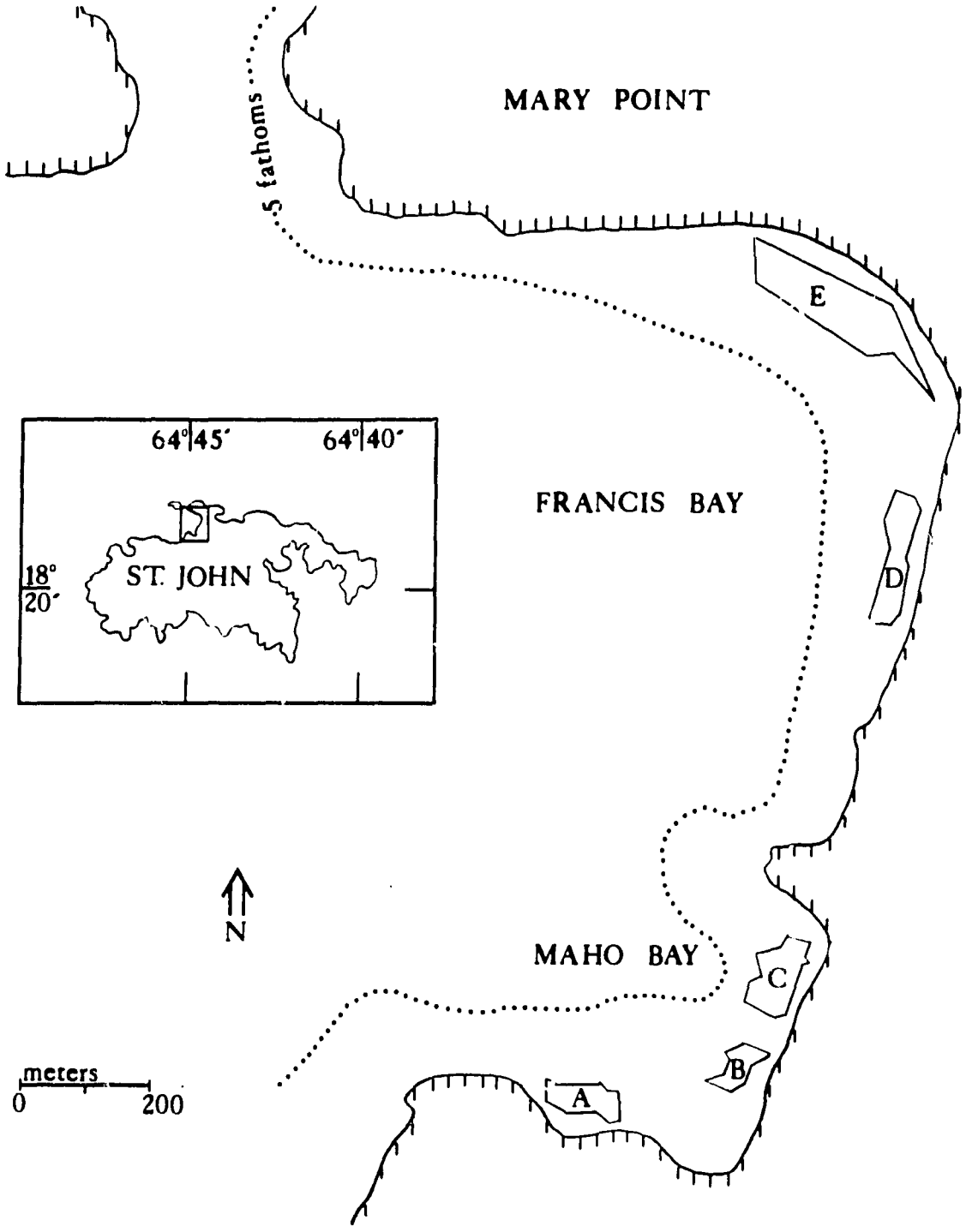

Figure 1. Location of seagrass beds within Francis and Maho Bays, St. John, U.S. Virgin Islands.

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METHODS

Seagrass distribution

An underwater survey of Francis Bay and Maho Bay was made in April 1986 by towing a diver on a sled behind a boat. Seagrass beds thus located were mapped. A 100 m reference transect was placed along the long axis of the bed (i.e., parallel to the shoreline). Successive transects were laid perpendicular to the 100 m reference transect at 10 m intervals. The presence of various seagrass species was recorded every m along the long reference transect and on the intersecting transect. Qualitative descriptions of *Thalassia* leaf shoot density (hereafter referred to as shoot density or density) were recorded likewise. "Good" refers to a shoot density of *Thalassia* per m^2 of > 200 shoots, "fair" to 100-200, and "sparse" to < 100. The beds were mapped again in December 1986.

The following bays on the north shore of St. John were surveyed for *Thalassia*: Hawksnest, Trunk, Cinnamon, and Leinster (Fig. 2).

Seagrass shoot density

Counts of leaves or shoots of each seagrass species were made in August 1986 in Hawksnest, Trunk, Cinnamon, Francis, and Maho bays using 10-20 1/4 m^2 quadrats dropped haphazardly from the surface.

Shoot density of *Thalassia* from FB and MB was converted to biomass using a regression between shoot density and dry weight after epiphyte removal using 5% HCl.

Disturbances to seagrass rhizomes and roots

The density of scars in seagrass beds in FB and MB caused by anchors or feeding activities of stingrays was counted along 50 transects of 10 x 1 m. Ten transects were evenly spaced within each of five seagrass beds (Fig 1). A scar was recognized by a depression in the sediments where damaged rhizomes and few shoots were usually visible. Anchor scars were distinguished from ray feeding scars by being deeper, more elongated, and having more broken rhizomes. Ten anchor scars were measured and marked in June 1986. These scars were remeasured monthly for 7 months. The error associated with measurement was ± 5 cm. The frequency of boat anchoring in FB and MB was determined daily by counting the boats anchored overnight.

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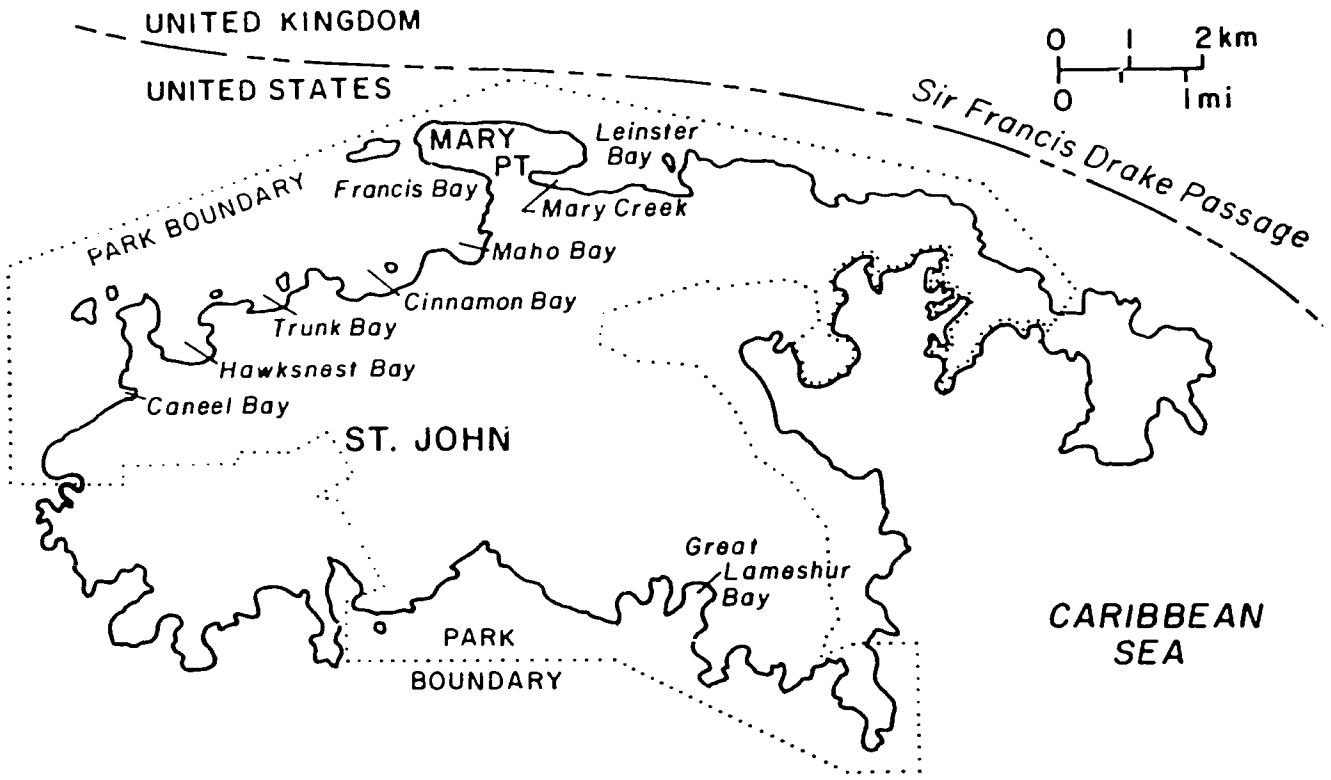

Figure 2. Map of bays on St. John.

Historical records of boat visitation were obtained from the National Park Service. Rays and green sea turtles were censused daily for 105 days along a transect 800 x 1 m in the swim area of FB (site D, Fig. 1).

Thalassia productivity

Thalassia leaf productivity was measured 7 times primarily in MB due to labor constraints. Once, productivity was measured simultaneously in MB and Great Lameshur Bay (GLB). Measurements in GLB were taken in the middle of GLB ca. 50 m from shore. All leaves within 1/4 m^2 quadrats were stapled above the meristem and collected 10-11 days later, following procedures of Zieman (1974). Leaf lengths and widths were measured. Epiphytes were removed from leaves with 5% HCl. Leaves were rinsed with fresh water and dried at 90° C and weighed.

Ecology of green turtles: grazing and movement patterns

The goal of this research section was to determine an estimate of the size of the turtle population in FB and MB, feeding rates, and diurnal patterns in feeding.

The size of the turtle population was estimated by daily direct observations by one individual for 10 months. A second estimate was made during one day in August by 5 individuals sighting turtles in defined sections of the bays. The Division of Fish and Wildlife (DFW) independently made three Snabel estimates of the population via capture-recapture techniques during 1986 (R. Boulon, personal communication).

The behavior and grazing rate of Chelonia on Thalassia was determined by observing 11 individual turtles for 57 hours as they fed. Grazing rates were calculated from estimates of the mean dive time of the turtle, mean number of bites taken per dive, and mean number of hours spent feeding per day. A "home range" is defined as the area traversed by a turtle during a normal 24 h day.

Diurnal patterns of grazing and movement of turtles within the bays were also monitored remotely using radiotelemetry (Ogden et al. 1983). Turtles were caught in a 200 x 10 m barrier net placed along the seaward edge of a seagrass bed. Turtles were herded into the net and then brought to the surface by swimmers. Turtles were measured, weighed, and tagged with NMFS monel tags. A subset of these individuals was surgically implanted with ultrasonic transmitters before all were released at the

capture site. The transmitters were 1 x 3-cm cylinders operating at unique frequencies and pulse intervals (Sonotronics, Tucson, AZ.) Antibiotic-coated transmitters were inserted subcutaneously into a 3-cm incision made between the left rear flipper and plastron after local anesthetization. The incision was sutured with digestible gut or nylon. A total of 5 turtles were tagged with transmitters.

Turtles were tracked using a directional hydrophone connected to a receiver and headphone on a small boat inside a transmitting range of 200 m maximum.

Turtle exclusion fences

In order to assess the potential for recovery of Thalassia, turtles and boats were excluded from areas of seagrass in 3 m water depth in the southern part of MB (site A, Fig. 1). Two 4 x 4 m fences of 6 inch (15.2-cm) mesh, extending from the sediment to just above the surface of the water, were placed in the seagrass bed on 1 August 1986. The corners of the fences were supported and anchored by steel reinforcing bars (rebars). Polypropylene guy ropes were attached from each corner and anchored to more rebars driven into the sediment. The emergent fence was painted fluorescent green and surrounded by buoys to alert boaters.

Placement of the fences was determined in the following manner. Fewer boats utilize the southern portion of MB where the fences would be less of a hazard to navigation. We sought to find areas in this section of MB that a priori were as similar as possible in terms of Thalassia density and productivity; however, these parameters are highly variable in FB and MB. Four sites in as similar Thalassia density as possible were identified as large enough for a fence, although one site was visibly more dense. Four productivity measurements were duplicated within each site (n= 8 per site). Two-way analysis of variance (ANOVA) of shoot density leaf, leaf growth rates, and productivity was used to select the most homogeneous sites for the fences and control areas (i.e., among sites, within sites). The site chosen did not differ significantly ($p < 0.05$) in the average leaf elongation rate; however, there were significant differences in density of Thalassia ($p < 0.05$) and productivity ($p < 0.01$). There were no significant differences among plots within a site nor did a site-subplot interaction occur.

Six productivity plots were then established in each exclosure and likewise outside each exclosure (controls). Plots were located in the center of the exclosures to minimize disturbance from the fences and were rotated to new areas at each sampling time to minimize experimental clipping of Thalassia. The control productivity plots were rotated likewise. Nested ANOVA's were used to detect differences in Thalassia productivity among treatments. Fences were checked for fouling and cleaned when necessary.

RESULTS

Seagrass distribution

Seagrass distribution in FB and MB has been declining. Kumpf and Randall (1961) reported seagrass beds extending unbroken to the 10 fathom (60'; 18.3 m) depth contour in both bays. Aerial photographs taken in 1975 showed the outlines of discrete small seagrass beds occurring shallower than 18.3 m. These outlines appear relatively unchanged in 1986 but seagrass coverage appears thinner. Seagrass beds of Thalassia, Syringodium, and Halodule cover 54,692 m^2 of the bottom of FB and MB (Figs. 3-7). Presently Thalassia is restricted to < 4 m (12') water depth and covers only 39,564 m^2 of the delimited seagrass beds. Thalassia typically occurs with Syringodium in the middle of the beds while Syringodium and Halodule grow below the lower depth limit of Thalassia to 6.2 m (20').

The mean density of Thalassia leaf shoots in FB and MB ranged from 80-200 shoots m^{-2}, with the density in FB slightly higher than in MB (Table 1). Using a regression between shoot density and dry weight, above-ground biomass was calculated to range from 1.8-4.6 g m^{-2} (Table 1). The leaf shoots appeared unhealthy. There was a reduced number of leaves per shoot (mean = 2.3 $\pm$ 0.5) (Zieman 1982). Leaves were very short and narrow, with a mean length of 3.9 $\pm$ 1.82 cm and width of 4 $\pm$ 0.7 mm (n = 265 leaves. The leaf material was very achlorotic, fragile and easily broken off by handling. It is difficult to estimate shoot density from leaf counts of Halodule because of the variable number of leaves per shoot. Syringodium shoots typically have two leaves, thus, half the leaf density is a reasonable estimate of shoot density.

Table 1. Density and biomass of Thalassia leaf shoots in Maho and Francis Bays. Mean values +/- 1 s.d., n = 10 1/4 m^2 quadrats.

Site	# shoots m^{-2}	g dry m^{-2}
Maho Bay		
A	80 ± 85.4	1.8 ± 1.96
B	138 ± 77.1	3.2 ± 1.77
C	134 ± 76.0	3.1 ± 1.75
Francis Bay		
D	200 ± 72.4	4.6 ± 1.67
E	152 ± 76.1	3.5 ± 1.75

FB and MB represent the only source of Thalassia for turtle grazing on the north shore of St. John between Hawksnest Point and Leinster Point. There was a large Thalassia bed on the south side of Mary Creek in Leinster Bay but most of the Thalassia was on a flat too shallow (<1 m water depth) for grazing by turtles. There was no evidence of grazing on this Thalassia. Watermelon Bay had a small amount of Thalassia growing among rocks in <0.5, water depth. This Thalassia also was ungrazed. The other bays surveyed had no Thalassia. Halodule and Syringodium were found in other northshore bays (Table 2).

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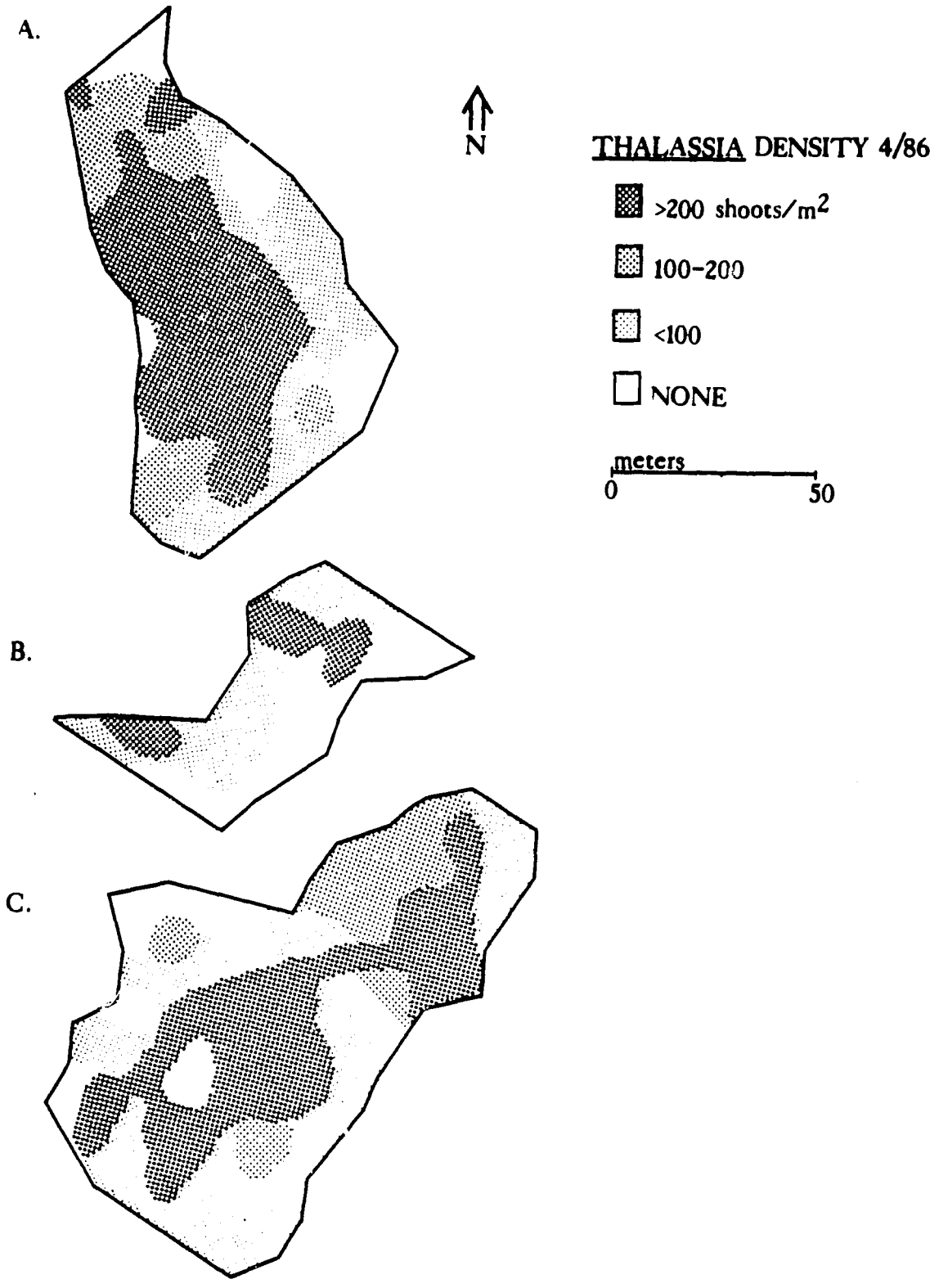

Figure 3. Thalassia coverage in three seagrass beds in April 1986. Refer to Fig. 1 for location within Francis and Maho Bays.

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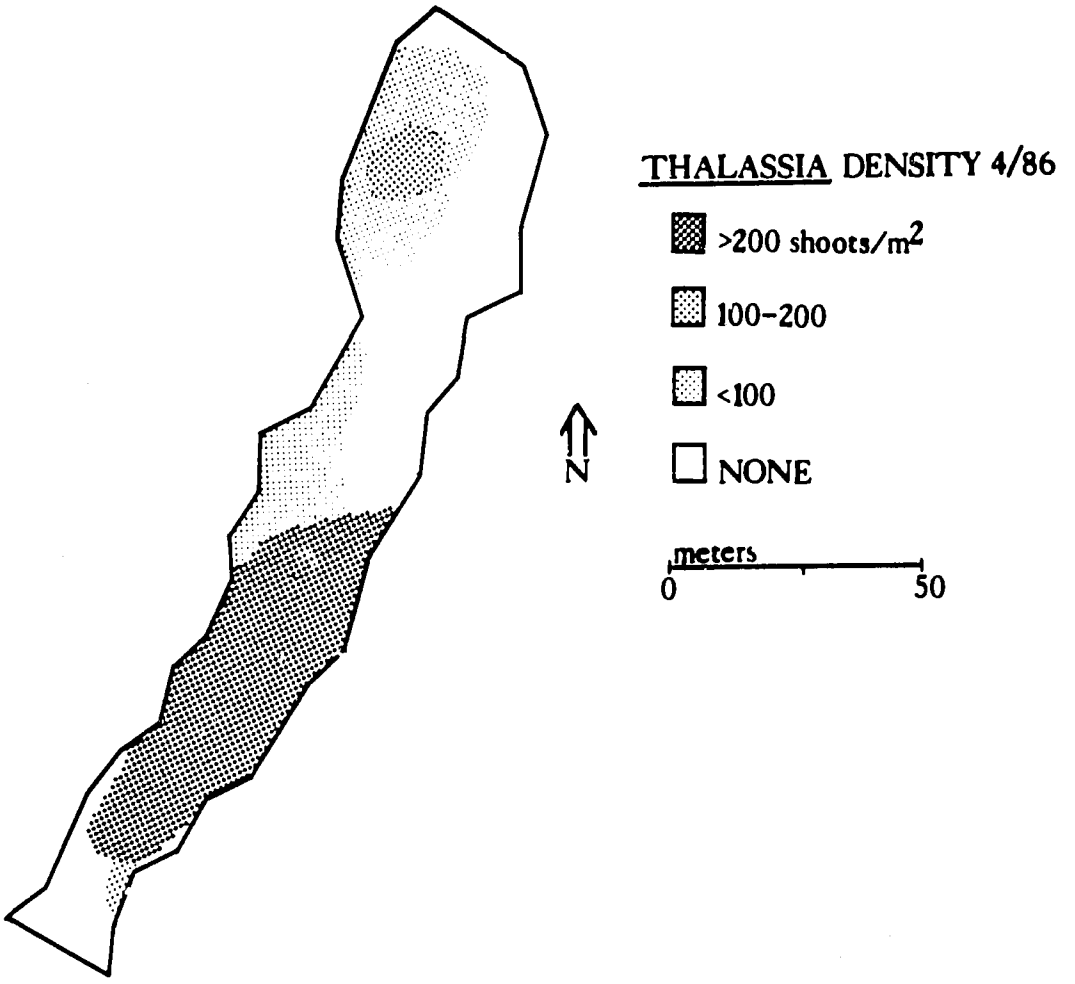

Figure 4. Thalassia coverage in one seagrass bed in April 1986. Refer to Fig. 1 for location within Francis and Maho Bays.

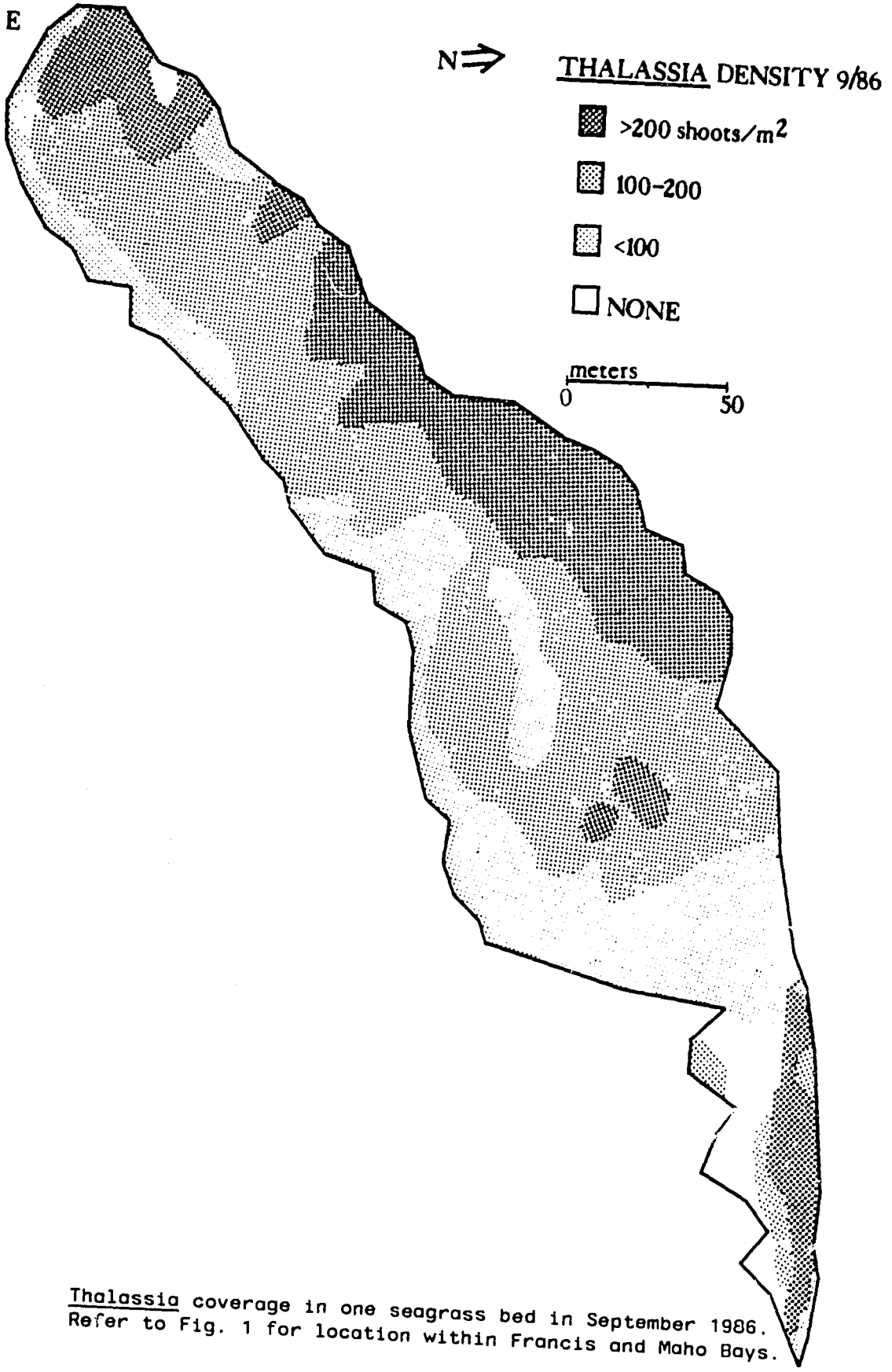

Figure 5. Thalassia coverage in one seagrass bed in September 1986. Refer to Fig. 1 for location within Francis and Maho Bays.

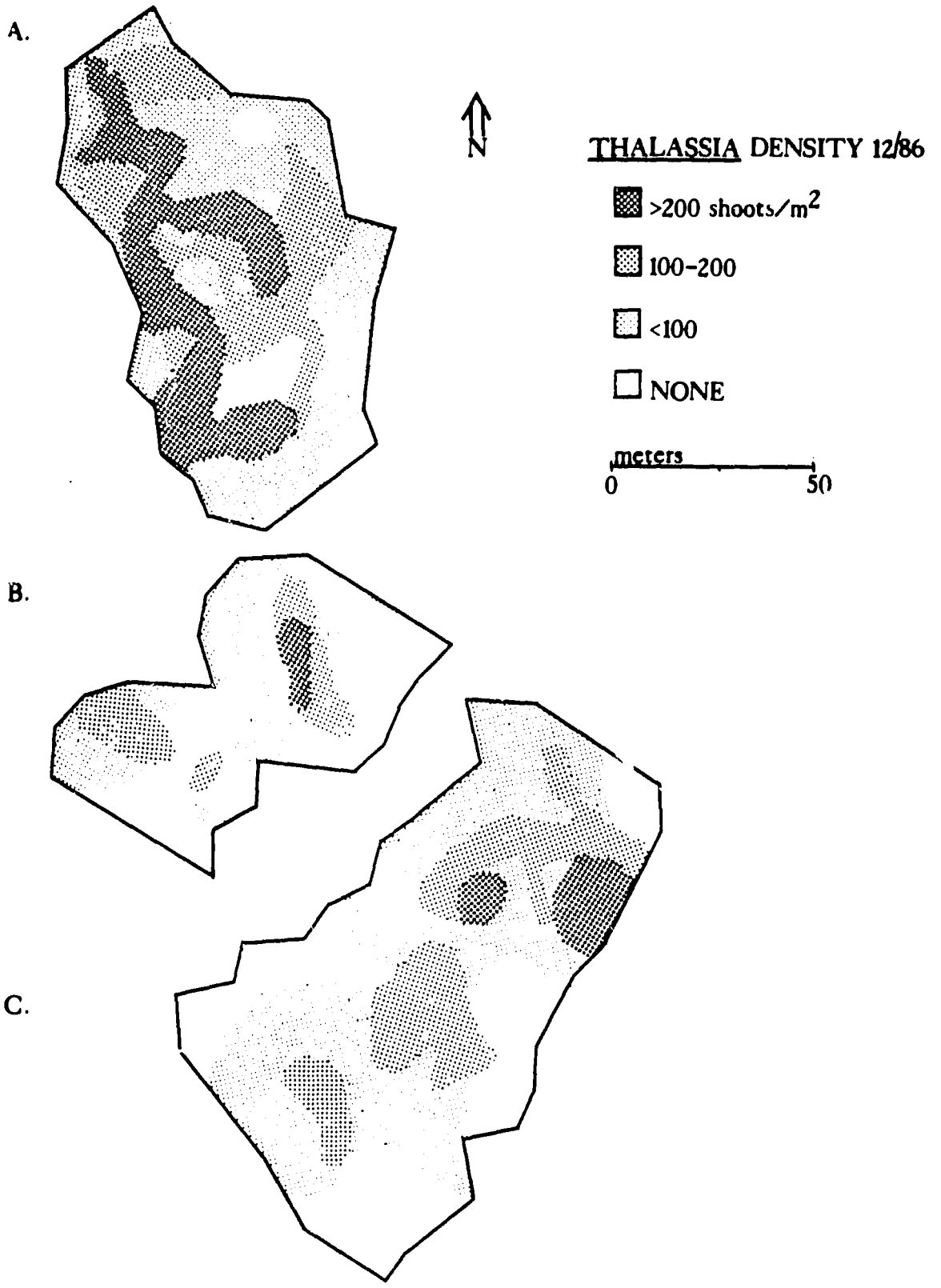

Figure 6. Thalassia coverage in three seagrass beds in December 1986. Refer to Fig. 1 for location within Francis and Maho Bays.

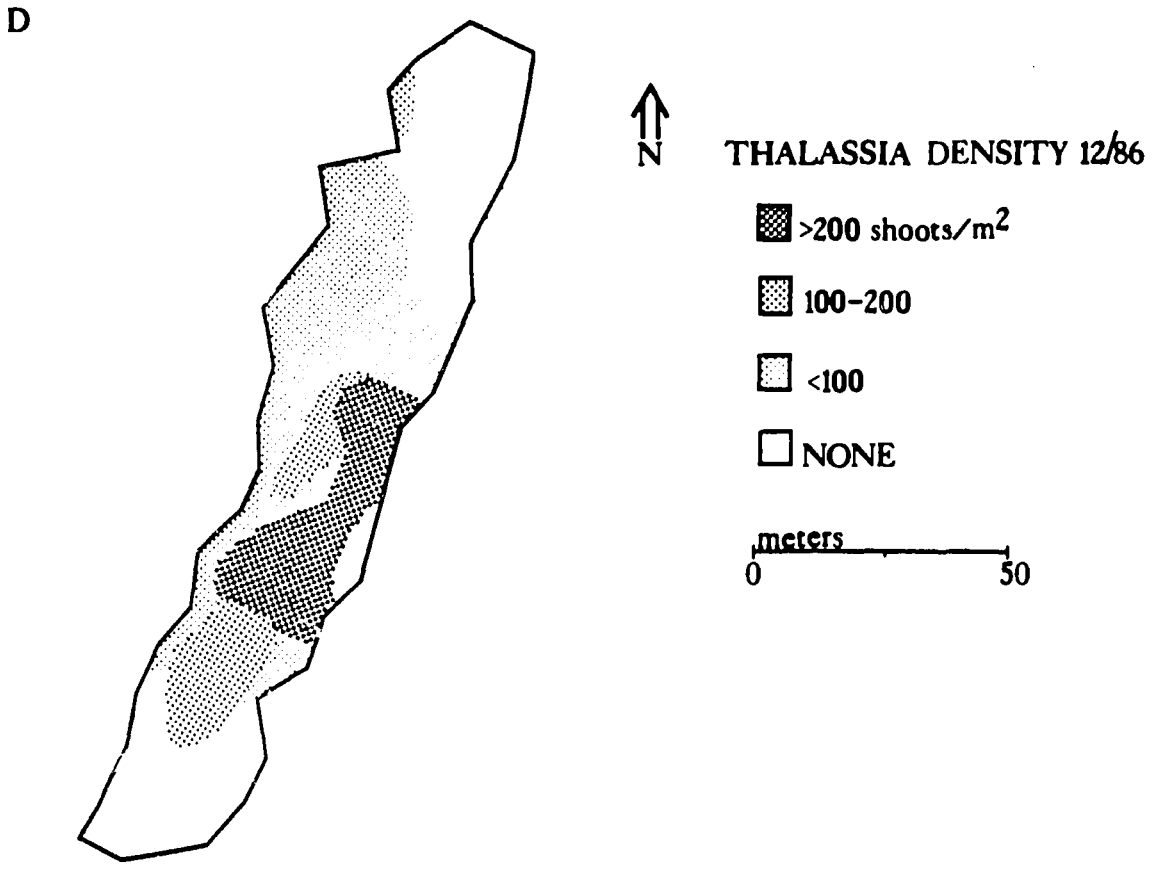

Figure 7. Thalassia coverage in a seagrass bed in December 1986. Refer to Fig. 1 for location in Francis and Maho Bays.

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Table 2. Leaf density of Halodule and Syringodium in bays on the north shore of St. John. Mean values +/- s.d.; n = 20.

Site	Depth (m)	# Leaves m^2	
		Halodule	Syringodium
Hawksnest Bay			
western section	3.1	290 ± 141	5 ± 10
	6.1	113 ± 98	50 ± 48
between public section and Gibney private section[1]	6.1	84 ± 71	154 ± 102
Trunk Bay[2]	6.1	143 ± 65	0 ± 0
Cinnamon Bay			
Peter Bay area	6.1	209 ± 115	21 ± 3

[1]near channel markers
[2]western end of beach by swim buoys

Disturbances to seagrasses

In MB and FB the major disturbances to seagrasses are boat anchor damage and grazing by green sea turtles. Southern stingrays (*Dasyatis americana*) and bonefish (*Albula vulpes*) create only minor disturbances in FB and MB. Grazing by green sea turtles will be treated in a separate section.

Anchor damage Damage to seagrass roots and rhizomes occurs when boat anchors are set in seagrass. When placed, anchors sever roots and rhizomes. When anchors are pulled up they disturb the sediments by exposing them to highly oxygenated seawater and remove roots and rhizomes from the sediments. Damage multiplies when anchors are dragged through the bottom as inexperienced boat operators use power to set anchors or when several attempts are made to set an anchor.

Boating activities have increased demonstrably in FB and MB (Fig. 8). In 1986, an average of ca. 10 more boats per day anchored than in 1984 or 1985. During the years data were taken, peak anchorage occurred in January through April. In 1986 over 1000 boats anchored in the

bays in both March and April. On certain weekends, 100 boats per day anchored in the bays. Reduced activity occurred over several years from August through October with minimum activity in September. Weekend days harbor more boats than midweek days. These figures are conservative because they represent only boats anchoring overnight and thus do not include the daily turnover of day visitations.

Recognizable anchor scars left in the seagrass beds ranged from 0-1 scar per 10 m^2 (Table 3.) The average size of the scars was 0.16 m^2. Scars were most numerous along the beach of MB (sites B and C, Fig. 1). This area is the preferred anchorage for a large fleet of pleasure boats that arrives on most holiday weekends when 10-30 boats were rafted together. These boats have been responsible for the loss of research quadrats from the seagrass beds. In contrast, the buoyed area designated for swimming only in FB (site D, Fig. 1.) had no recognizable anchor scars.

Bioturbation The feeding activities of rays cause characteristic scars in the bottom (Williams *et al*. 1985); however, the resultant damage to seagrass roots and rhizomes is not as severe as that created by anchors. Except for the protected swim area of FB (site D, Fig. 1.), scars judged to be caused by rays were less frequent than anchor scars (Table 3). Rays tend to be excluded from well-developed seagrass beds (Ogden 1976), which is another indication of the status of the seagrass in FB and MB. The average sighting of rays on the census transects conducted was one ray every 3.6 $\pm$ 1.9 days or 1 ray per 2857 m^2.

Several hundred bonefish were observed feeding in groups of roughly 20 which would merge occasionally into a large school. When schooled, bonefish created a large sediment cloud which settled onto the seagrass blades. Bonefish, however, did not break and expose rhizomes.

Thalassia leaf productivity

The productivity of leaves was measured 9 times from April through November 1986 (Table 4), excluding measurements made during the turtle exclusion experiment to be described later. Productivity ranged from 33-97 mg dry weight m^{-2} d^{-1}.

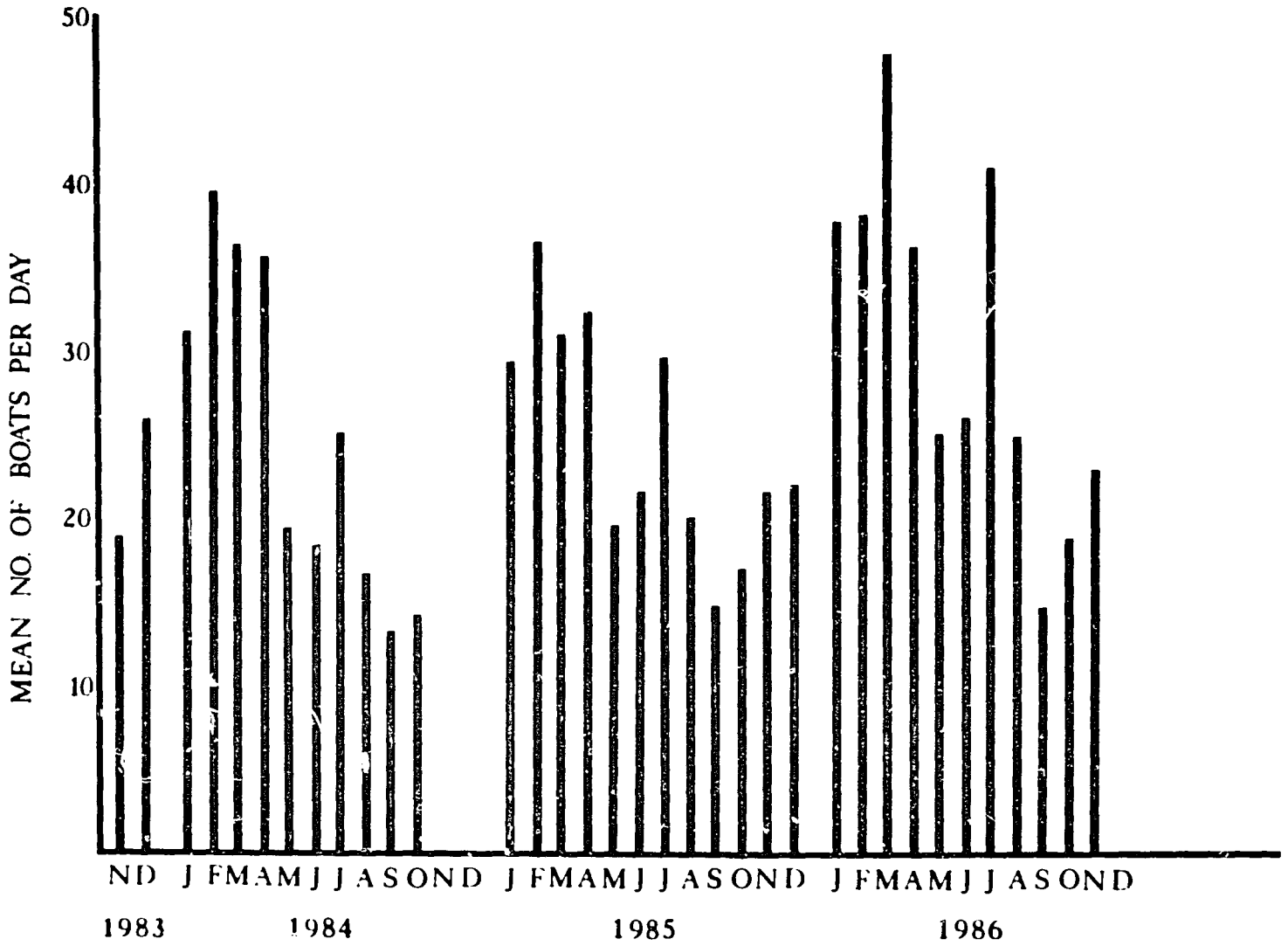

Figure 8. Mean number of boats anchoring overnight in Francis and Maho Bays.

Table 3. Frequency of scars in seagrass beds left by anchors or feeding activities of rays. Mean values +/- s.d., n = 10 transects.

Site	# Scars 10 m^{-2}	
	anchor	boat
Maho Bay		
A	0.5 ± 0.1	0.3 ± 0.5
B	0.6 ± 0.8	0.1 ± 0.3
C	1.0 ± 1.2	0.2 ± 0.4
Francis Bay		
D	0 ± 0	0.2 ± 0.4
E	0.1 ± 0.3	0.1 ± 0.3

The effects of disturbances on the net productivity of the seagrass beds in FB and MB is shown in the comparison (September 1986) between MB and Great Lameshur Bay. GLB is on the south shore of St. John and has few turtles and relatively little usage by boaters, although there may be other, less obvious factors that differ. The mean areal productivity in GLB differed significantly from that in MB at a similar depth ($p < 0.001$). The productivity of Thalassia in GLB was 2.6 times greater than in MB, attributable in part to significantly higher shoot density in GLB ($p < 0.02$). More importantly, the average leaf growth per individual shoot was also significantly higher in GLB ($p < 0.001$). Thalassia in GLB was green and healthy appearing.

Observations on green sea turtles in Francis and Maho Bays

The green sea turtle population size in FB and MB is estimated at roughly 50 subadults (4-60 kg, averaging 26.2 kg; R. Boulon, pers. com.). The average frequency of turtles sighted on the census transects was 3.1 ± 1.1 turtles per day or 1 turtle per 258 m^2. The turtles sighted on the transects were usually one or more of 5-6 individuals. In 1986, DFW tagged 62 individuals during 7 captures in FB and MB (R. Boulon, pers. com). Only three

of these marked individuals were subsequently recaptured and many untagged individuals remain, indicating a fairly high turnover of turtles in the bays. At least 6 individuals, however, maintained their home ranges throughout the 8 months of observation and three recaptured turtles were found where originally caught. The population size remained fairly constant during the study indicating that emigration from the bays was equal to immigration into the bays.

Five turtles were implanted with radio transmitters. One turtle was lost immediately upon release, either moving out of the bays or remaining undetected in the bays due to a disfunctional transmitter. Two turtles were tracked for 103 h between 0430-1200 h, 87 h between 1200-1800 h, and 12 h between 1800-2400 h over 27 days before their transmitters fell out. These individuals were then observed in their home ranges until the end of the study (5 additional months). The other two turtles were tracked for 57 h between 0430-1200 h, 40 h between 1200-1800 h, and 3 h between 1800-2400 h over 17 days before they left the bays.

These radio-tagged turtles maintained discrete home ranges 300 m in diameter, that included areas of the bottom covered by Thalassia and rocks where the turtles slept. Each morning the turtles left their rest area to begin feeding on seagrass approximately 2 h after dawn. The turtles continued to feed for 9 h before retiring to the rocks to sleep. Occasionally a turtle would sleep at midday. No movement occurred at night. The behavior of the turtles tracked was similar to that of other turtles observed in the bays.

The average time that turtles spent on a dive to feed was 3 minutes 52 seconds $\pm$ 1 min. 27 seconds, ranging from 1-9.25 min. During each dive, an average of 20 $\pm$ 4 bites of seagrass were taken per minute, ranging from 10-36. Turtles bit off the upper exposed half of whole shoots of Thalassia, although occasionally an entire shoot would become detached due to the fragility of the seagrass. The frequency of consumption of plants was Thalassia > Syringodium > Halodule and algae.

Carrying capacity for green sea turtles

Net productivity of Thalassia in FB and MB was estimated to be sufficient to support 11-31 subadult green turtles (Table 6). This estimate is quite close but lower than the estimated population size of 50 turtles. The calculation assumes that all Thalassia productivity goes

to turtle grazing while in reality an undetermined amount of detritus is formed and a minimal amount goes to other herbivores. Syringodium, Halodule, and algae were not considered as food although they were utilized by the turtles. The calculation suggests that if such alternate resources are not utilized at a rate equivalent to grazing of Thalassia, then the resident turtle population would cause a reduction of Thalassia standing stock at a rate of 1-7% d^{-1}.

Table 4. Productivity of Thalassia leaves in Francis (FB), Maho (MB), and Great Lameshur (GLB) Bays. Mean values +/- s.d. (s.d. in parenthesis for shoot density). Data are from 1986.

Date	Site	n	Shoot Density	Productivity		New Leaf Production
				mg dry m^{-2} d^{-1}	ug dry shoot $^{-1}d^{-1}$	# m^{-2} d^{-1}
4/8-22	MB-A	10	67(48)	33.0 ± 25.8	480 ± 82	7.3 ± 5.9
	MB-B	10	121(65)	42.0 ± 23.6	350 ± 110	3.0 ± 3.2
5/16-27	MB-A	10	75(67)	57.1 ± 32.6	670 ± 200	4.0 ± 4.1
	MB-B	10	128(76)	33.3 ± 21.5	480 ± 170	8.0 ± 5.5
6/2-13	MB-A	32	140(46)	80.6 ± 31.3	590 ± 160	9.4 ± 5.4
9/6-14	MB-A	10	166(53)	96.5 ± 43.9	590 ± 150	11.2 ± 5.2
	GLB	10	222(45)	252.3 ± 70.5	1240 ± 260	6.6 ± 2.8
11/12-20	MB-A	10	164(46)	72.5 ± 16.0	450 ± 78	8.3 ± 3.2
	FB	10	202(53)	86.5 ± 23.0	440 ± 130	7.5 ± 4.3

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Table 5. Percentages of time spent by radio-tagged green turtles in different areas of seagrass beds in Francis and Maho Bays.

	TYPE OF SEAGRASS BED	
	Syringodium and Algae	Syringodium and Thalassia
Turtle		
1	50	50
2	20	80
3	100	0
4	0	100

Table 6. Calculation of the carrying capacity of Thalassia in Francis and Maho Bays for green sea turtles. Data from this study.

Grazing Requirements for *Chelonia*	
Consumption of *Thalassia*:	11.5 mg dry bite $^{-1}$ turtle^{-1}
Feeding rate:	1200 bites turtle^{-1} h^{-1}
Feeding duration:	9 h turtle^{-1} d^{-1}
Grazing rate:	124.2 g dry turtle^{-1} d^{-1}
Thalassia Production	
Size of *Thalassia* beds:	39,463 m^2
Thalassia productivity:	33-97 mg dry m^{-2} d^{-1}
Total *Thalassia* production:	1,302 g dry d^{-1}
Carrying Capacity:	11-31 subadult turtles
Estimated Impact of Population on *Thalassia*	
Population size:	50 subadult turtles
Grazing requirements:	6210 g dry population^{-1} d^{-1}
Grazing requirements unsupported by *Thalassia* productivity:	2,382-4,908 g dry d^{-1}
Thalassia standing crop:	72,612-181,530 g dry
Rate of loss of standing crop to grazing:	1-7% d^{-1}

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Potential for recovery of Thalassia from disturbances

Anchor scars There was little recolonization of anchor scars by seagrasses during 7 months (Table 7). The age of the scars when marked was unknown thus 6 months represent a minimum recovery period. Swells acted to fill the scars with sediment. Regrowth of *Halodule* occurred more frequently than *Syringodium* or *Thalassia* regrowth. *Thalassia* regrowth was limited to one rhizome in one scar.

Turtle Exclusion Experiment There were no significant differences in productivity parameter when exclosures were established in August 1986 (Table 8). After 3 months of being excluded from turtle grazing and anchor damage, *Thalassia* inside the fences showed higher rates of productivity per shoot than the controls. The leaves of *Thalassia* in the exclosure were significantly longer ($p < 0.001$) than those outside: 6.4 ± 2.7 cm versus 3.7 ± 1.8 ($n = 67$).

Table 7. Changes in size of anchor scars. Length and width of scars in cm. No change in size indicated by "nc".

DATE	4/14	5/16	6/23	7/24	8/23	9/20	10/26	11/30
Scar								
1	35x25	nc	35x30	45x25	55x35	40x35	25x30	35x25
2	45x30	nc	nc	35x30	nc	40x35	nc	40x25
3	50x30	nc	50x40	nc	nc	40x30	nc	35x25
4	60x35	60x30	nc	40x35	55x55	40x40	30x30	nc
5	45x30	40x30	35x35	35x20	40x25	35x30	35x35	35x25
6	35x30	nc	40x35	nc	nc	40x45	35x35	30x25
7	40x50	35x50	55x40	50x30	nc	45x40	45x35	35x40
8	70x40	60x40	55x40	60x35	55x45	55x40	35x20	nc
9	40x40	nc	45x35	50x40	60x45	50x45	45x45	nc
10	40x30	45x35	nc	50x35	nc	40x35	40x40	45x40

Table 8. Comparison of productivity of Thalassia leaves grazed by turtles (controls) and protected from turtle grazing and anchor damage (exclosures). Mean values +/- s.d. n = 6. Mass in dry weight.

Date	Months Elapsed	Treatment		Shoot Density	Productivity		
					mg m^{-2} d^{-1}	ug shoot $^{-1}$ d^{-1}	new lvs m^{-2} d^{-1}
8/1	0	Controls					
			East	85 ± 35	42.0 ± 16.0	630 ± 520	4.3 ± 1.1
			West	83 ± 45	53.2 ± 14.9	600 ± 171	3.3 ± 1.7
		Exclosures					
			East	117 ± 58	52.8 ± 16.3	490 ± 110	5.4 ± 2.2
			West	100 ± 32	64.0 ± 14.8	670 ± 100	3.6 ± 1.5
10/31	3	Controls					
			East	109 ± 34	67.3 ± 23.7	630 ± 200	6.0 ± 2.1
			West	177 ± 32	78.7 ± 17.3	450 ± 85	8.7 ± 2.1
		Exclosures					
			East	147 ± 41	108.0 ± 20.0	750 ± 170	7.5 ± 2.3
			West	106 ± 23	95.3 ± 19.8	910 ± 150	3.8 ± 0.8

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DISCUSSION

The seagrass beds in FB and MB are very stressed. The extent of the beds has declined dramatically since the 1960's (Kumpf and Randall 1961). This study is the first comprehensive survey of the seagrass in FB and MB since then although Beets and Lewand (1984) described one transect across a depth gradient in MB where seagrass grew to a lower depth of 3 m.

Stress is also evident in the extremely low productivity of Thalassia in FB and MB. A typical range in leaf productivity for Thalassia is 0.7-27 g dry m^{-2} d^{-1} (using carbon conversions and data of McRoy and McMillan 1977; assuming 90% of whole plant productivity is contributed by leaves, Patriquin 1973). Thalassia leaves produce 1-6 g dry m^{-2} d^{-1} in slightly deeper beds in Tague Bay (hereafter referred to as "TB"), St. Croix (Williams, unpublished data). Lameshur Bay on the south shore of St. John provides the best available example of an undisturbed seagrass bed for comparison to FB and MB. Although areal productivity of Thalassia in LB is only in mg m^{-2} d^{-1}, the rate is twice as great as in MB.

Density and biomass of photosynthetic shoots and leaf growth rate all contribute to areal productivity. Leaf shoot density is somewhat lower in FB and MB but still within the range of the more undisturbed seagrass beds above for comparison. For example, density of Thalassia ranges from 132-236 shoots m^{-2} in TB on St. Croix and 152-276 in LB. The comparatively low productivity in FB and MB is apparently more a function of sparse stunted leaves and slow growth rates than shoot density. Leaf and biomass in FB and MB ranges from 2-5 g m^{-2} compared to 15-81 in TB (Williams unpubl. data). Thalassia leaves in FB and MB grow < 2 mm d^{-1}. Typical rates range from 2-6 mm d^{-1} (McRoy and McMillan 1977).

Similar studies on the effects of grazing by green sea turtles on Thalassia productivity have been made in St. Croix (Tighe 1981, Miller 1981, Zieman et al. 1984). The results are not strictly comparable to FB and MB because no shoot-specific productivity values are available from St. Croix where leaf biomass of turtle-grazed Thalassia is an order of magnitude higher than in FB and MB.

The green sea turtle population in FB and MB is one of the largest in U.S. territory. Grazing by turtles in FB and MB is more intensive than reported elsewhere (Bjorndal 1980, Ogden et al. 1983). Except for a small area in FB, the turtles graze all the seagrass in the bays

rather than creating grazing scars buffered by adjacent ungrazed seagrass. Turtles in FB and MB graze continuously for 9 h daily instead of resting at midday. Despite feeding throughout the day, the turtles consume half the amount reported elsewhere ($\geq$ 200 g dry turtles^{-1} d^{-1} Fenchel et al. 1979, Bjorndal 1980, Thayer et al. 1982). Consumption rates, however, may be related to turtle size. Turtles in FB and MB were smaller than the 50-170 kg size in the studies cited above. Such differences in feeding behaviour may occur in response to reduced food sources in FB and MB. Thalassia productivity is very low. Achlorotic leaves suggests nitrogen stress and thus poor quality forage.

The suboptimal quality of FB and MB as habitat for the turtles is also expressed in its low carrying capacity of 1 subadult turtle per 1000-3600 m^2. Bjorndal (1981) calculated a much higher capacity of 1 turtle per 72 m^2 for a less disturbed Thalassia bed despite using a higher consumption rate. The turtle population in FB and MB is presently at or above its carrying capacity. If alternate food resources cannot be utilized at the necessary rate, a decline in the population is predicted. If declines in the seagrass or its productivity continue, the carrying capacity will be further reduced. Whether green turtles have become concentrated in FB and MB in response to the decline of seagrass beds on St. John over the years is unknown. FB and MB, however, are presently the sole source of Thalassia, the turtles' preferred food, on most of the north shore of St. John. Other bays on the north shore support smaller populations of juvenile turtles.

Damage to the seagrass caused by anchors in FB and MB is more serious than grazing by turtles because anchors destroy the regenerative capacity of seagrass roots and rhizomes. An average of 2.5-6.5 m^2 of the bottom of the bays is destroyed by boat anchors every day. If one quarter of the damage occurs in the existing seagrass beds, 0.7-1.8% of the seagrass beds will be lost yearly and the carrying capacity for turtles will be reduced accordingly.

Thalassia is extremely slow to recover from disturbances and often requires decades once roots and rhizomes are uprooted (e.g., Fuss and Kelly 1969, Kelly et al. 1971, Patriquin 1975, Zieman 1976). Uprooted quarter m^2 plots completely surrounded by a dense well-developed seagrass bed on St. Croix required 4-5 years to recover their former seagrass vegetation (Williams unpubl. data). Initial regrowth into anchor scars in this study took at least 6 months and the colonizing plant was Halodule more frequently than Thalassia. Although only 3 months of data

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were obtained after the turtle (and boat) exclosures were established, initial results are promising for recovery of Thalassia when protected. Longer leaves inside the exclosures provided more photosynthetic area and although areal productivity changed little, the productivity per shoot increased.

Recommendations for management

The seagrass beds in FB and MB are in critical need of preservation. They provide a large population of endangered green turtles with the only source of their preferred food Thalassia on the north shore of St. John. The bays are at or above their carrying capacity for the turtles. This carrying capacity appears low compared to less disturbed Thalassia as a result of the suboptimal seagrass forage (i.e., low productivity, low biomass). Perhaps in response to the poor food resources, which are nevertheless the best available, the turtles exhibit deviations from the feeding behavior observed in less disturbed seagrass beds.

Reduction or elimination of anchorage in the existing seagrass beds is recommended. The temporary buoys established in September 1986 in the seagrass beds in FB appeared to be effective at restricting boats. Restrictive demarcation of boats in the bays should extend as far beyond the lower depth limit of seagrass growth as feasible. The additional zone may enable the beds to expand after several years; presently, this would be the only means of increasing the carrying capacity of the beds and reducing the grazing stress--assuming that the turtle population does not increase.

The consequences of taking no management action are profound, given the increase in boating activity and the decline in the seagrass beds to their current fragile state. Sustained loss of the seagrass would have a large effect on the turtle population. Loss of the seagrass could also result in loss of the valuable beaches in FB and MB. Seagrasses exert considerable influence on water motion and sediment transport processes and stabilize sediments (Scoffin 1970, Burrell and Schubel 1977, Fonseca et al. 1982, Fonseca et al. 1983). Although sparse, the seagrass beds in FB and MB may be preventing beach erosion.

Procedures for mitigation of loss of seagrass beds have been developed; they include transplantation of intact plugs of seagrass of seedlings (Thorhaug and Austin 1976, Lindall et al. 1979, Thayer et al. 1982, Phillips and Lewis 1983). Presently, however, results from

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experimental restorations are not consistent (Fonseca 1987). Seedlings are prohibitively expensive at $182,900/hectare and their survival is < 30%. Plugs show a higher survival rate and cost $27,000-85,000/hectare. Plugs need to be taken from a nearby source seagrass bed. Because of the resultant damage to the source bed and the long recovery time involved, the plug technique has been recommended only where there are nearby source beds scheduled for destruction. Material for FB and MB would have to come from the south shore. Because of the relatively steep slope of FB and MB and the exposure to ocean swells, transplanted plugs are likely to fare poorly and seedlings would not be recommended. If these procedures are pursued, transplants would require protection from anchors and grazers.

Recommendations for research

The following list provides recommendations for research topics to follow this study:

1. Determine the amount of forage other than *Thalassia* in the turtles' diets and calculate a carrying capacity including all food resources.

2. Determine the nutritional quality of the forage (protein and carbohydrate analyses).

3. Monitor changes in productivity and shoot density of *Thalassia* in the exclusion cages every 4-5 months for at least 1 year. If cages are removed, observe grazing on the previously protected *Thalassia* to determine if it is preferred.

4. Map the seagrass beds every 3-5 years.

5. Monitor anchoring that occurs in the seagrass beds.

6. Monitor the turtle population for changes in size and growth rates of individuals.

7. Monitor seagrass size, density, and productivity within areas protected from boating activities.

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