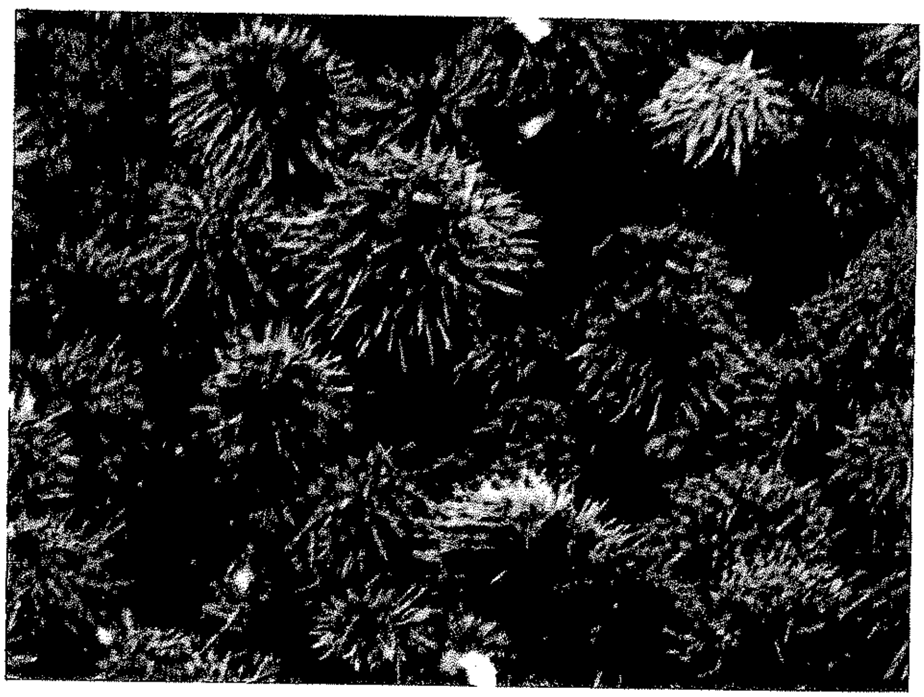
1994 Workshop on the Management and Biology of the Green Sea Urchin (*Stongylocentrotus droebachiensis*)

September 27 & 28, 1994
Maine Department of Marine Resources
Research Laboratories
Boothbay Harbor, Maine



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and
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INTRODUCTION

The recent growth of the fishery for Green sea urchins (*Strongylocentrotus droebachiensis*) throughout the Gulf of Maine, has drawn the attention of managers, scientists and industry from Atlantic Canada to Massachusetts. Research into the biology, ecology and effects of the fishery is being conducted in Maine, New Hampshire, Massachusetts, and New Brunswick. In order to efficiently obtain new and useful information, as well as share existing knowledge it was felt that a conference with representatives from all regions involved in the sea urchin fishery as well as all concerned groups would help to enable the future success of the industry.

WORKSHOP SUMMARY

On September 27 & 28, 1994 the Massachusetts Division of Marine Fisheries (MADMF), the Maine Department of Marine Resources (MEDMR) and the National Oceanic and Atmospheric Administration (NOAA) co-sponsored a conference on the biology and management of the green sea urchin (*Strongylocentrotus droebachiensis*). The goal of the meeting was to bring together the people connected to the fishery relatively early on in the process in order to avert some of the mistakes that have been made in managing other fisheries that have developed quickly and then collapsed due to the ensuing gold rushes. The conference was attended by over 40 people from a range of interests including managers, biologists, harvesters and law enforcement personnel from Maine, New Hampshire, Massachusetts, Florida, New Brunswick and Nova Scotia. The format included presentations of new research on sea urchins as well as discussion sections on future needs for research and approaches to management.

The urchin fishery is a relatively new fishery. However it has grown rapidly in the past few years. In the Maine fishery hand harvesting licenses more than doubled and boat licenses more than quadrupled in number between 1992 and 1994. Until 1992 activity in Massachusetts was an extension of Maine's primarily SCUBA fishery. With the advent of the Irish or Green Dredge (named after the maker), effort in the Beverly - Salem - Gloucester region increased. The MDMF became concerned with this increased effort and the effects it could have on the resource, the benthos and the other important fisheries which co-occur in the area. These concerns are shared by many other agencies and researchers in the Gulf of Maine and as a result some very interesting new work has been conducted on green sea urchins. Much of this work is described in the papers presented in these proceedings.

The meeting generated discussions concerning what further biological and ecological information needs to be collected in order to understand the implications of commercial harvests of urchins on the urchins themselves as well as on the benthic community of which they are a part. This information was prioritized with the emerging fishery in mind, and divided into two categories, basic biological research and information on the current aspects and impacts of the existing harvests. The following represents a consensus on what these needs are:

■ Knowledge of spatial and temporal patterns of distributions in order to be able to separate impacts on populations due to the fisheries from naturally occurring fluctuations.

■ A better understanding of larval supply, juvenile distributions, settlement and growth is necessary in order to determine the amount of removal of adult urchins that can sustain a fishery.

■ The presence of critical phases in the life histories of marine organisms has been noted. For instance the early benthic phase has been considered a crucial stage in the life history of the American lobster that may determine the numbers of lobsters surviving to adult hood. The habitats in which this stage occurs has been considered of critical importance to lobsters as the juveniles are particularly vulnerable to predation. Participants considered it a priority to identify if such a stage exists for urchins. If there are certain habitats that are necessary for the survival of urchins through this stage, they need to be identified as well. (Figures 1 and 2).

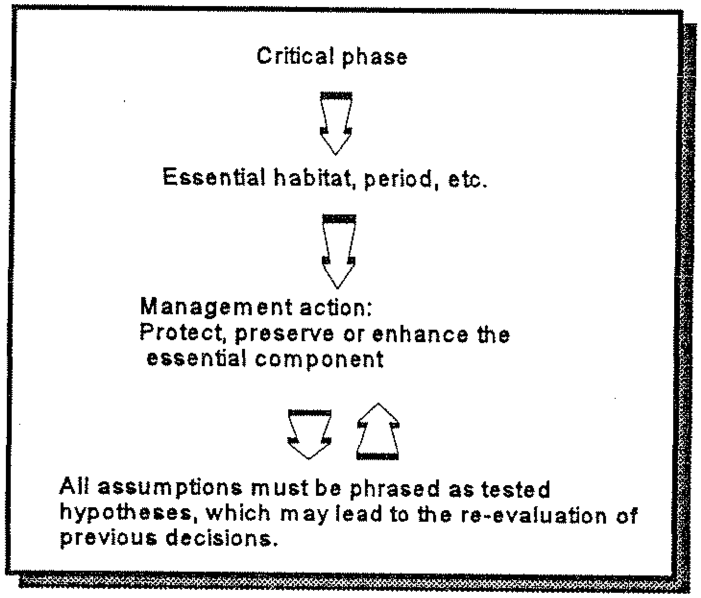

Figure 1

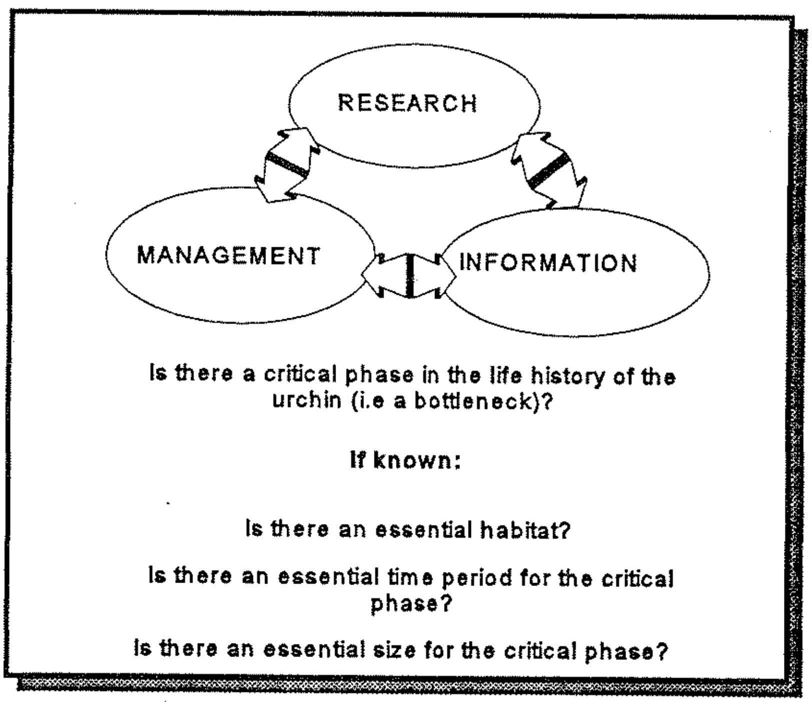

Figure 2

■ The impacts of current harvesting techniques remain unquantified. Arguments were presented regarding the advantages and disadvantages of both hand harvesting on SCUBA and harvesting with dredges (Table 1).

Table 1. Impact and knowledge level of human activity with sea urchins- workshop consensus.

Issue	Ignorance Level		Potential Impact	
	Mobile gear	Diving	Mobile gear	Diving
A. Discards : Sea urchin discards:				
direct	high	high	moderately high	moderately high
indirect	high	high	moderately high	low to moderate
unharvested	high	moderate	moderately high	low to moderate
Kelp	high	moderate	?	low to moderate
Lobster	high	moderate	moderately high	low to moderate
B. Gear Conflict	moderately high	moderate	moderately high	low to moderate
C. Over harvesting	high	high	moderately high	moderately high
D. Disease Introduction	high	?	?	?
E. Mariculture	moderate	?	?	?

■ The survival of discards and the impacts of this discard on the sustainability of the fisheries was identified as a priority for further research.

■ The impacts of the fishery on other existing valuable fisheries is also an important question. Concerns have been raised as to the effects of dredging on early benthic phase lobster, and winter flounder that co-occur in the areas that are fished using this mobile gear.

■ The plausibility of mariculture was considered. Can urchins be grown commercially in terms of both biological and economic feasibility?

■ Finally, socio-economic demography of the current use of the urchin resource or the impacts of a change in this use need to be addressed. Lack of this information has caused many problems in the past with traditional fisheries and this needs to be addressed as early as possible in this fishery in order to avoid much of the gridlock that has hindered management of other fisheries.

Much of the information mentioned above is necessary for the intelligent management of the fishery. However, there is also need for immediate action so that a viable fishery may continue to exist until such information is acquired. The three strategies that the conference attendees voiced as being of top priority were:

1) The implementation of log books and catch reports for both harvesters and processors in order to gain a better understanding of how much effort there is, where the effort is exerted, who is exerting it and what the value of the effort is.

2) In some areas it was felt that reserves should be set up which exclude harvesters. This would serve to allow the discrimination of impacts due to natural causes from impacts due to the fisheries.

3) Establishing a fleet (including all types of harvesters), appropriate to the size of the resource was also considered a top priority. For example, Maine and Massachusetts have a relatively large harvesting fleet whereas New Brunswick Province licences a small number of individuals. Should harvesting be limited to a few and would this lead to a more sustainable fishery or should it be a more public program restrained by other management methods?

Gear restrictions, rotating closed areas, timing of open and closed seasons, methods of harvesting and dealer/processor regulations were management techniques also suggested for immediate consideration. Of these strategies only the gear restrictions and closed seasons are currently in effect in New England fisheries. Massachusetts has a control date for the limitation of new entries into the fishery, however it is unknown if the current fleet size is appropriate to the amount of urchin resources within state waters.

In the relatively short time that there has been an urchin fishery, a great deal of effort has occurred. Hopefully, the enthusiasm and energy exhibited by the participants in this conference will continue and will enable biologists, managers and harvesters to continue to work together to create a sustainable fishery.

The Sea urchin fishery in Massachusetts, current trends, concerns and research.

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Introduction

Through the late 1980's and early 1990's the urchin fishery within the waters of the Commonwealth of Massachusetts was really just a modest extension of the Maine's fishery where SCUBA divers harvested urchins by hand and all urchins were trucked to processors in Maine.

Two years ago, during the winter of 1992-93, harvesting methodology changed with the introduction of the sea urchin drag or dredge. This "new" technology had been used in Ireland and burst on the scene in Massachusetts. Within a couple of months, 150 fishermen were using this gear along the northern shores of Massachusetts, notably near Boston, Salem, and Cape Ann. With the increased landings, urchin processors arrived in Gloucester.

This increased activity and landings brought increased concerns for the resource and the environment. Maine enacted legislation in 1993 to regulate fishing practices; the Commonwealth followed suit. Today we have permit requirements, a closed season between March - August, 2" minimum size, maximum drag size for fishing nearshore, and requirement that fishermen reside in the Commonwealth or in a state that allows urchin fishing access to Mass. residents. N.H. does, Maine does not.

Characterization of the Massachusetts Fishery

In late 1993, MDMF sought to acquire more information on the fishery. First, interviews were conducted with sea urchin fishermen. The purpose of the interviews were to identify those specific areas (and sub-areas) fished, to do so identifying gear type, to try to determine an idea of pressure, and to improve our characterization of the fishery.

The fleet of urchin draggers could be characterized as inshore fishermen with two components: fin-fishermen (draggers, gillnetters) looking for an alternative to depressed finfish stocks and the second group is lobstermen looking for a winter fishery. The gillnetters and small draggers interviewed were more "full-time", that is they targeted urchins during those months the market would accept them. However most lobstermen switched to urchin dragging in late fall and fished until the early spring decline in "uni" quality. The drag attracted much interest since the gear was rather inexpensive; most fishermen spent less than $1000 to purchase or build an urchin drag, and as already noted, their inshore vessels were ideal for this fishery that is conducted primarily in waters less than 30 ft deep, with some harvesters preferring to fish the 10 - 20' range. Preferred bottom types were primarily hard bottoms but some included gravel bottom.

Divers remained primarily within 3 - 15' depths, working on the "feed line", where they were able to select the urchins of highest quality. Several divers said they work an area and then leave it alone for a couple weeks and then return to check if more urchins have moved onto the feed line. All expressed concern regarding the potential damage done be dredgers to the urchins and bottom, and felt that dredging should not be allowed. One harvester also felt that as dredgers are less selective as to the quality of urchin they harvest, they drive prices down. Several divers would like to see the fishery open to divers year round.

Sea Sampling

The second means of acquiring information on the fishery involved direct monitoring of the sea urchin harvesting in the two principle fishing areas. A total of 8 sampling trips were conducted on three separate days and from the ports of Beverly, S. Boston and Gloucester. One trip from each area was administered by the Gear Technology group to view the effects on benthic habitat in the dredge fishery by using underwater video equipment. The remaining trips were analyzed exclusively by the sea sampling group. The monitoring included an overview of fishing activity by MDMF and Environmental Law Enforcement personnel aboard a USCG patrol boat.

In Salem Sound the dredging occurred throughout much of the harbor (Figure 1). Some fishermen worked specific areas while others seemed to fish less discriminately. In Boston Harbor dredging was confined to specific sites (Figure 2).

Dredge type differed in the two harbors. All dredges were 48 inches wide and employed a chain mat behind the bail. In Salem Sound, a variety of dredges were seen; most weighed about 150 pounds (Figures 3 & 4), but one dredge probably weighed about 400 pounds. In Boston Harbor, the dredge was fairly uniform in construction; it was similar to the illustration attached here, but had fixed round rubber discs on each side between the springs and the chain. These discs were presumably used to protect the vessel when hauling back the drag, particularly when done with a lobster pot hauler.

Salem Sound

The catch data was analyzed by area and by vessel (trip). Percent discard rate of urchins ranged from 46% at the Eagle Bar area to 71% near Searle Rocks and averaging 57% for all areas. The condition of the discarded urchins (undersized) appeared to be good, however it is unknown at this point how cold air temperatures and abrasions of trawl-caught urchins can effect survival. The air temperature on this particular day was between 10 - 15° F and discarded urchins were kept on deck for about 5-10 minutes.

The amount of urchins retained per hour was determined in order to compare relative catch rates for the different areas. The lowest rate of retained urchins per hour was determined to be 33 lbs. at the Searle Rocks subarea and the highest was 172 lbs. per hour near the Dry Breakers. Average retained per hour for all subareas sampled in Salem Sound was 111 lbs. The amount of kept urchins per tow was lowest at 5 lbs. near the Searle Rocks subarea and peaked at 77 lbs. per tow near Haste Shoal. The average for all areas was about 32 lbs./ tow. The following chart gives the overall results for the three sampling trips conducted in the Salem Sound area.

AVG. URCHINS RETAINED/HR	111 lbs
AVG. % DISCARD	57 lbs %
AVG. # TOWS/TRIP	18
TOTAL # TOWS	54
AVG. TOW DURATION	16 min
TOTAL TOW TIME	885 min
TOTAL URCHINS RETAINED	1935 lbs
TOTAL URCHINS DISCARDED	2418 lbs
TOTAL ROCK	1221 lbs
TOTAL MUSSELS	959 lbs

The catch usually included a bycatch of cobble, kelp, blue mussels, crustaceans and a few lobster and winter flounder. The marine animals were still alive and suffered little damage. Macroalgae, particularly *Laminaria*, was only caught in two of about 10 areas fished.

Boston Harbor

Fishing activity during the four trips took place in four general areas: northern edge of Spectacle Island, northern tip of Long Island, the west head area of Peddock's Island, and the area south of Boston light from Nash Rock Shoals northeast to Shag Rocks.

The fishery here was very similar in method to the Salem Sound area fishery, however, the volume of available sea urchins was far less and the quality and percent roe content was quite superior with the majority of kept product having a 10- 20% roe yield. Subsequently, the Boston - based fishermen were able to compete on a daily basis with those from the Salem Sound region since prices paid for higher roe yields will offset smaller landings.

Tow durations in the Boston Harbor areas averaged 8 minutes. Dredge style between the two areas was similar to that of Salem Sound, however, one Boston vessel was documented as having a 4" mesh size on the cod-end. Top squares panels of twine above the bridles and wheels were common on the dredges here but were not present on the Salem Sound vessels.

Relatively large quantities of rock were present in tows made in Boston Harbor. For this reason, rates of catch per hour were determined to compare take of rock within the different subareas. Kelp was present in the catches from only one area and this consisted of substantial quantities with severed stalks and ripped holdfasts.

Underwater Observations

Underwater video was mounted on three different dredges: two in Beverly-Salem Harbor and one in Boston Harbor. This totaled an at-sea effort of three days. The underwater video documented the action of the dredge and the bottom type fished by the dredge. The dredge was seen to be effective in fishing rough bottom and catching sea urchins. The bottom type in most cases did vary with sandy areas seen between rocky outcrops. One area that was an exception was on Middle Ground and several other areas in Salem Sound. The bottom type observed by video was of a finer particulate substrate. This was also evident when some of the dredges were hauled back and a plume of mud/silt trailed the dredge. The dredge did detach kelp and overturn cobble. The magnitude of each of these actions is unknown. The results of the video will be shown later today.

As is often the case when new technologies emerge in fisheries, problems developed.

1) Gear conflicts occurred when urchin draggers towed through lobster trawls. These conflicts occurred during the late summer and fall when lobster fishing was at its peak. Since most lobstermen were still fishing for lobsters, these conflicts were caused by fishermen unfamiliar with the setting patterns of lobster gear. MDMF was petitioned by Salem area lobstermen to ban urchin dragging in Salem Sound. DMF and the Massachusetts Marine Fisheries Commission have "tabled the request hoping these two user groups can find ways to co-exist without the requested ban.

2) Concerns were raised about impacts on winter flounder spawning. This issue was first raised by some gillnetters who were banned from winter flounder fishing within 1-2 miles from shore February-May since 1985. They resisted any new DMF management proposals to conserve winter flounder since they suspected the dredging would impact winter flounder spawning. Most of the areas being dragged for urchins had been closed to dragging for over 50 years. Moreover the areas of high urchin density being shallow and primarily hard bottom **were probably never dragged at all.** Supporting evidence for dragging never occurring in these areas is the number of antique bottles, anchors and other surprises appearing in the catches.

The repeated dragging over the urchin "beds" concerned these fishermen and DMF staff biologists concerned about winter flounder. Regulations were enacted that prohibited the urchin draggers from fishing during the flounder spawning closure, but soon over 75 fishermen pressured DMF and MFC to allow dragging during Feb and early March. DMF suspended the closure and intensely sampled the fishery during February 1994 with observers on 8 trips, studies of dredge action through underwater cameras, and a complete census of all urchin drag fishermen to determine where and when they fish with a description of their gear.

3) Concerns were raised about impacts on juvenile lobster.

DMF received many complaints from divers about the impacts of the urchin drag on kelp, cobble beds and juvenile lobster. Wardens also reported seeing small lobster often retained in the catch especially during the warmer months when the lobster activity is greater. Many of the lobstermen have testified that they do not want to risk their primary fishery (lobstering) by damaging habitat and small lobster. "Show us there's a problem, and we'll put the drags away", they've said.

4) For purposes of licensing the fishermen and gear type, how should the drags be treated? DMF established a control date and enacted a moratorium on new "mobile gear" permits. Confusion was created when at first we required all urchin draggers to possess a mobile gear permit. But we reconsidered when we realized most were small scale fishermen that never dragged before and do not have the capability of towing an otter trawl, the primary gear type of the Commonwealth's mobile gear fleet. Currently, fishermen do not need our "Mobile Gear Coastal Access Permit" as long as they employ a drag less than 4 ft. wide.

Concerned about the impacts on habitat, flounder spawning, juvenile lobster, - as well as gear conflicts, DMF and MFC have established a "control date" for urchin dragging and may limit participation in the future.

In conclusion, DMF Administration and the members of the Commission are all anticipating advice from us at this conference about how to manage the urchin fishery. The Commonwealth has 360 permitted urchin fishermen and about half may be eligible to drag. Experience has shown that when fishing practices become "traditional", they become very difficult to regulate due to the social and financial cost. After just two controversial years, this fishery is <u>not</u> yet traditional so the time is now for assessing the gear and its risks, and make those hard choices to manage the urchin fishery to make it sustainable, but also ensure that other affected fisheries for flounder and lobster are sustained as well.

This work was supported by the Inter-jursidictional Fisheries Management Support Program (IJFMSP) granted by the National Oceanic and Atmospheric Association (NOAA).

Figure 1. Urchin grounds in Beverly- Salem harbor.

Figure 2. Urchin grounds in Boston harbor.

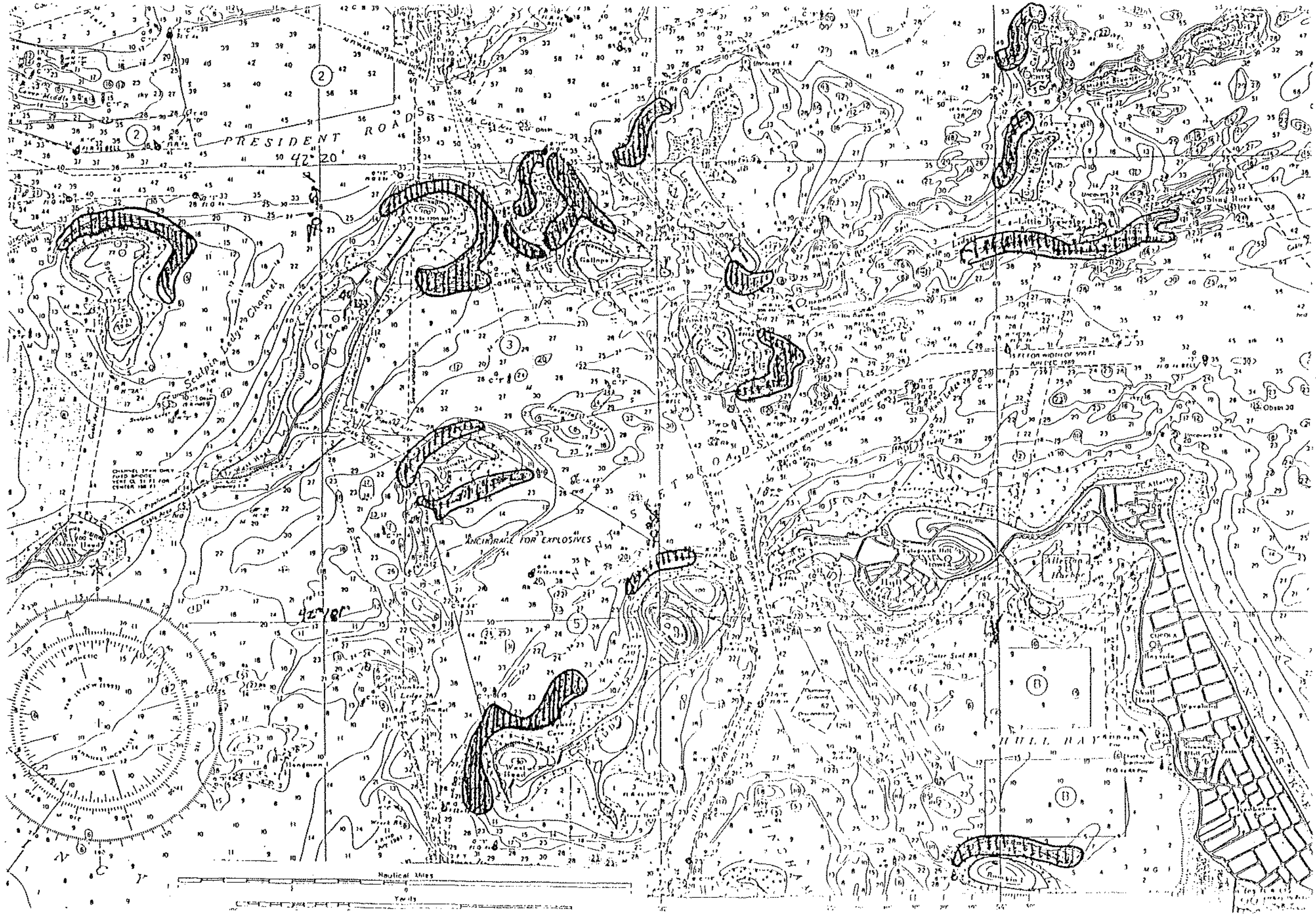
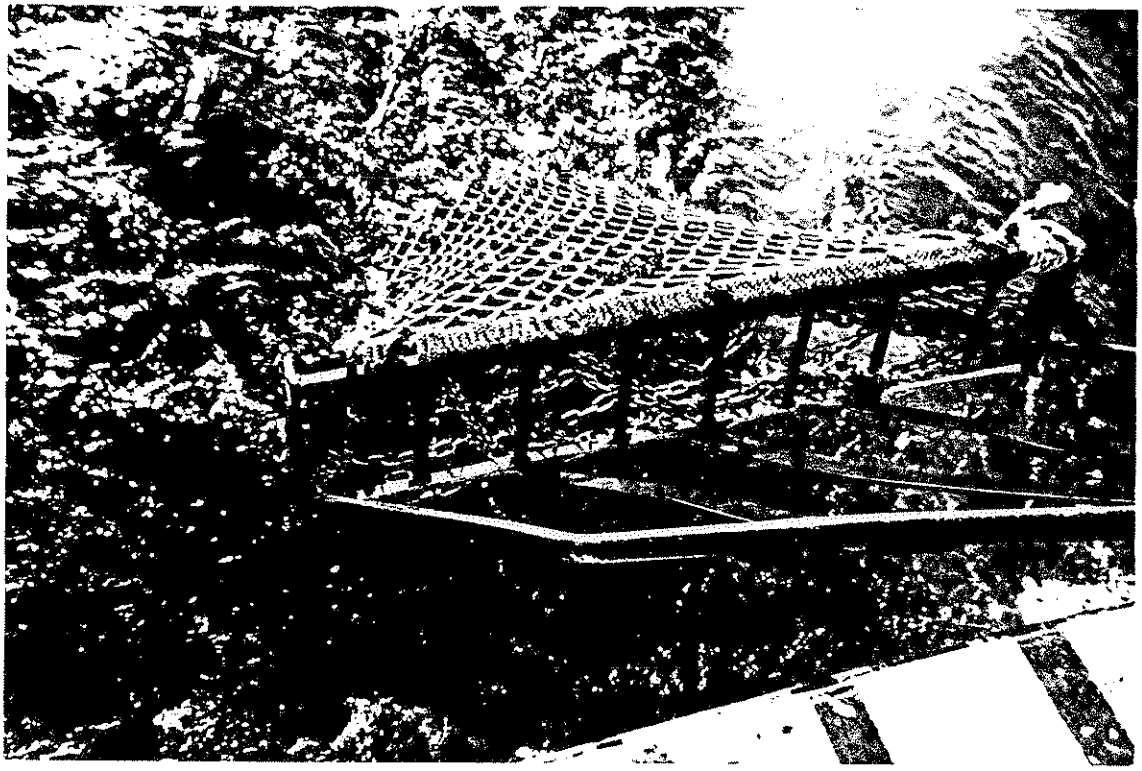


Figure 3. Typical sea urchin dredge.



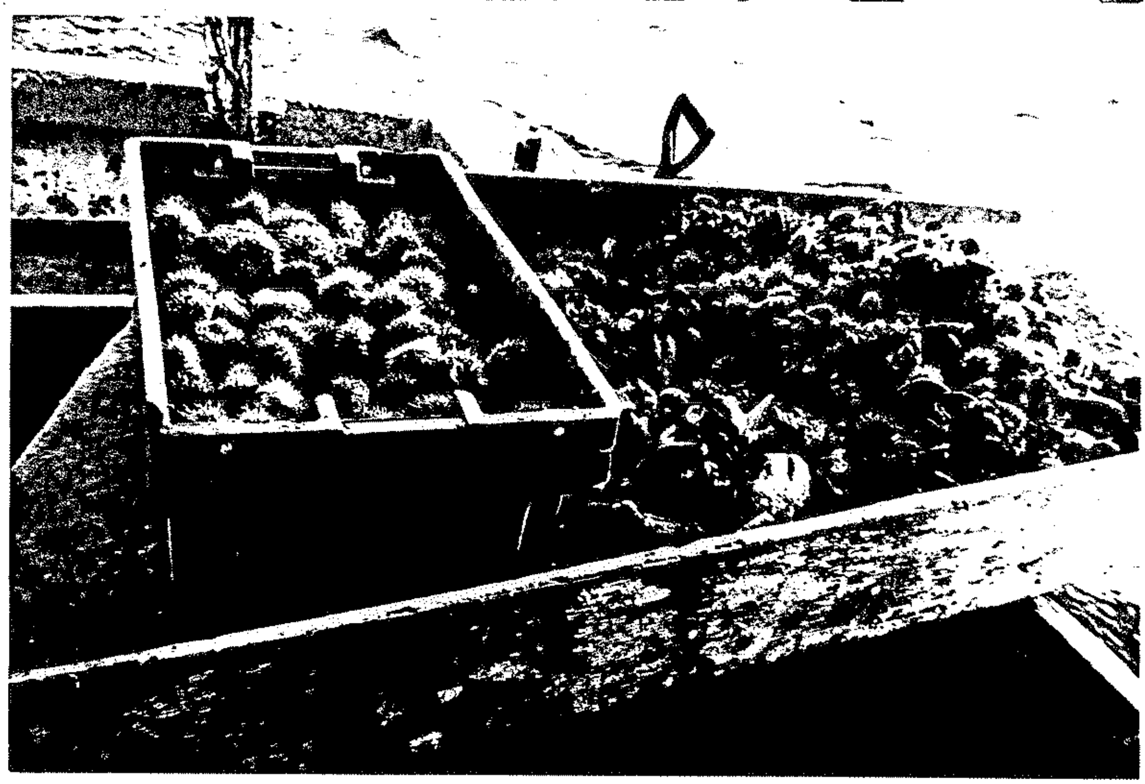


Figure 4. Kept urchins(in tote) and discard from one tow of the dredge.

The Green Sea Urchin Fishery
in Southwestern New Brunswick.

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Introduction

The fishery for the green sea urchin *Strongylocentrotus droebachiensis* in New Brunswick is currently centered in Charlotte County in what is termed the Quoddy region. It encompasses Grand Manan, Campobello, Deer Island, Passamaquoddy Bay and the coastline up to Point Lepreau (Fig. 1). There are three main fishing areas which are defined on the basis of lobster fishing areas (LFA's). The Lepreau area (LFA 35) has two licenses, the lower Quoddy region (LFA 36) has 18 licenses and the Grand Manan area (LFA 38) has 6 licenses for a current total of 26 licenses. The fishery is composed of a combination of divers and draggers who generally participate in several other fisheries as well such as scallops and lobster. The current division of licenses are 16:10 for dragging versus diving. The landings from the fishery have been rising continually from 1989 as the experience of the fishermen grows and the markets improve. Official landing statistics from 1993 were approximately 1,000 mt (Fig. 2). There is a small fishery for sea urchins developing in Nova Scotia, but the landings are presently only about 10% of the New Brunswick landings (Fig. 3).

History

The fishery in New Brunswick originally started on a very small scale in the early 1960's as a supplement for the American market. The sea urchins were harvested from small wooden boats in either Harbour deLute or the Narrows using two scallop drags welded together and which had a codend made of double-knit twine. Buyers from Maine or Massachusetts would come to Campobello just before Christmas and purchase approximately 100 to 200 bushels of sea urchins at a price of $2.50/bushel. In the 1970's, a sea urchin processing plant was established on Grand Manan (Pesca Seafood) where urchins were processed for a few years, but it subsequently closed. This operation was investigating the use of a pump harvesting system for collecting sea urchins from the bottom. At this time there were also two surveys done for sea urchins; one by Neish (1973) in the Grand Manan area and the other by MacKay (1976) for the general Quoddy region. The fishery in New Brunswick remained on hold until the early to mid 1980's when boats from Campobello began to supply the American market through Lubec, Maine when the demand for sea urchins was in excess of that able to be supplied by the local Maine fishermen. There was also some diving occurring during this period on Grand Manan. By the end of the 1980's the fishery had become established and the markets were becoming stronger. Processing was initiated at this time on both Grand Manan and Deer Island.

Management

The sea urchin fishery is tightly regulated in New Brunswick and at current there are no permanent licenses, but rather the fishermen are using developmental permits to prosecute the fishery. This will likely change shortly for those fishermen who have established themselves in the fishery and their licenses will be made permanent. Management of the fishery is based on the Lobster Fishing Areas (as described above) and is a consultative process where the industry and management produce a conservation management plan for the fishery which deals with the regulations (Table 1), effort expended, required research and the penalties for breaking the rules (Table 2). Basically, the regulations revolve around seasons with a minimum size limit with restrictions on the type of gear used (Green sea urchin drag) and the number of divers which can be in the water from a single vessel. There is mandatory reporting of catches with standardized log forms in order to track the catch-per-effort in different areas during the evolution of the fishery (Fig. 4). Industry members are asked to sign a Memorandum of Understanding which is attached to their permit which indicates that they understand the regulations, agree with the principles and that they are willing to abide by them and the established sanctions (Fig. 5). The industry has also set aside refuge or conservation areas so that unharvested populations of sea urchins can be studied and compared to those that are being harvested. *(A video was shown during the presentation which showed the various harvesting procedures being used in the fishery either presently or in the past).*

Biology

Initial biological studies dealt with the estimate of the standing stock of sea urchins, their distribution and also their size-frequency distribution. In 1992-93 a stratified-random survey was conducted around Grand Manan, Campobello and Deer Island using divers and a spooling transect method. A total of 56 boat charter days were used to accomplish 199 transects and the measuring of over 60,000 sea urchins. Results show that for the Deer Island and the Campobello areas there is a large percentage of the population which is below 50 mm while that proportion decreases dramatically as one approaches Grand Manan (Fig. 6). The survey indicated the total biomass and harvestable biomass for each of the three areas varied from approximately 2,000 to 37,000 tonnes (Fig. 7) based on a 50 mm test size and not including any assessment of the gonad quality. There was significantly more biomass associated with the shallow waters at all sites examined (Fig. 8).

Recruitment to the benthic stage was measured using 100 cm^2 astroturf panels at four sites in the Quoddy region; two on Grand Manan, one at Beaver Harbour and the other in the St. Croix estuary off the Biological Station. Results indicated that settlement ranged from 20 to 60 juveniles per m^2 and that settlement seemed to occur in late July and August (Figs. 9, 10).

Some research was also conducted on the relationship between the test diameter and the demi-pyramid length as a possible indicator of nutritional condition of the sea urchin. Urchins from the same population were taken into the lab and one group was fed *Laminaria* while the other group was starved. Significant morphometric differences were found between the two groups after five months (April). Comparison of the two groups with animals harvested from the field in July indicated the animals from the two field sites appeared to be in relatively good shape (Fig. 11).

References

MacKay, A. 1976. The sea urchin roe industry on New Brunswick's Bay of Fundy coast. Report to the New Brunswick Department of Fisheries. Fredericton, New Brunswick. NB75-1. 92p.

Neish, I.C. 1973. The distribution of sea urchins in Charlotte County, New Brunswick. Report to New Brunswick Dept. of Fisheries and Environment, Fredericton, New Brunswick. AMR 73-3B. 21p.

Figure Captions

Figure 1. Map showing the current centres of fishing activity for the green sea urchin in southwestern New Brunswick.

Figure 2. Landing figures for the green sea urchin in southwestern New Brunswick from 1987 to 1994. Note that the landing figures are on a yearly basis and therefore the landings from the second half of 1994 have not yet been recorded. Data from the Statistics Branch, Dept. Fisheries and Oceans, Halifax, Nova Scotia.

Figure 3. Division of the landings of green sea urchins between Nova Scotia and southwestern New Brunswick for the fishing season 1992-1993 (October to May). Data from the Statistics Branch, Dept. Fisheries and Oceans, Halifax, Nova Scotia.

Figure 4. Copy of the fishing log for draggers used to monitor the activity of the fishing vessels and to calculate the catch-per-unit-effort of the fleet. Logs for divers are very similar in composition.

Figure 5. Copy of the Memorandum of Understanding between the fishermen and the Dept. of Fisheries and Oceans which indicates that the licensee understands the regulations, the sanctions involved and that he is willing to abide by these terms. This form is not compulsory to obtain a fishing permit.

Figure 6. Size frequency of sea urchins taken during the biomass survey in 1992 of Grand Manan, Campobello and Deer Island.

Figure 7. Total biomass and harvestable biomass of green sea urchins determined from the biomass survey in 1992 taken at Grand Manan, Campobello and Deer Island. The harvestable biomass was calculated from animals greater than 50 mm in test diameter. No account is made of roe quality in this estimate which would tend to reduce the figures for the harvestable biomass.

Figure 8. Mean harvestable biomass in shallow water (<10 m) and deep water (>10 m) determined from the biomass survey in 1992 taken at Grand Manan, Campobello and Deer Island. The harvestable biomass was calculated from animals greater than 50 mm in test diameter.

Figure 9. Settlement rates of sea urchins onto 100 cm^2 panels of astroturf at Prescription Weir and Green Island on Grand Manan from June to August in 1994.

Figure 10. Settlement rates of sea urchins onto 100 cm^2 panels of astroturf at Beaver Harbour and the St. Croix Estuary near the St. Andrews Biological Station (SABS) from June to August in 1994.

Figure 11. Mean jaw length (demi-pyramid) to test diameter ratio for sea urchins which were either starved or fed from November 1993. Two sites from commercially fished areas (Nantucket Island, Grand Manan and Beans Island, Deer Island) were also included in the June 1994 sample for comparison.

Table 1

Conservation Harvesting Plan Provisions

LFA 35

No licenses are currently valid due to inactivity. Consideration will be given to a new draw in September if applicants can demonstrate an ability and interest to fish in the portion of LFA 35 open to dragging. LFA 36 CHP provisions will apply if replacement licenses are issued, pending further consultations with the two licensees.

LFA 36 + LFA 38

Season: LFA 36 - October 1 - May 15
LFA 38 - November 1 - April 15

Comments: Season will be "tested" this year and reviewed in context of growing conservation oriented scientific information and relative to roe yields and quality. The request for an experimental extended season east of Point Lepreau will be further evaluated pending internal industry review.

Size Limit: 2"

Comments: Enforcement officers will be working with fishers to determine best methods to measure urchins. Initially, the horse-shoe type of measure used in the US will be tried; efforts will be made to harmonize measuring techniques in both countries. Initially, for the purposes of sanctions recommendations, the degree of violation will be assessed on the basis of weight, not by count. Success of this method will be assessed early in the fishery.

Sea urchins to be sorted at sea with undersized animals to be returned promptly to viable sea urchin habitat.

Comments: The intent is to assure that every effort is made to return undersized urchins to the fishing grounds for recruitment purposes. In 1994-1995, this provision will allow for urchins to be culled "at sea" with small urchins to be returned on viable habitat in recognition of difficulties in sorting on the grounds in poor weather conditions. The wording may have to be reviewed if it is found that urchins are not being placed on viable habitat. Industry and DFO efforts to further develop (and possibly include as a CHP provision) on-board automated sorters is essential.

Time of Harvesting: Between daylight and dark.

Comment: Fishing cannot commence before 1/2 before officially reported time of sunrise; it must cease before 1/2 hour after official sunset. Self-enforcement is required.

Gear Limits:

Draggers:

LFA 38, Maximum of 6' of "Green" gear, scallop drags prohibited.

LFA 36, Maximum of 10' of "Green" gear; scallop drags prohibited.

Divers:

LFA 38, Maximum of 2 divers in the water. One skiff to be used. One diver may be suited on the surface for safety purposes.

LFA 36, Maximum of 4 divers in the water; one diver may be suited on the surface for safety purposes. Two open skiffs of a maximum of 21' each may be used in the operation and must remain within 1000' and within sight of the licensed vessel.

> *Comments*: Occupational Health and Safety rules may require an in-season revision to these provisions. High fishing effort remains a concern of DFO; evaluation of these limits will be an ongoing feature of the plan. The drag limits set in the CHP will be unchanged for a minimum of two fishing years (ie until May 1996) given the level of investment to change over to the new limit.

Statistical Reporting: Fishers will report accurately all landings and sales monthly by the 10th day of the following month.

> *Comments*: Accurate and timely statistics are essential for the effective conservation and orderly management of the fishery. For this section respecting the timeliness of reporting, one reminder will be provided before sanction action is taken. If mis-reporting is deemed to be a significant problem in the new fishing year, industry will be called together for the consideration of a Dockside Monitoring Program. The industry request for proper log books will be followed up budget limitations may require "user-pay" for log books (now being costed). Attached to this CHP (or to be provided by September 25) is a checklist of reporting requirements/responsibilities.

Protected Areas for Scientific Research: Fishers have identified potential sites for protected areas including the Prescription weir area of LFA 38 and a site in proximity to Pendleton Island in LFA 36. The actual coordinates of the areas will be finalized and distributed.

Sanctions: See attached table for recommended penalties that have been agreed to by all participants:

> *Comments:* Concern about how officers will enforce the 2" size limit have been raised. This will be a matter for ongoing consultation and will be refined as experience is gained by fishers and by officers as to the best methods and how to deal with unanticipated problems. The enforcement focus will be on deliberate retention or an unacceptable disregard for the provision.

Table 2.

RECOMMENDED PENALTIES (LICENSE SANCTIONS) IN THE SWNB SEA URCHIN FISHERY

- The Regional Director General of the Department of Fisheries and Oceans, on authority delegated by the Minister, may cancel or suspend ("sanction") licenses through an administrative law process.

- The penalties suggested in this document are supported, in writing, by the SWNB sea urchin license holders. The level of penalty is deemed necessary to deter illegal activity and sustain the resource.

- The penalties suggested are for "first offenses"; subsequent offenses would result in stiffer penalties. The penalties would apply from the opening of the following season.

OFFENCE	PENALTY
No Valid License/condition	2 weeks
Night Fishing	1 month
Unauthorized Vessel/operator	2 weeks
Unauthorized Gear	6 months
Exceeding authorized number of divers or size or number of drags	6 months
Fishing in closed or unauthorized area including scientific study area	6 months
Fishing in closed time (out of season)	6 months
Shackled gear in closed area	6 months
Transhipping to or from unlicensed vessels	1 year, all fishing privileges
Size Limit Not sorting/returning undersized to grounds	1 week for < 10% of catch, by weight 2 weeks for 10-25% of catch, by weight 6 months for > 25% of catch, by weight 6 months
Retention of unauthorized species	6 months
Failure to submit log record/purchase slip	6 months
Misreporting so as to misrepresent actual captures	6 months
Late or incomplete reporting	1 month
Obstruction of fishery officer; making false statements	6 month
Other violations of license conditions or regulations	1-6 months

Fig. 1

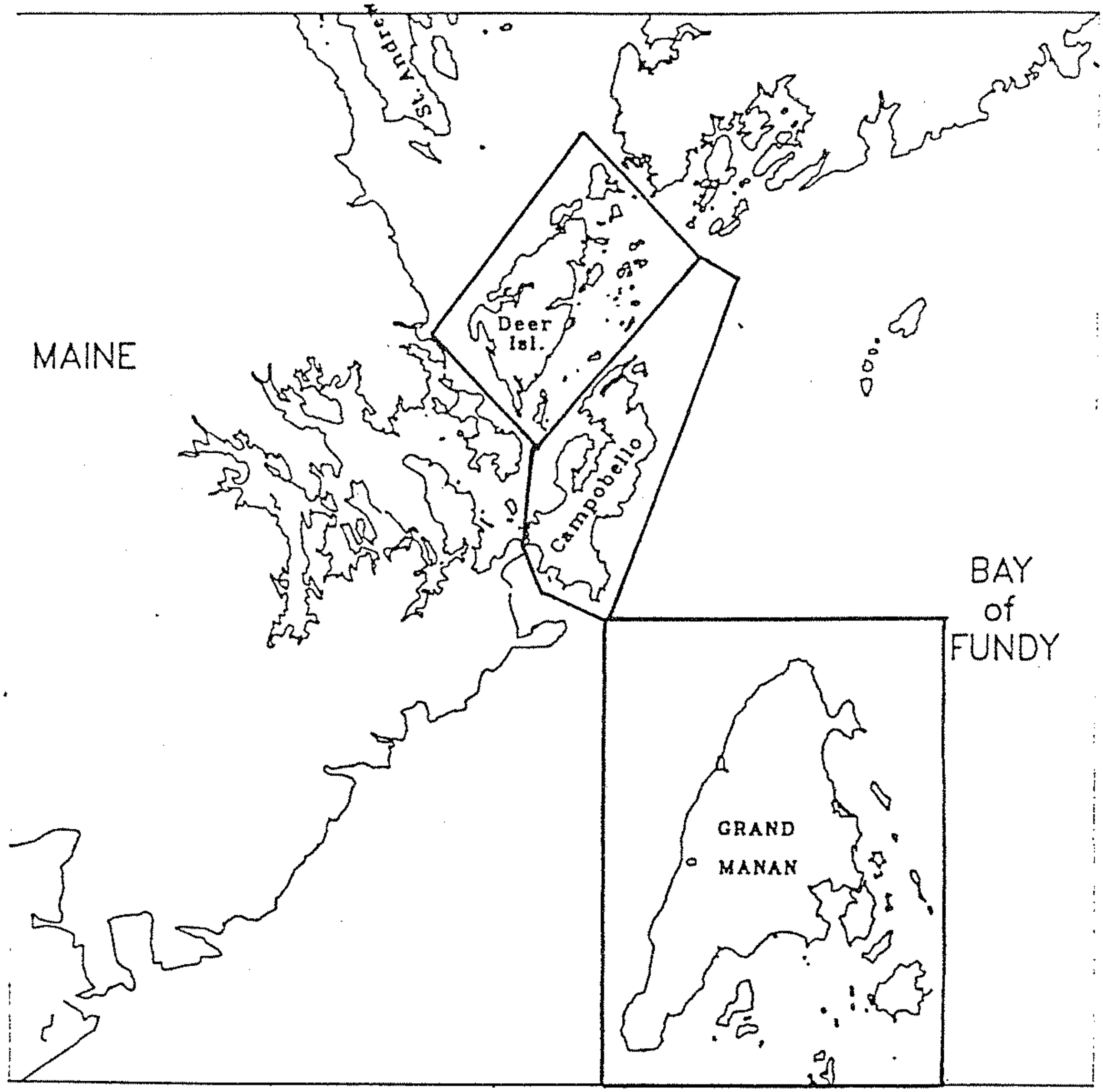

St. Andrews
Deer Isl.
MAINE
Campobello
BAY of FUNDY
GRAND MANAN

Fig. 2

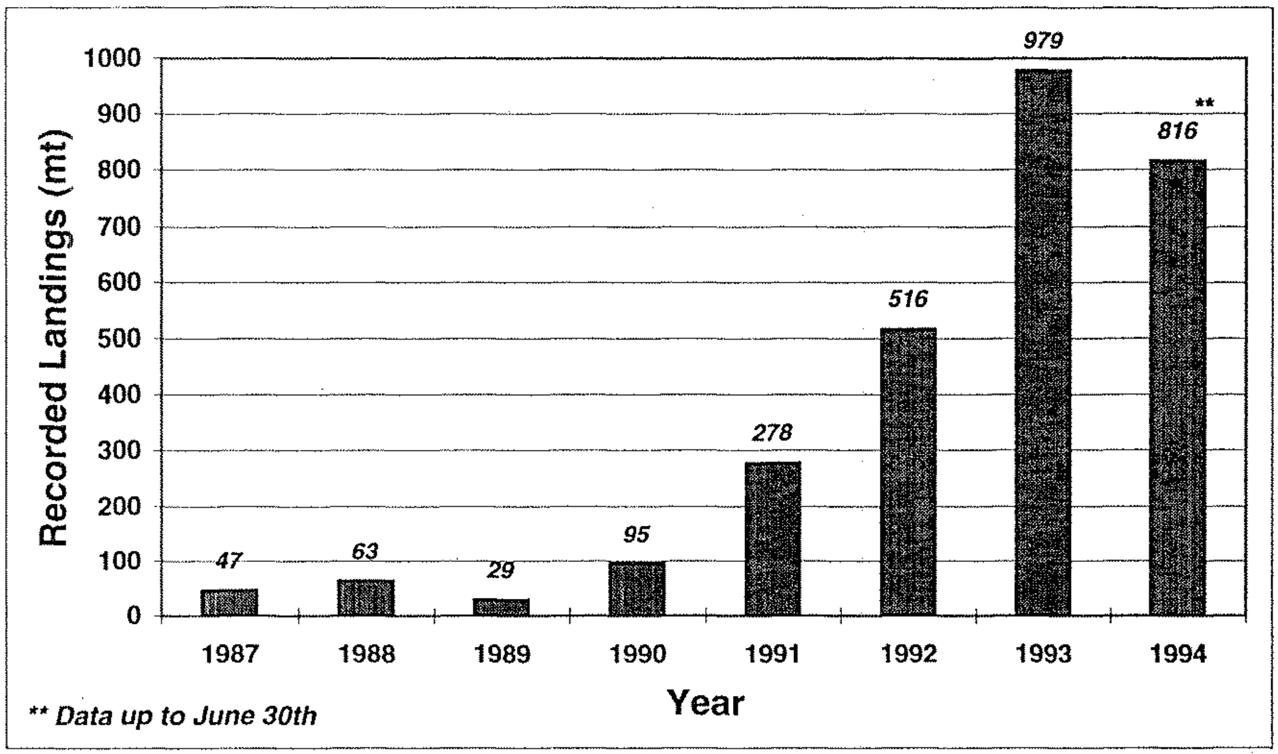

Recorded Landings (mt)
1000
900
800
700
600
500
400
300
200
100
0
47
63
29
95
278
516
979
816
**
1987
1988
1989
1990
1991
1992
1993
1994
Year
** Data up to June 30th

Fig. 3

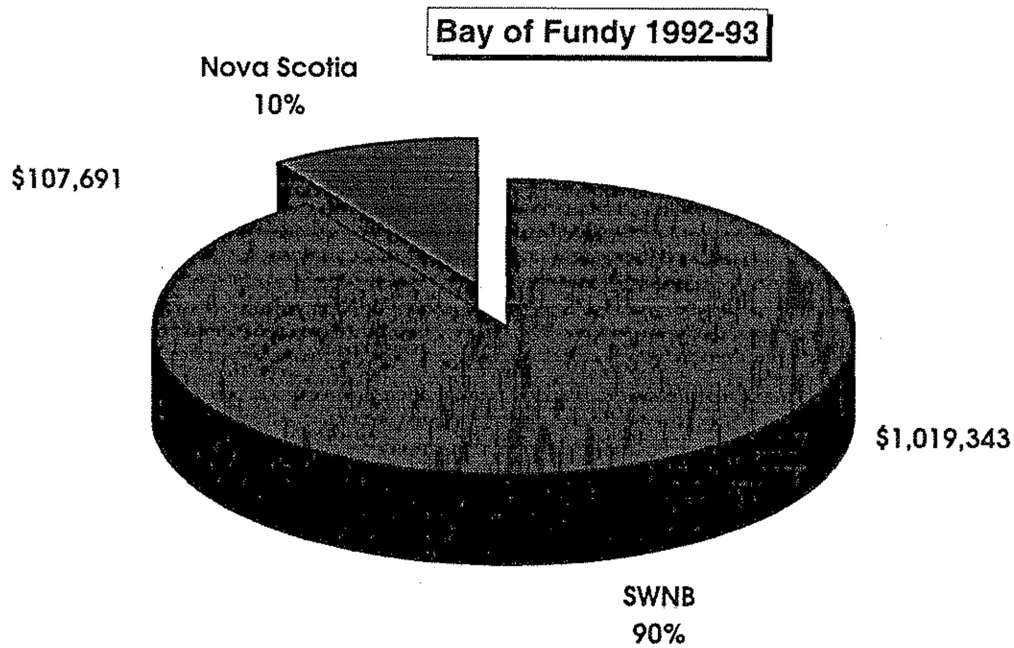


Fig. 4

Exploratory Urchin Fishing Log/ Slip (Dragging)

Please Return To:

Mr. Hank Scarth, Area Manager
Dept. Fisheries & Oceans, P.O. Box 210
St. Andrews, New Brunswick, E0G 2X0
(506)529-5850 (Phone)
(506)529-5858 (FAX)

License Holder: ____________ Number of Crew: ______ Size of Gear: ________

Vessel: __________ CFV #: __________ Vessel Size (ft) ________ ICNAF Division: ______

Date (Day/Mon/Yr)	Fishing Location (be specific)	No. Tows	Average Tow Time (min)	Fishing Time Start	Fishing Time Stop	Amount Fished (lbs)	Amount Sold (lbs)	Price per lb	Buyer	Port Landed	Comments: Bottom type egg size, roe quality

This log/slip must be received no later than 10 days from the end of the month to DFO

Licensee Signature: ______________

Fig. 5

The SWNB Sea Urchin Conservation Harvesting Plan

Memorandum of Understanding

For the License Holder

I, ____, sea urchin license holder in Lobster Fishing Area _______, acknowledge receipt and acceptance of the provisions of the 1994-1995 Sea Urchin Conservation Harvesting Plan. I understand and support the Recommended Penalties (Sanctions) in the SWNB Sea Urchin Fishery contained herein.

Signature: ________________________________

Location ________________________________

Date: ________________________________

For the Department of Fisheries and Oceans

I, ____, representative of the Department of Fisheries and Oceans acknowledge and confirm DFO's commitment to the principles of co-management and partnership in the conservation and management of the sea urchin fishery as embodied in the Conservation Harvesting Plan.

Signature: ________________________________

Location ________________________________

Date: ________________________________

Fig.6

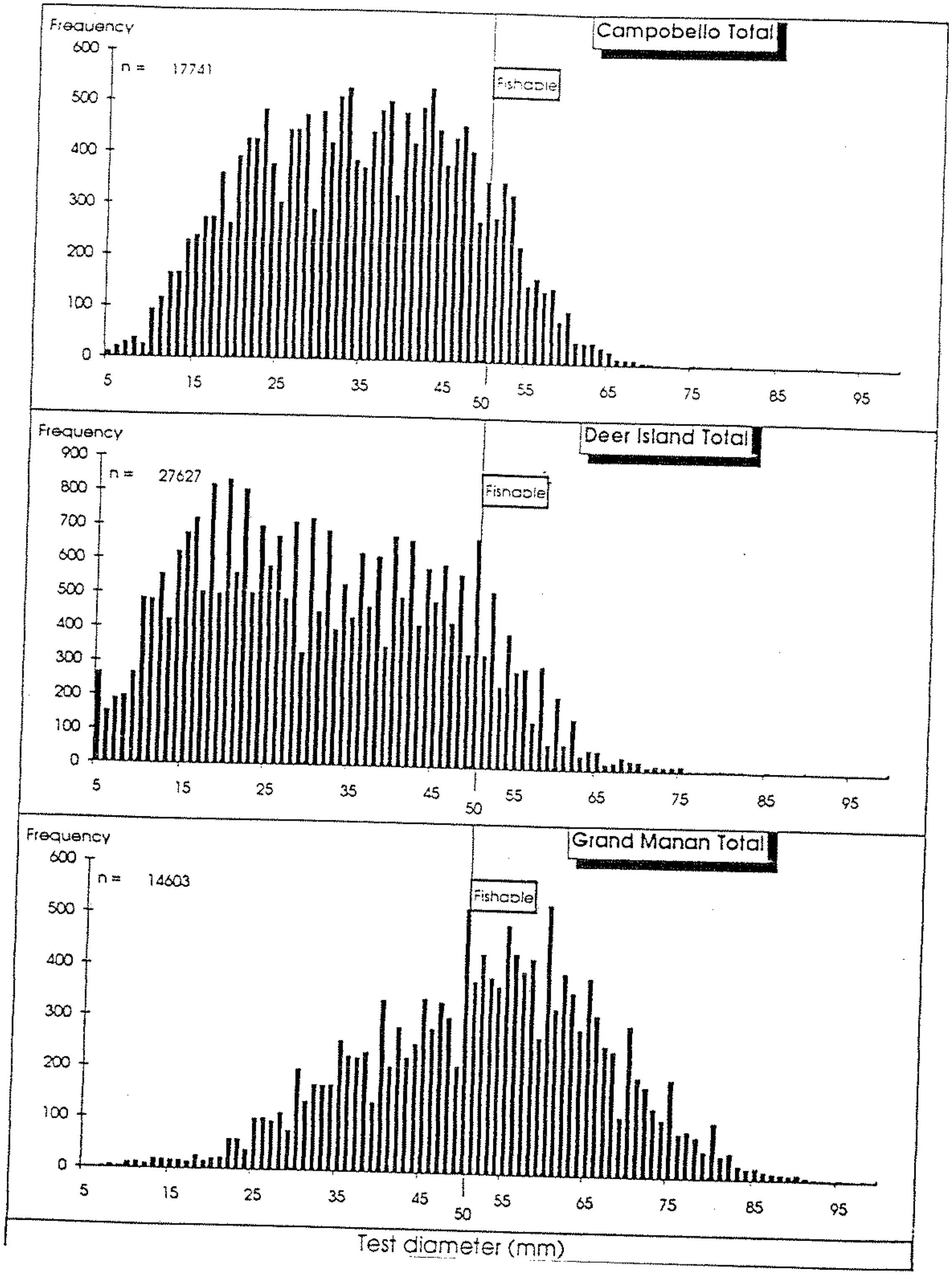

Campobello Total
Frequency
n = 17741
Fishable
Deer Island Total
Frequency
n = 27627
Fishable
Grand Manan Total
Frequency
n = 14603
Fishable
Test diameter (mm)

Fig. 7

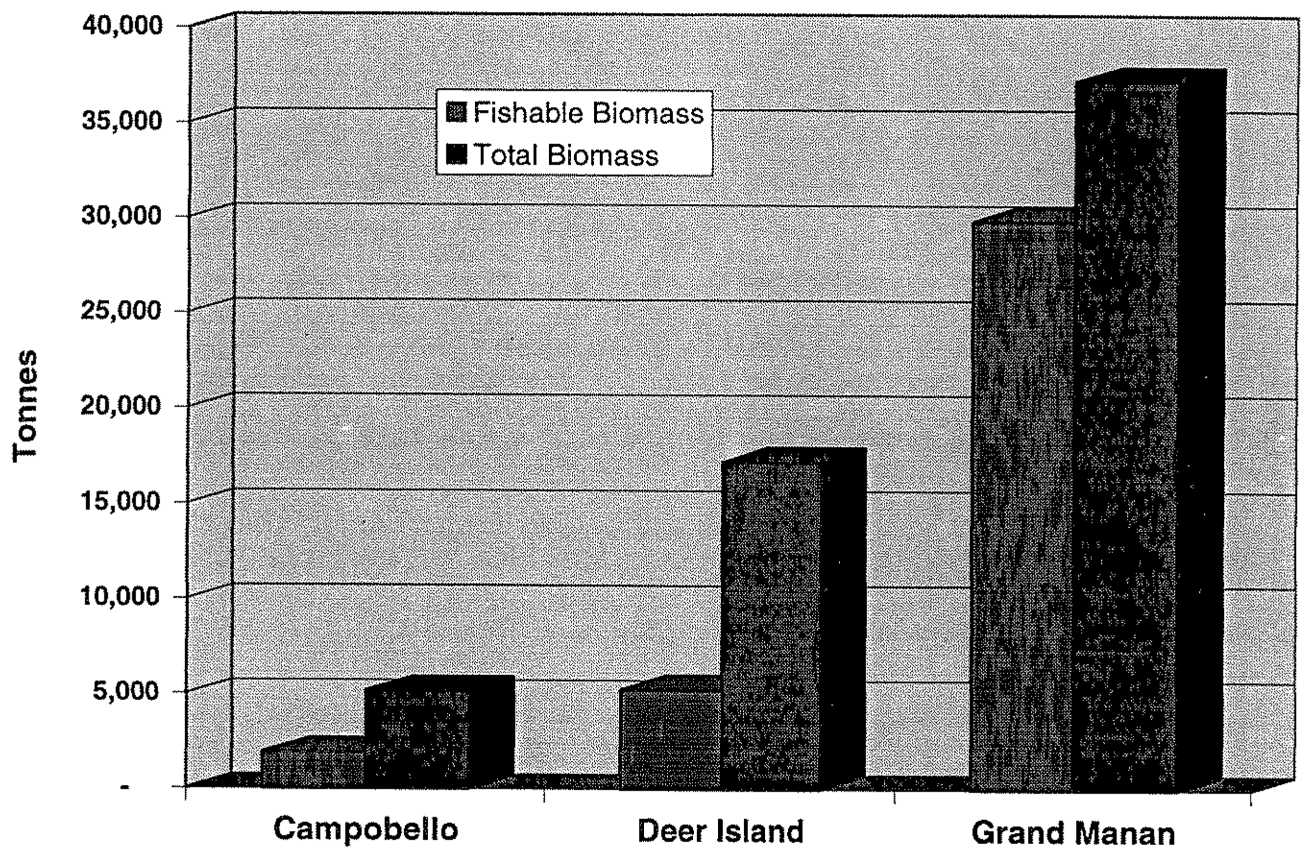
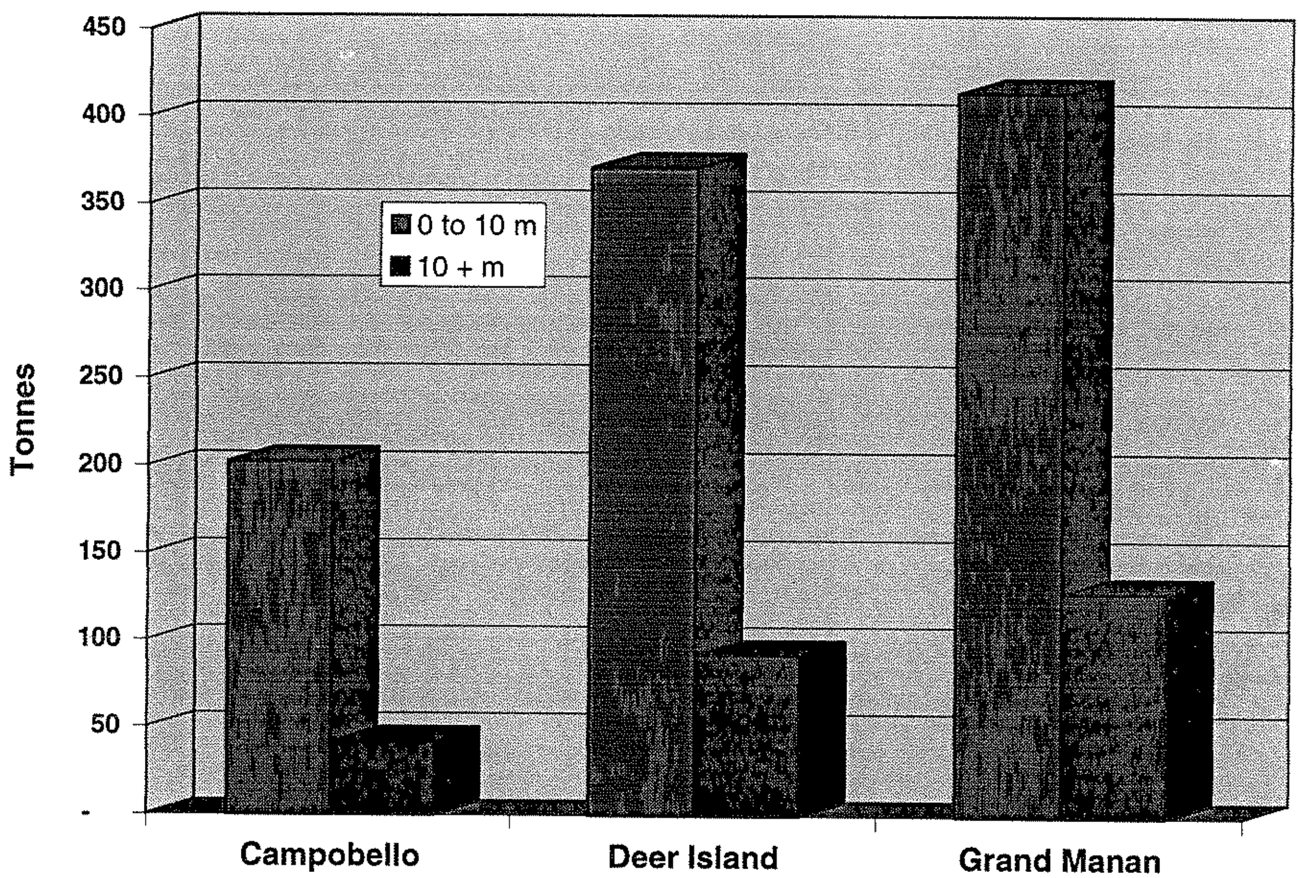
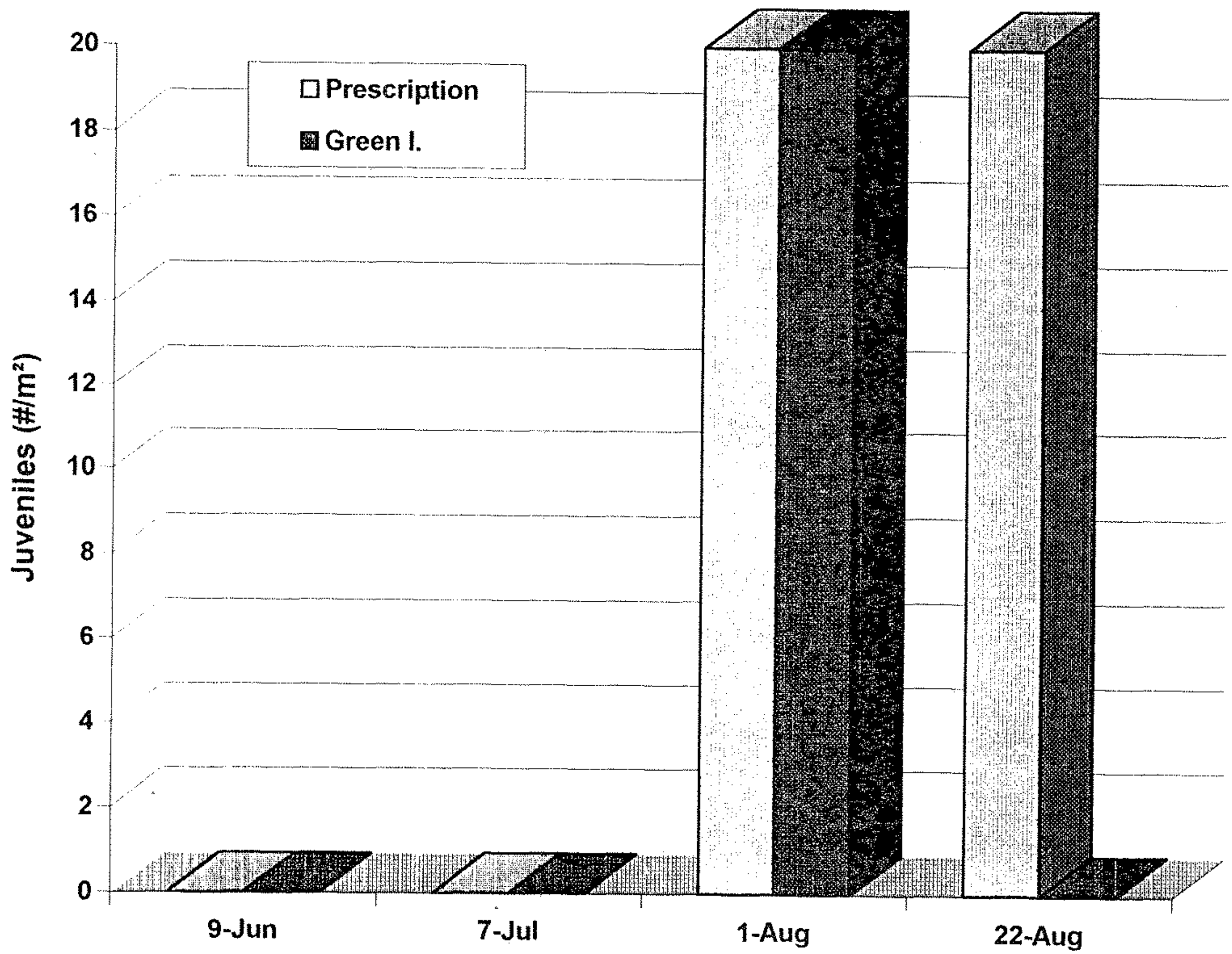

40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
-
Tonnes
Fishable Biomass
Total Biomass
Campobello
Deer Island
Grand Manan

Fig. 8

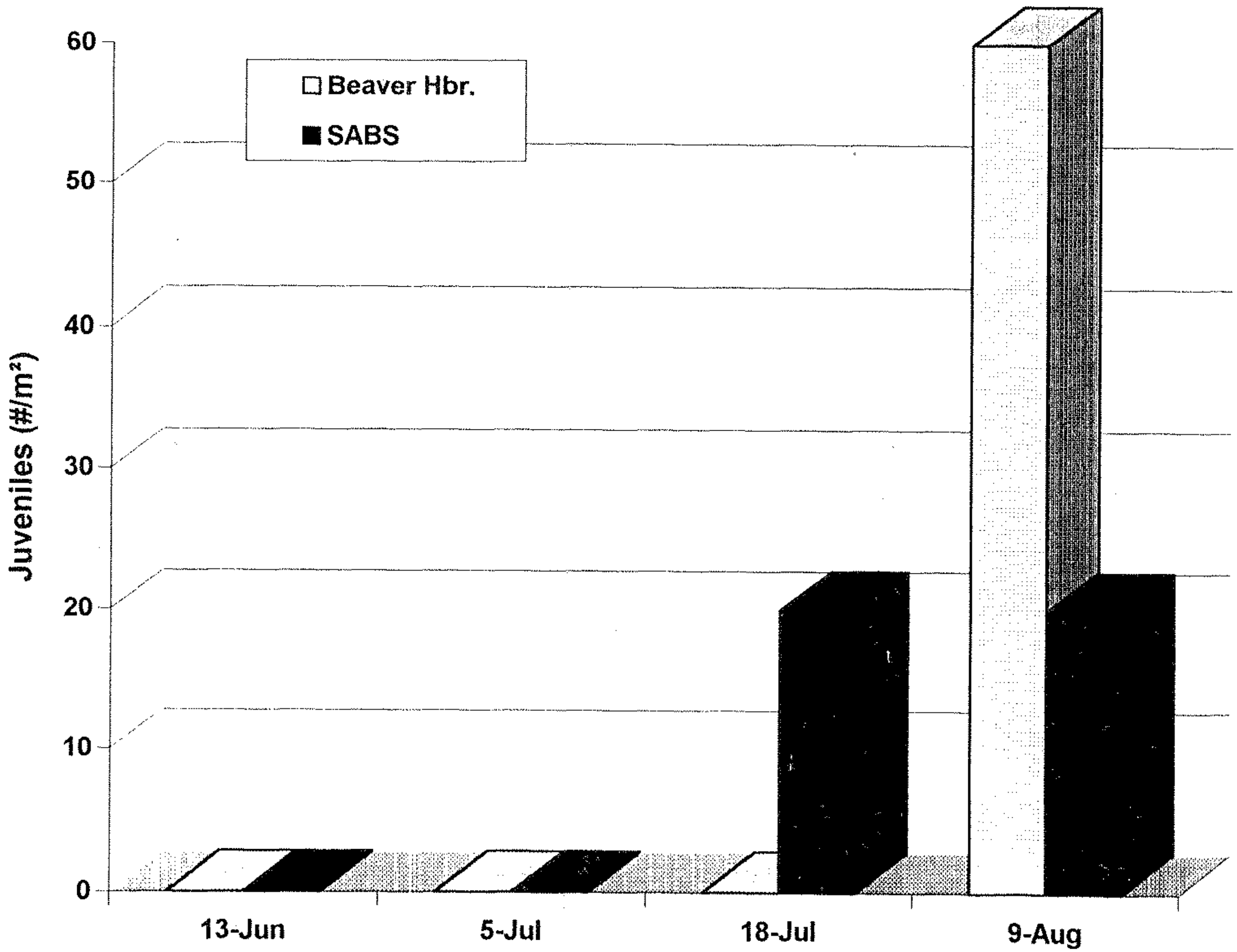


450
400
350
300
250
200
150
100
50
-
Tonnes
0 to 10 m
10 + m
Campobello
Deer Island
Grand Manan

Fig. 9



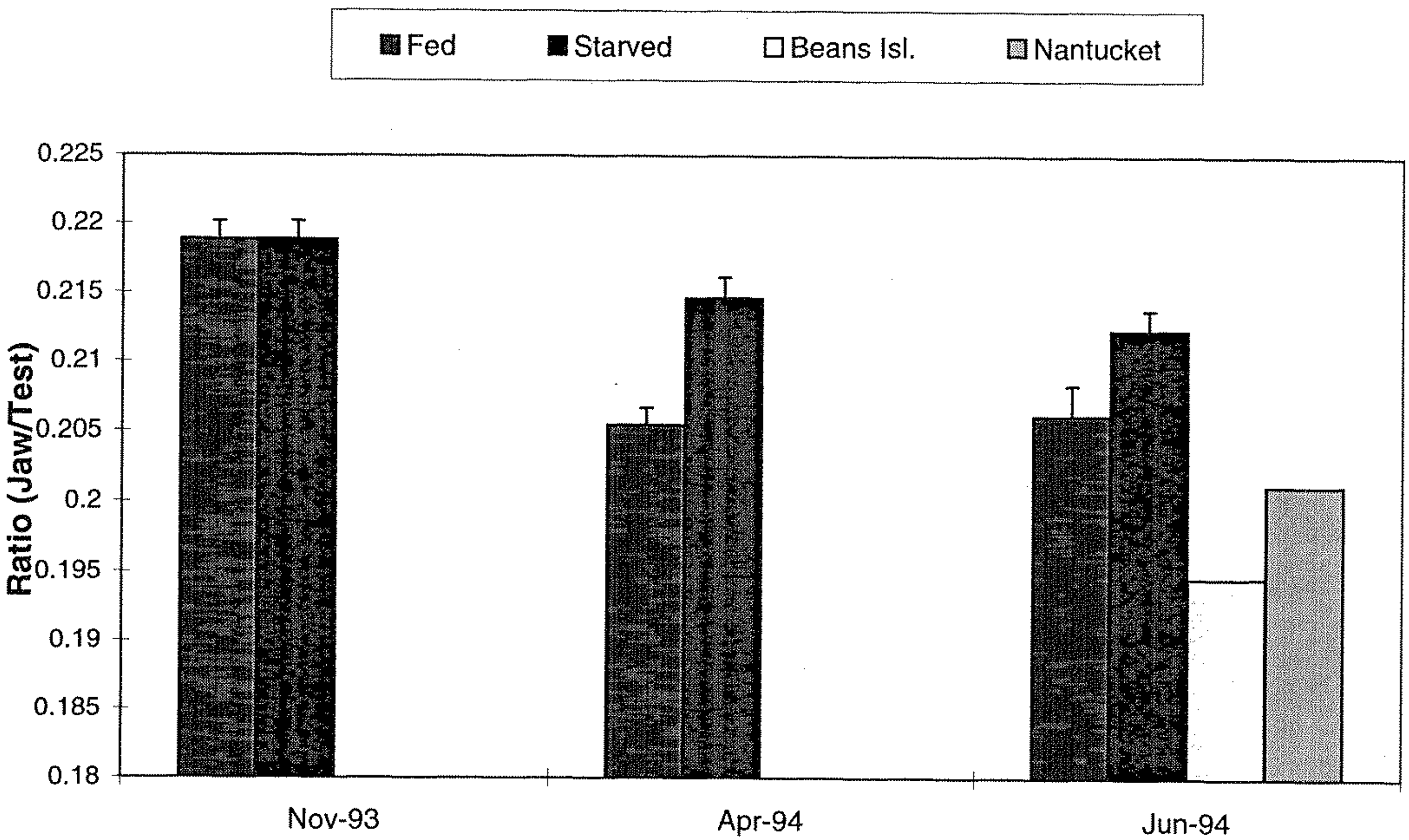
Juveniles (#/m²)
20
18
16
14
12
10
8
6
4
2
0
Prescription
Green I.
9-Jun
7-Jul
1-Aug
22-Aug



Beaver Hbr.
SABS
Juveniles (#/m²)
60
50
40
30
20
10
0
13-Jun
5-Jul
18-Jul
9-Aug

Fig. 10

Fig. 11


Fed
Starved
Beans Isl.
Nantucket
Ratio (Jaw/Test)
0.225
0.22
0.215
0.21
0.205
0.2
0.195
0.19
0.185
0.18
Nov-93
Apr-94
Jun-94

Spatial and temporal patterns in sea urchin populations, herbivory and algal community structure in the Gulf of Maine: Evidence for Impacts of Harvesting

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Department of Oceanography
Darling Marine Center
University of Maine
Walpole, ME 04573

Abstract

Sea urchin (*Strongylocentrotus droebachiensis*) population densities, herbivory and algal community structure werequantified at seven sites throughout the Gulf of Maine. Several coastal, near shore (20 km from the mainland) and offshore (>100 km from the mainland) sites were chosen for study. Prior to harvesting impacts, considerable spatial variability was observed in sea urchin population densities, body size, levels of herbivory (measured via a kelp-strip herbivory bioassay technique) and macroalgal abundance. At one nearshore and two offshore sites, urchins were virtually absent from the benthic communities. Invariably, coastal and nearshore areas with abundant urchins had reduced cover of fleshy macroalgae.

Long-term studies at coastal sites initiated in 1975 with periodic surveys since show an increase in urchin population densities at all depths and a shallowing of the kelp zone until the onset of urchin harvesting late in the 1980s. However, urchin population densities have not declined in all zones since harvesting began. Perhaps more importantly, a significant decrease in average test size is coincident with the increase in urchin harvesting in the 1990s. The loss of the largest and most deeply grazing members of the population may have resulted in an observed decrease in herbivory. Whereas algal community structure remained largely unchanged over most of the pre-harvesting period (1975 - 1985), the recent changes in sea urchin sizes correspond with observed changes in macroalgal abundances. The most striking changes are the appearance of macroalgae in regions formerly dominated by encrusting coralline algae. At one such site,

increased kelp cover corresponds with a shift in the preferred habitat lobsters occupy. Whereas lobsters chose shelter space between boulders for most of the past decade, recently they have switched to the shelter of kelp fronds.

Because herbivore diversity is so low in the rocky subtidal Gulf of Maine, changes in this sea urchin species's demographics translate to changes in the frequency and intensity of herbivory in the system. A recently published model predicts that such changes in herbivory will change the biomass, diversity and dominance of algal communities (Steneck and Dethier 1994). We will use this model as a means of assessing possible cascading impacts of urchin harvesting to shallow subtidal communities throughout the Gulf of Maine.

Introduction

Sea urchins have often been identified as important in structuring coastal marine communities (e.g., Lawrence 1975). High population densities of sea urchins can denude coastal regions of macroalgae (e.g., Estes and Duggins 1994, for the eastern North Pacific; Sammarco et al 1974 for the Caribbean; Hagen 1983, for the eastern North Atlantic). The recent decline of coral reefs throughout the Caribbean are thought to be the result of disease-related declines in sea urchin populations and the subsequent release of their controlling influence on the abundance of macroalgae, which now dominate many formerly coral reefs (e.g., see Steneck 1993, Hughes 1994).

Early reports of *Strongylocentrotus droebachiensis* (hereafter "sea urchin") populations denuding coastal regions in the Gulf of Maine date back to at least the early 1960s (e.g., Adey 1963, 1965). Whereas regions of Nova Scotia reportedly experienced significant disease-related fluctuations in urchin populations (i.e., Edelstein et al 1969, Breen and Mann 1976, Wharton and Mann 1981, Moore and Miller 1983, Novaczek and McLachlan 1986), there are no such reports for the Gulf of Maine. Over most of the past three decades, urchin populations were generally thought to be increasing in density and expanding in geographic extent. Recently, however, sea urchin harvesting has exploded. It is the fastest growing marine industry in North America, but the consequences of this fishery on sea urchin populations and associated coastal communities is virtually unknown.

Central to any question of change is understanding the natural variability in the system. Often researchers visit a single site and assume it is representative of the region and that the entire system is temporally stable as well. The history of science is replete with examples of initial assumptions of homogeneity being shattered by the reality of a spatially and temporally heterogeneous world. Therefore, questions of large regional importance in highly complex natural systems should be studied at several scales to assess the harvesting "signal" against the spatial and temporal "noise" of naturally variable systems.

We report on large-scale spatial and long-term temporal patterns in the distribution, abundance, body size and community impact of the sea urchin, *Strongylocentrotus droebachiensis* in the Gulf of Maine. We will draw from a "snap-shot" taken at seven sites widely spaced within the Gulf of Maine for our spatial patterns and from two sites that have been studied for over a decade (since 1975 and since1983) for our temporal patterns. Because urchin harvesting in Maine accelerated only recently (i.e., 1987), we can use our long-term data to assess its impact. We take both the broad-regional and the long-term, site-specific approaches to this question because we will show regional heterogeneity is a natural part of this system independent of harvesting. Thus to report temporal changes requires that we control for regional variability by repeatedly sampling sites fixed in space. Below we will first demonstrate regional heterogeneity, suggest some possible causes for it, and then go on to examine, in detail, a few sites where significant changes in urchin demography have been observed, and the resulting "cascading" community consequences.

Study Sites and Methods

Quantitative studies and experiments were conducted at seven sites throughout the Gulf of Maine (Fig. 1). Two offshore sites, North Ammen Rock (NARP) and Ammen Rock (ARP) are part of Cashes Ledge which is 104 km east of Boothbay Harbor, Maine. There *Laminaria* spp. (hereafter "kelp") beds grow as shallow as depths of 25 m at NARP and 10 m at ARP. Two near shore island sites, Mt. Desert Rock (MDR at 20 m) and Matinicus Rock (MAT at 10 m) are about 20 km from the nearest mainland coast. Three coastal sites at Pemaquid Point (PEM), Crow (CROW) and Rutherford Islands (RUT) are all within 5 km of each other along the central coast of the Gulf of Maine. Pemaquid is an exposed site, whereas Crow and Rutherford sites are relatively protected. Due to logistical reasons, we could only quantify urchin and algal abundances in 1990 at our offshore sites; however, our dive experiences are much more extensive than that. Between 1984 and 1991 we visited the Ammen Rock area each year and consistently found the kelp to be abundant and urchins rare (see Vadas and Steneck 1988 for more information about the offshore sites and their algal and herbivore components).

Quantitative data on urchin abundances were obtained using SCUBA divers and square quadrats ranging from 25 cm to 1 m on a side. Specific techniques have varied slightly over the years and these details will be described where appropriate below.

Herbivory was measured using a kelp-strip bioassay technique. This approach is identical to the *Thalassia* bioassay technique of Hay (1984) except we used strips of kelp 2.5 cm wide by 15 cm long instead of *Thalassia* sp. sea grass blades.

Results and Discussion

Large-scale Spatial Patterns:

Population Densities, Algal Abundance and Herbivory

Regional Variability: Patterns Unrelated to Harvesting

Sea urchin abundances vary greatly throughout the Gulf of Maine (Fig. 2). In 1990 when we did our regional surveys, urchin harvesting was increasing, but as far as we know, was only limited to coastal sites. The three sites most distant from the mainland, North Ammen Rock, Ammen Rock and Mt. Desert Rock were devoid of urchins. Matinicus Rock which is relatively far from the mainland had the highest densities we found that year. All sites were visited in 1987 and patterns similar to those we quantified in 1990 (Figs. 2, 3) were evident. Such large-scale variability was not likely the result of harvesting.

Macroalgal abundance also varied throughout the Gulf of Maine. Areas devoid of urchins typically had significant macroalgal cover (Fig 3). NARP, ARP and MDR sites were all dominated by kelp (*Laminaria* spp.) but other corticated macroalgae (sensu Steneck and Dethier 1994) were also present. The three sites with relatively little macroalgal cover (i.e., Matinicus, Pemaquid Point and Crow Island) were dominated by encrusting coralline algae (i.e., *Lithothamnion* spp., *Clathromorphum* sp., and *Phymatolithon* spp.).

At sites where urchin abundances were high, macroalgal abundances were low (Fig. 4). Note the proximity of data points near both the *x* and *y* axes. In this case, few intermediate states appear to exist (i.e., where urchin and algal abundances were intermediate). This is similar to urchin-algal patterns observed by Estes and Duggins (1994) in the Aleutian islands of Alaska.

To determine if rates of herbivory correspond with the decline in macroalgae in areas with abundant urchins, a kelp-strip herbivory bioassay was deployed (Fig. 5). For this, fresh kelp was collected, strips were cut from the thicker, central (unfouled) portion of the frond, and held on the bottom with a clothespin. At variable intervals ranging between a few hours and a day, the kelp-strips were revisited to determine if any portion of the thallus had been grazed. Percent area consumed was measured. Knowing the duration since the last observation, the percent consumed per day was calculated.

Herbivory, as measured using the bioassay (Fig. 6), corresponds with regional patterns in urchin population densities (Fig. 2). Of the two coastal sites, Pemaquid Point had higher rates of herbivory than did Crow Island.

Since rates of herbivory vary directly with the local sea urchin population densities (Fig. 7), urchins alone are probably the dominant kelp herbivore. Different rates of herbivory may be found with other algae, but given the biomass and structural impact of kelp in shallow subtidal systems, rates of herbivory on it were deemed most important. No data were recorded on urchin body sizes for the regional study.

Thoughts on Factors Controlling Regional Patterns: Are predators responsible?

Why were some sites devoid of sea urchins? Are presettlement (i.e., larval delivery) or post-settlement (e.g., predation) processes contributing to this pattern? From 1984 through 1987 at the two offshore sites (NARP and ARP) R.L. Vadas and R.S. Steneck conducted ecological studies on the distribution and abundance of the local algal flora (see Vadas and Steneck 1988). During the course of that study, minute (i.e., newly recruited) urchins were found among the macroalgae. Therefore it is likely that post-settlement processes are important to the conspicuous lack of urchins at the three sites (Fig. 2). One possibility is that the absence of larger urchins is due the elevated levels of predation that result from the conspicuous presence of large predatory fishes (described in Witman and Sebens 1992).

To quantify the abundance of large predatory fish, we set up several video cameras which monitored a one-meter cube of water directly over the bottom for periods of two hours. This was repeated at several sites over several days (Fig. 8) and resulted in measurable differences in visitation rates by Atlantic cod, pollack, cunner (only cod was plotted). A clear pattern of abundant large predators (Fig. 8) at sites without urchins (Fig. 2) was evident.

Predation rates on tethered urchins (Fig. 9) was somewhat equivocal. Although attack rates were highest on large urchins where predatory fishes were abundant, attack rates were also high where those predators were rare. Divers observed that rock crab (*Cancer irroratus*) predation was responsible for most of those attacks. Subsequent laboratory studies found that when individual crabs of specific size classes were placed in a tank with a tethered and untethered urchin (of the size classes listed in Fig. 9) that only tethered urchins were attacked. Untethered urchins were either unattractive to the crab or able to avoid the crab predator (unlikely). Tethered urchins may have been especially attractive because they were wounded and "leaking" due to the tethering method. We strung monofilament through the test so an escaped urchin could not survive, as we did not want any escaped urchins contaminating the regions.

Temporal and Depth Patterns:

Sea Urchin Population Densities, Size Distributions, Herbivory, Algal Abundance

Temporal Trends in Sea Urchin Population Densities: Mixed messages

Quantitative demographic surveys were conducted along a depth gradient at Pemaquid Point (Fig. 1) during the summers of 1975, 1984, 1985, 1986 and 1994 (Fig. 10). In general, consistent features seen over the years were low densities in the shallowest zones (1 - 3 m), a peak abundance which varied over the years but prior to 1994 was found at less than 10 m depth, and a decline in population densities with depth reaching zero by 30 m. SCUBA and submersible observations elsewhere in the Gulf of Maine found this to be a general pattern. Nowhere have we found a population of sea urchins at depths greater than 30 m.

During the 1980s, urchin population densities increased in all depth zones (Fig. 10). Peak densities increased from 38 urchins / m^2 in 1975 and 1984, to 62 / m^2 in 1985 and to a high of 133 / m^2 in 1986. The 1994 depth distribution of urchin densities was in many ways the most different of the series. Not only was peak density lower (down to 50 / m^2), but also the depth of maximum abundance of urchins exceeded 5 m for the first time and was at 10 m in 1994 (Fig. 11).

Temporal comparisons of population densities at similar depths of 10 m at Pemaquid Pt. (Fig. 12) and 5 to 10 m at Crow Island (Fig. 13) show no significant decline in population densities coincident with harvesting urchins. In fact, Crow Island in particular shows a steady significant increase in urchin population densities since 1985.

However, these comparisons were made at only one depth range. On a larger scale at Pemaquid Point, there were significant decreases in urchin densities at shallower depths (Fig. 10). At 3 meters, urchin densities in 1994 were significantly lower (ANOVA $p < 0.0001$) than 1984, 1985, and 1986, a period over which density actually increased. These shallow depths are those which urchin divers frequently harvest.

Temporal Trends in Body size: Significant decreases

Before harvesting impacts, the urchin size distributions should reflect the natural population dynamics. At Pemaquid Point, near normal distributions of urchins were evident with the mode at 7 cm test diameter (TD) size class in 1985 and 1986 (Fig. 14). A distinct mode at 8 cm was evident at Crow Island in 1986, but proportionately fewer 7 and 9 cm TD size class urchins were at that site at that time (Fig. 15). No urchins larger than 10 cm were found at either site.

The most dramatic change in natural populations of sea urchins, coincident with harvesting, is the virtual elimination of large individuals (Figs 14 and 15). This loss of large ($\geq$ 8 cm TD size class) individuals caused average sizes at both Pemaquid Point and Crow to decline. At Pemaquid Point, the average size of urchins declined from 6.4 cm TD in 1985 and 1986 to 4.0 and 4.3 cm TD in 1993 and 1994, respectively (Fig. 14). A similar pattern was observed at Crow Island where the average size of 5.4 cm TD in 1986 dropped to 3.5 cm TD in 1994 (Fig. 15). The body size decrease at Crow Island was reflected in the estimated biomass change over time. The 1986 estimated biomass of 98.4 $\pm$ 6.6 g wet weight/m^2 dropped significantly ($P < 0.001$) to 47.1 $\pm$ 4.9 g wet weight/m^2 in 1994. Crow Island is a good example of a right-skewed size-frequency distribution of large urchins in 1986 and a strongly left-skewed one in 1994.

Temporal Trends in Herbivory: Significant decreases

The largest and deepest-grazing herbivores in marine systems usually have the strongest controlling influence (Steneck and Dethier 1994). It is for that reason, that the changes in body size should not be ignored. Sea urchins in the western North Atlantic are both the largest and deepest-grazing herbivore in this system. Factors that impact urchin body size may also impact the herbivory in the system as a whole.

To assess herbivory in a quantitative way that eliminates the complicating and possibly offsetting relationship between population density and body size, the herbivory bioassay was used. For this, kelp strips were repeatedly deployed over several years in the same location to determine grazing rates expressed as the percent of the kelp strip grazed daily which can be converted directly to rates of kelp biomass ingested if necessary.

Rates of herbivory were consistently more than twice as high at Pemaquid Point compared to Crow Island (Figs 6, 16, 17). At both sites, grazing rates in 1994 were significantly lower than those recorded for previous years. The decline was most dramatic at Crow Island where the time record was also longer. For example, in 1983 a consumption rate of 34% was recorded whereas in 1994 it was 1.3% (Fig 17).

Temporal Trends in Macroalgal Communities: Significant Increases

Both Pemaquid Point and Crow Island had dramatic increases in algal abundance (Figs 18 and 19, respectively). In the 5 - 10 m zone at Pemaquid Point, where urchin abundances remained relatively constant or increased somewhat (Fig. 12), their sizes (Fig. 14) and measured rates of herbivory (Fig 16) decreased, while macroalgal abundances increased (Fig. 18). The transformation from a coralline community with virtually no erect macroalgae to one dominated by macroalgae is significant. The conspicuous rocky prominence of Pemaquid Point is a popular location for biologists and ecologists. As a result, considerable anecdotal and quantitative data exists for this site. Adey (1963) reported crustose coralline algae dominating the subtidal zone at Pemaquid Point in the early 1960s and our periodic quadrat sampling (Fig. 18) supplemented with additional dives nearly every year since 1975, observed no noticeable change in community dominance (Steneck personal observation, Steneck and Dethier 1994) until 1994. The coralline community at Pemaquid Point seemed "stable" by most definitions of that term (e.g., Connell 1986). Although corticated macroalgae is more abundant now than ever before at depths between 5 and 10 m, perhaps of greater significance is the zonal extension of the kelp. Whereas the kelp "fringe" was found at 3 m in 1975 and only at 1 m in 1985 (Fig. 20) it now extends to at least 7 meters (McNaught observation 9/25/94). This observation is the deepest record of *Laminaria* at this site over the past 20 years (Steneck personal observation). The extension of macroalgae and the concommitant increase of drift algae at 10 m at Pemaquid Point (McNaught observation) may explain the observed increase in urchin density since urchins from deeper water may "collect" at this new, but more diffuse, feeding line.

Crow Island also experienced a significant increase in macroalgal cover, especially kelp (Fig. 19). This site had consistently lower population densities (Fig. 13) of often larger (Fig 15) sea urchins than found at the Pemaquid Point site (Figs 12 and 14 respectively). It is possible that the community structure shifts resulted from those demographic differences. Recently, Steneck and Dethier (1994) suggested that under similar productivity potentials (e.g., depth and water flow) and similar herbivore regimes that similar algal community structures will develop. The two most important components of herbivory or any form of disturbance is the frequency (the number of events per area per unit time) and intensity (the amount of biomass removed in each event). As it applies to herbivory, grazing frequency corresponds with the population density of herbivores in the system (Fig. 21), and grazing intensity corresponds with the body sizes of the herbivore involved (Steneck et al 1991).

Under a continuum of high grazing frequency and low intensity, and high grazing intensity and low frequency, coralline algal communities dominate (Fig. 21). With increased levels of grazing, the algal assemblages that dominate the system vary. Under conditions of very low levels of grazing and/or highly productive conditions, large leathery macroalgae (i.e., kelp) dominate the system. A simplified version of a conceptual model that predicts changes in the dominance of algal communities based on changes in the frequency and intensity of grazing was applied to the Crow and Pemaquid sites (Fig. 22). Since Crow Island had lower population densities (Fig. 13) of slightly larger urchins (Fig. 15) than Pemaquid before harvesting impacts, it was plotted to the above and to the left of Pemaquid Point. Because urchin harvesting is regulated to a minimum harvestable size, the scope for change in the algal community will likely be greater in the sites where urchin body sizes were initially greater, Crow Island site, than it is for the Pemaquid site (note the downward arrow at Crow Island is longer than that for the Pemaquid site).

Cascading Community Changes, Positive Feedback and Some Causes for Concern

Cascading Effects

Some coastal sea urchin populations in the past several decades may have been unnaturally abundant due to the absence of predators capable of eating large adults. The well known loss of predatory fishes from coastal zones (e.g., Witman and Sebens 1992) may have released them from predatory control. Our tethering work supports that idea, in that areas still possessing an abundance of large predatory finfish had measurably higher rates of predation on urchins than were observed in coastal sites (Fig. 9). The expansion of urchins through the 1980s may have been a continuation of this predator release. The subsequent reversal in this trend due to harvesting is not simply a reversion to the natural predator-controlled condition because predators and harvesters have fundamentally different impacts (see *Cause for concerns* below). However, the algal community structure may parallel that which once existed in coastal zones prior to finfish harvesting impacts.

Improved Quality and Quantity of Food for Urchins

There is some potential for a positive feedback by which urchin harvesting may improve the growth potential and quality of the urchins habitat. If harvesting sea urchins reduces the local grazing intensity in shallow marine (potentially productive) systems, a shift to macroalgae can be expected. Since crustose coralline algae have the lowest mass-specific productivity of any of the algal forms in the system (Steneck and Dethier 1994), then the shift in community structure from coralline to macroalgae should also increase local primary productivity. Since a shift to a kelp community (e.g., our Crow Island example) actually increases the availability of preferred food for urchins (Vadas 1989), then the trophic carrying capacity for the urchins may go up! Furthermore, urchins fed on high quality foods develop larger gonads thereby increasing their fishery value (see Vadas et al, this volume).

Improved Habitat Architecture for Lobsters, Potential Growth Among Macroalgal Detritivores.

Macroalgae and kelp are habitat for organisms as diverse as amphipods (Hacker and Steneck 1990) and lobsters (Bologna and Steneck 1993). In the former case, the size, shape and arrangement of space within macroalgae can control the distribution, abundance and body size of a species of amphipod (Hacker and Steneck 1990). Bologna and Steneck (1993) showed that lobster's local distribution and abundance pattern changes depending upon the presence of kelp cover. They speculated that changes in the the abundance of kelp, especially on ledge substrata (such as we observed at Pemaquid Point), could locally concentrate lobsters in areas where they would otherwise be rare. The recent change in kelp abundance at our Crow Island site has resulted in a dramatically different habitat use by lobsters in the area (Fig. 23). The recent shift from rock shelter to kelp shelter use in 1994 may be another indirect consequence of urchin harvesting. Obviously, the advantages of expanded kelp beds would be reduced by harvesting techniques, such as dragging, that could destroy the kelp beds.

Expanded beds of kelp and other large macroalgae could contribute to the abundance of detrital macroalgae which could increase the trophic carrying capacity for detritivores of macroalgae such as nereid polychaetes and numerous suspension feeders (Duggins and Eckman 1994). Organisms responding to elevated levels of detrital macroalgae may in turn be food for other commercially important species such as flounder.

Cause for concerns

The abundance of small urchins, coupled with steady or locally increasing population densities, suggests that the broodstocks are currently healthy at the sites examined. However, if predators can contribute to the regional-scale patterns of sea urchin abundance and are potentially capable of affecting much larger areas than harvesting because they are full-time, all-depth harvesters, then they may be more important than is currently appreciated. However, as with all predators, they are limited in the size on which they can prey (e.g., prey body size, predator mouth size scaling). The removal of the largest potential prey through harvesting leaves vulnerable the smaller sizes which may also have a reduced reproductive potential. By shifting urchin populations to smaller size classes (e.g., Fig. 15), it is possible that a higher proportion of the population is being shifted to a size with much higher vulnerability to small commercially-unimportant species of fishes such as rock gunnel, sculpins and shannies. Predator impacts on intermediate sized urchins was suggested by Ojeda and Dearborn 1989 who observed a consistent decrease in the mid-sized urchins. We observed a similar dip at 5 cm TD urchins (e.g., Fig. 14). If predators are reducing intermediate size-class urchins and harvesting is reducing larger size classes (e.g., Figs 14 & 15), the combined threat to the broodstock could be great.

Acknowledgements

We received help from many sources. Bob Vadas was largely responsible for getting R. Steneck actively involved in this research two decades ago and has contributed substantially over the years. Cathy Pfister along with numerous summer interns helped gather data on algal and urchin abundances in the 1980s. In the 1990s, we received critical field and research assistance from our captain and dive buddy, Nikolas Greenson, and from Laurie Stearns. Liz Hearon helped with our data analyses. Research funding was from the National Science Foundation (OCE 83151136, OCE 8600262), NOAA's National Undersea Research Center at the Univ. of Connecticut, UM/UNH Sea Grant Program (R/RMD-169, NA86AA-D-SG-047). To all we are grateful.

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Captions

Fig. 1. Study sites within the Gulf of Maine.

Fig. 2. Regional patterns of population density of sea urchins (error bars indicate one standard deviation). Site abbreviations are listed in Study Sites and Methods.

Fig. 3. Regional patterns of percen0t cover of macroalgae (error bars indicate one standard deviation).

Fig. 4. Regional patterns of macroalgal abundances as a function of urchin population densities, 1990.

Fig. 5. Kelp-strip herbivory bioassay.

Fig. 6. Regional patterns in the herbivory bioassay, 1990.

Fig. 7. Regional patterns of rate of herbivory (kelp-strip bioassay) as a function of sea urchin population density.

Fig. 8. The predation potential from Atlantic cod based on visitation rates observed within several 1 m^3 areas monitored with video cameras.

Fig. 9. Predation rates on different sized sea urchins tethered at six sites. The sites were subdivided according to those where large predators were abundant (NARP, ARP, MDR) and those where those predators are rare (MAT, CROW, PEM) based on video observations (see Fig. 8).

Fig. 10. Temporal trends in sea urchin population densities at Pemaquid Point, Maine. Error bars indicate standard error. Note the scale changes on the *y* axis.

Fig. 11. Comparison of population depth profiles for 1975, 1985 and 1994.

Fig. 12. Temporal trend in urchin population density (with standard error) at Pemaquid Point.

Fig. 13. Temporal trend in urchin population densities at Crow Island, Maine. One way analysis of variance (ANOVA) was performed on these data with a Fishers LSD multiple comparison test at 0.05 level. Sample averages that are not significantly different are identified under the horizontal bar.

Fig. 14. Temporal trends in size frequency distribution of sea urchins at Pemaquid Point. All urchins were measured in situ with SCUBA divers at 10 m depth Sample sizes are the number of urchins measured.

Fig. 15. Temporal trends in size-frequency distribution of urchins at Crow Island. Samples were taken in the same area at depths between 5 and 10 m.

Fig. 16. Temporal trend in herbivory rates at Pemaquid Point. Caged controls showed no loss of biomass throughout the duration of the experiment (n = 10). ANOVA analysis as described for Fig. 13.

Fig. 17. Temporal trend in herbivory at Crow Island. Caged controls as described in Fig. 16, and ANOVA analysis as described for Fig. 13.

Fig.18. Temporal trends in macroalgal abundance for Pemaquid Point at depths between 5 and 10 m.

Fig.19. Temporal trends in macroalgal abundance for Crow Island at depths between 5 and 10 m. ANOVA analysis as described for Fig. 13.

Fig. 20. Temporal and depth trends in percent cover of macroalgae at Pemaquid Point. The abrupt decrease in algal abundance with depth in 1975 and 1985 is coincident with the decline of kelp abundances at that those depths. In 1994, in contrast, other algal forms comprise a significant proportion of the algal cover at depths greater than 5 meters.

Fig. 21. A conceptual model that predicts changes in algal community structure based on the grazing characteristics of the system (after Steneck and Dethier 1994). Algal dominance and fleshy algal biomass (i.e., noncalcified) varies directly with the lines of similar impact from the crustose corallines under highest grazing pressure to the kelp under lowest grazing pressure.

Fig. 22. Applying the case studies of Pemaquid Point (circle) and Crow Island (square) grazing intensity and frequency before and after urchin harvesting is represented. Pre. and Post notations refer to before and after harvesting impacts on sea urchin populations.

Fig. 23. Changes in shelter use by lobsters at Crow Island (5 - 10 m). Note that the shift to kelp-shelters is coincident with the dramatic increase in kelp abundance at that site.

Fig. 1

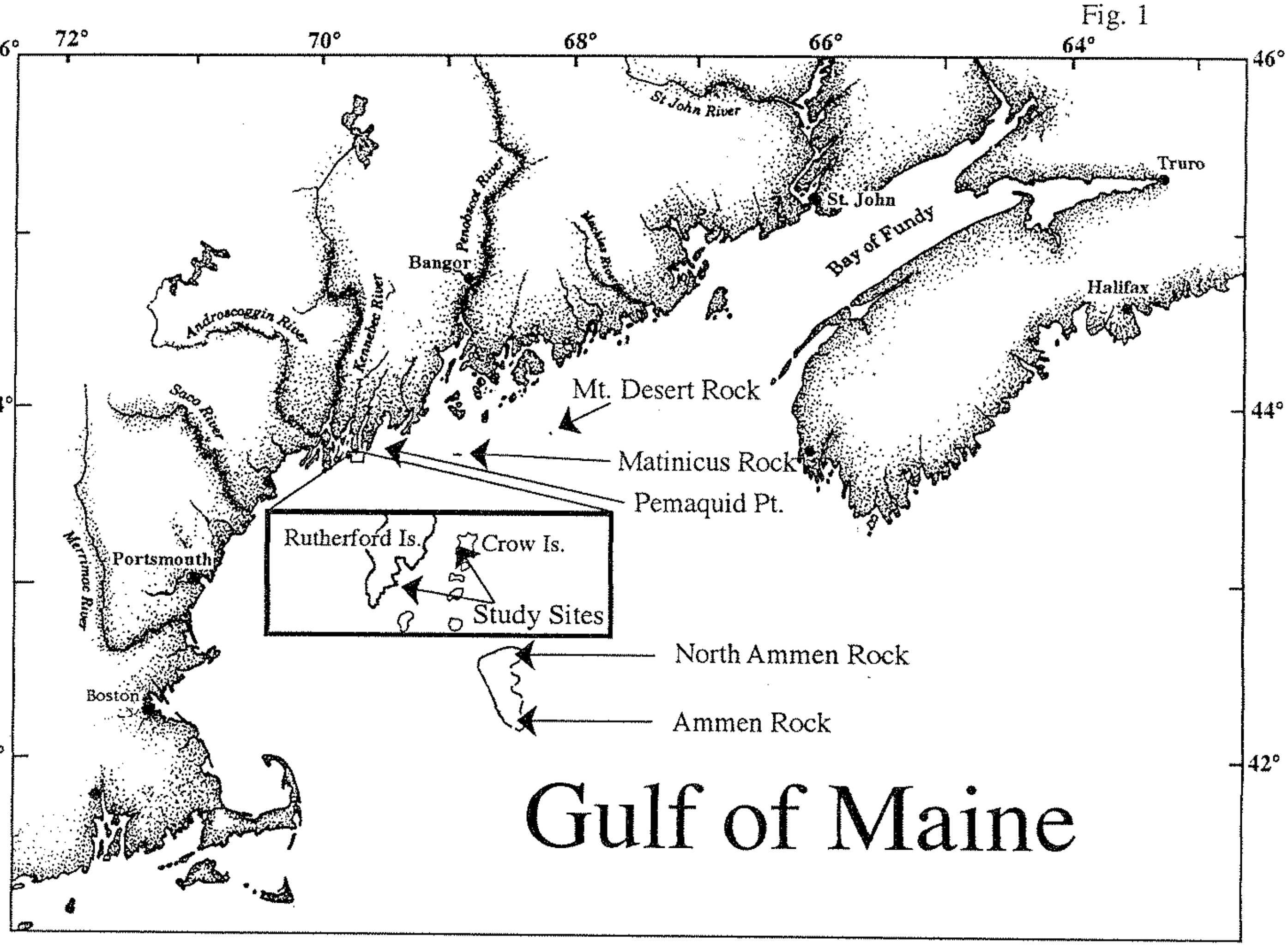

72°
70°
68°
66°
64°
46°
44°
42°
St John River
Truro
St. John
Bay of Fundy
Halifax
Bangor
Penobscot River
Machias River
Androscoggin River
Kennebec River
Saco River
Merrimac River
Portsmouth
Boston
Mt. Desert Rock
Matinicus Rock
Pemaquid Pt.
Rutherford Is.
Crow Is.
Study Sites
North Ammen Rock
Ammen Rock
Gulf of Maine

Fig. 2

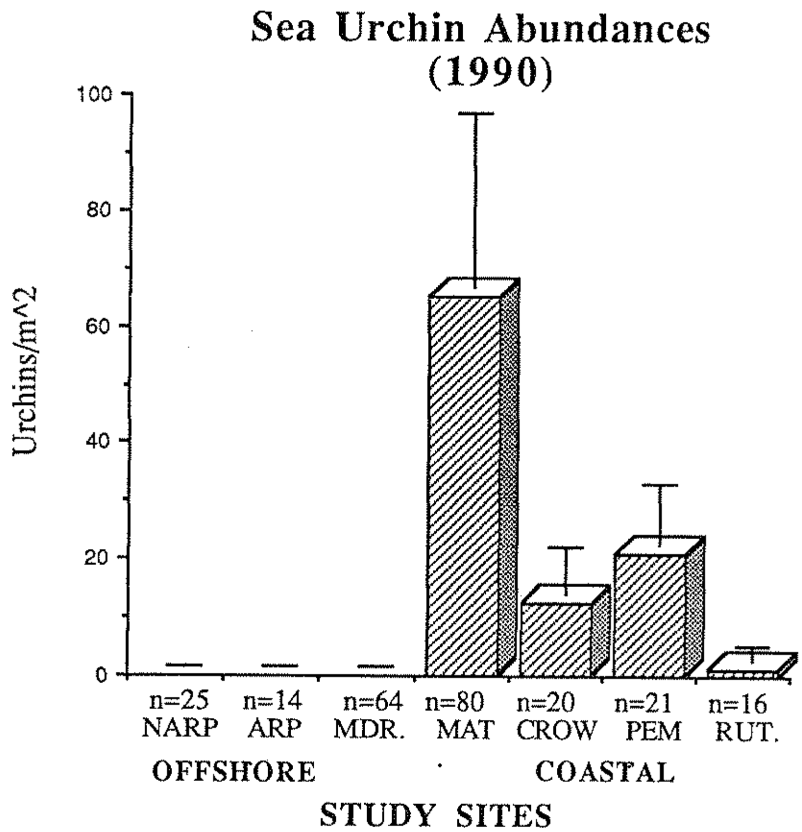

Sea Urchin Abundances
(1990)
100
80
60
40
20
0
Urchins/m^2
n=25
NARP
n=14
ARP
n=64
MDR.
n=80
MAT
n=20
CROW
n=21
PEM
n=16
RUT.
OFFSHORE
COASTAL
STUDY SITES

Fig. 3

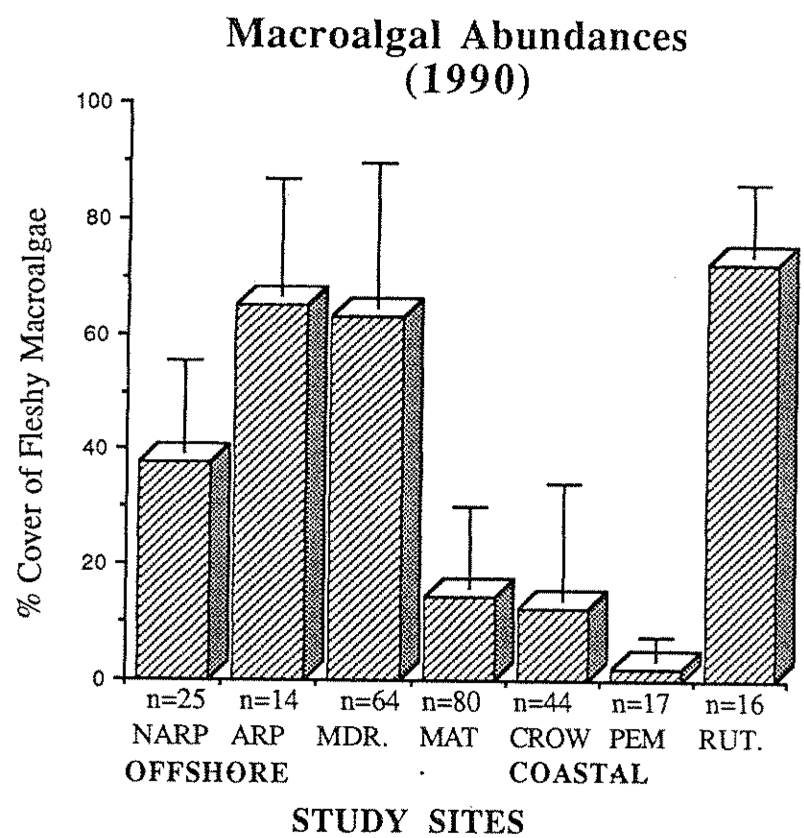

Macroalgal Abundances
(1990)
100
80
60
40
20
0
% Cover of Fleshy Macroalgae
n=25
NARP
n=14
ARP
n=64
MDR.
n=80
MAT
n=44
CROW
n=17
PEM
n=16
RUT.
OFFSHORE
COASTAL
STUDY SITES

Fig. 4

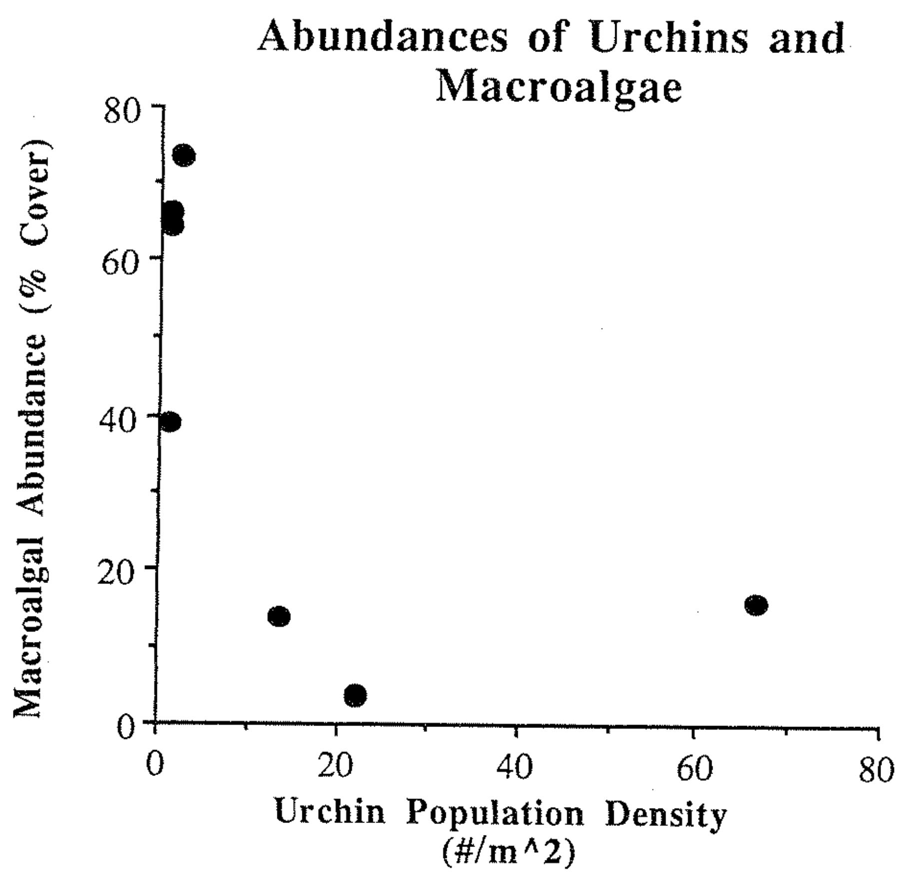

Abundances of Urchins and Macroalgae
Macroalgal Abundance (% Cover)
80
60
40
20
0
0
20
40
60
80
Urchin Population Density (#/m^2)

Fig. 5.

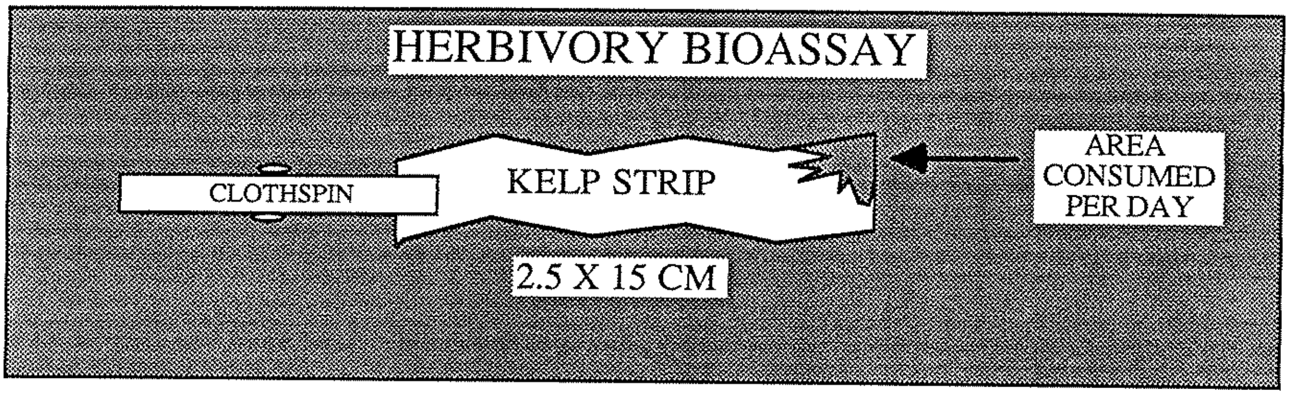

HERBIVORY BIOASSAY
CLOTHSPIN
KELP STRIP
AREA CONSUMED PER DAY
2.5 X 15 CM

Fig. 6

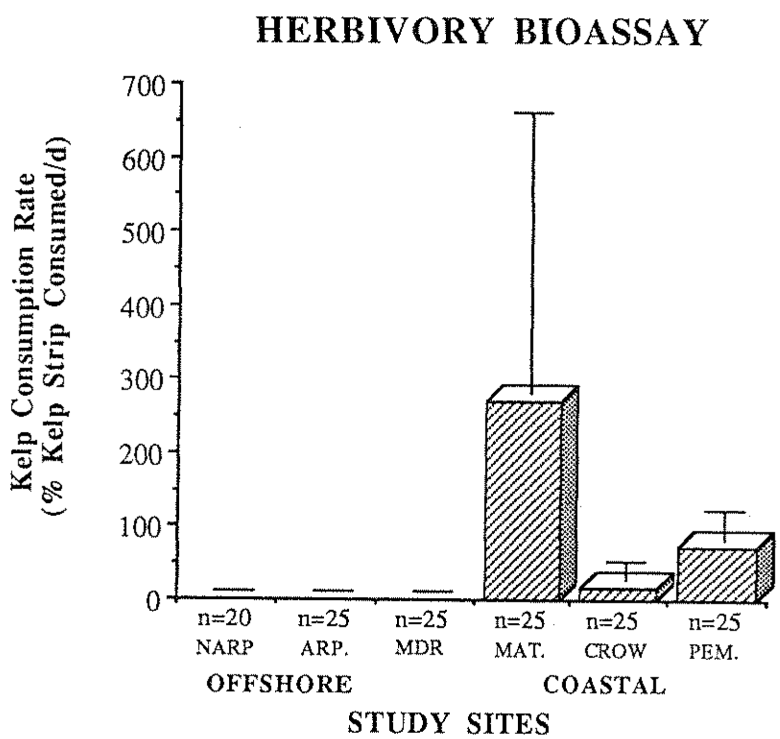

HERBIVORY BIOASSAY
Kelp Consumption Rate
(% Kelp Strip Consumed/d)
700
600
500
400
300
200
100
0
n=20
NARP
n=25
ARP.
n=25
MDR
n=25
MAT.
n=25
CROW
n=25
PEM.
OFFSHORE
COASTAL
STUDY SITES

Fig. 7

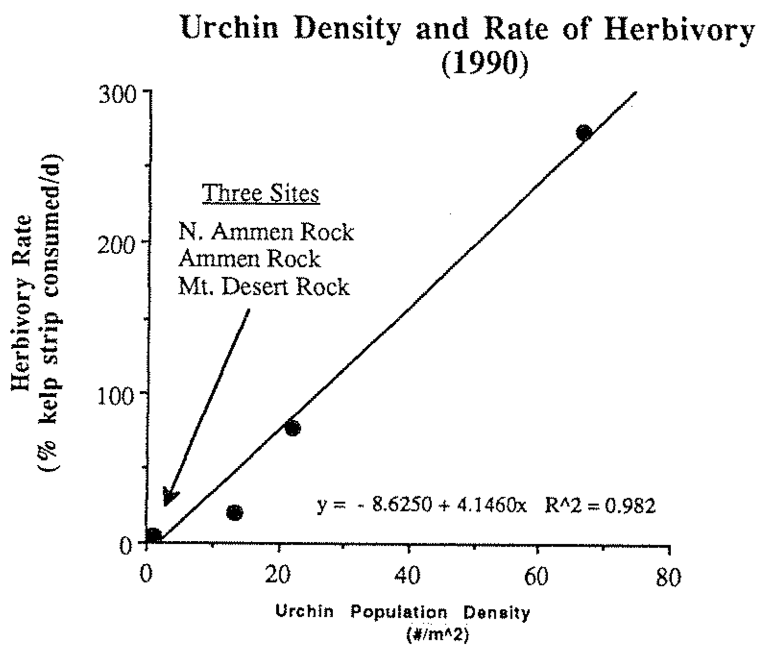
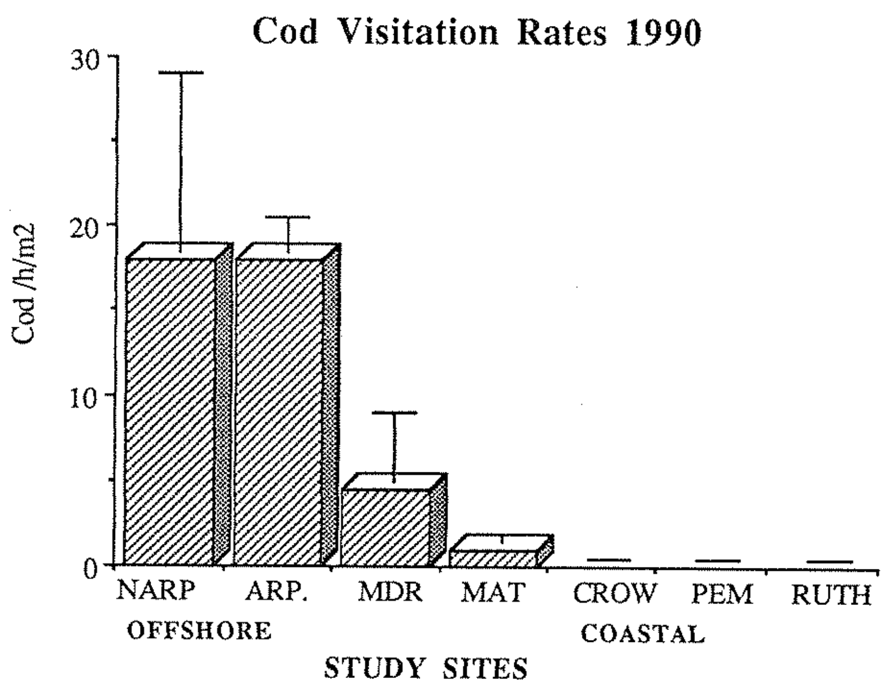
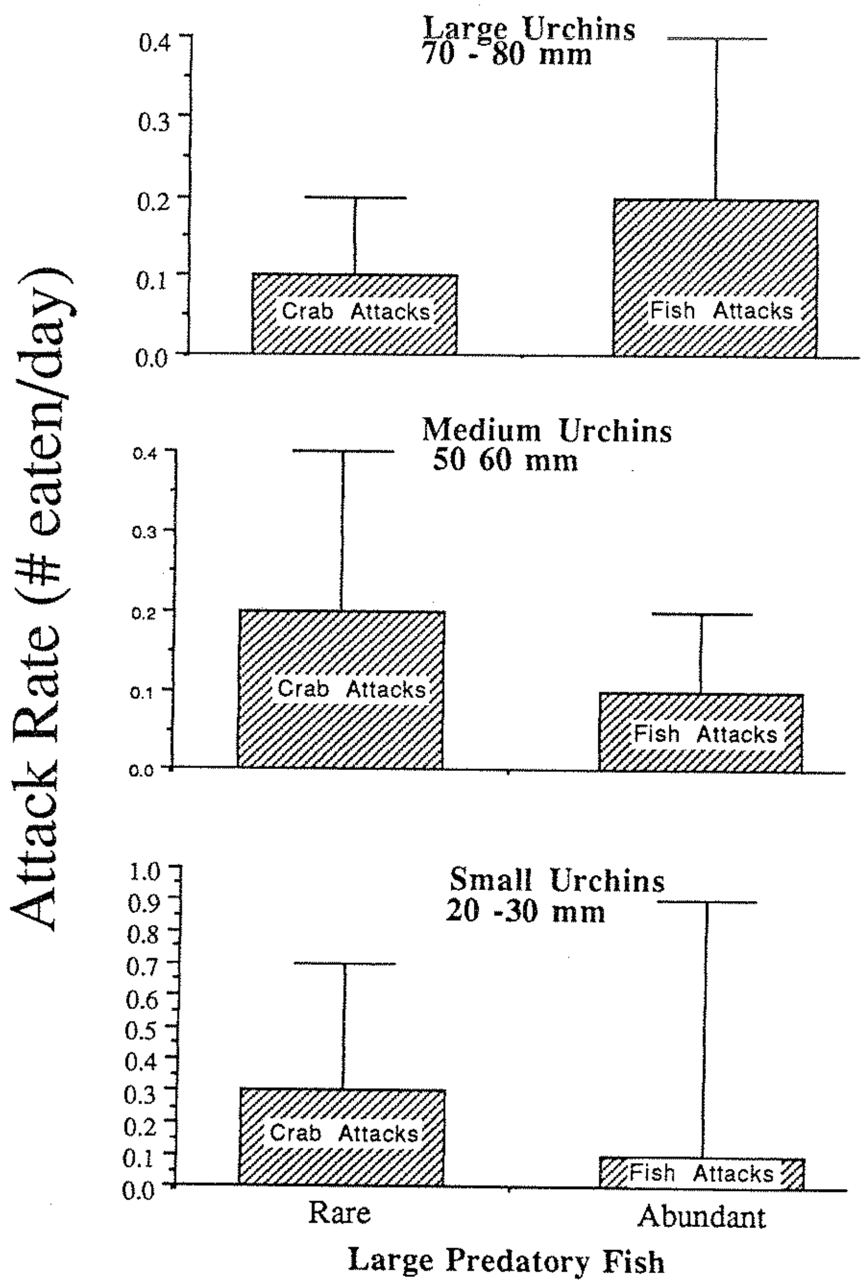

Urchin Density and Rate of Herbivory
(1990)
300
200
100
0
Herbivory Rate
(% kelp strip consumed/d)
Three Sites
N. Ammen Rock
Ammen Rock
Mt. Desert Rock
y = - 8.6250 + 4.1460x R^2 = 0.982
0
20
40
60
80
Urchin Population Density
(#/m^2)

Fig. 8



Cod Visitation Rates 1990
30
20
10
0
Cod /h/m2
NARP
ARP.
MDR
MAT
CROW
PEM
RUTH
OFFSHORE
COASTAL
STUDY SITES

Predation on Urchins



Temporal Trends in Sea Urchin Population Densities
Pemaquid Pt., Maine

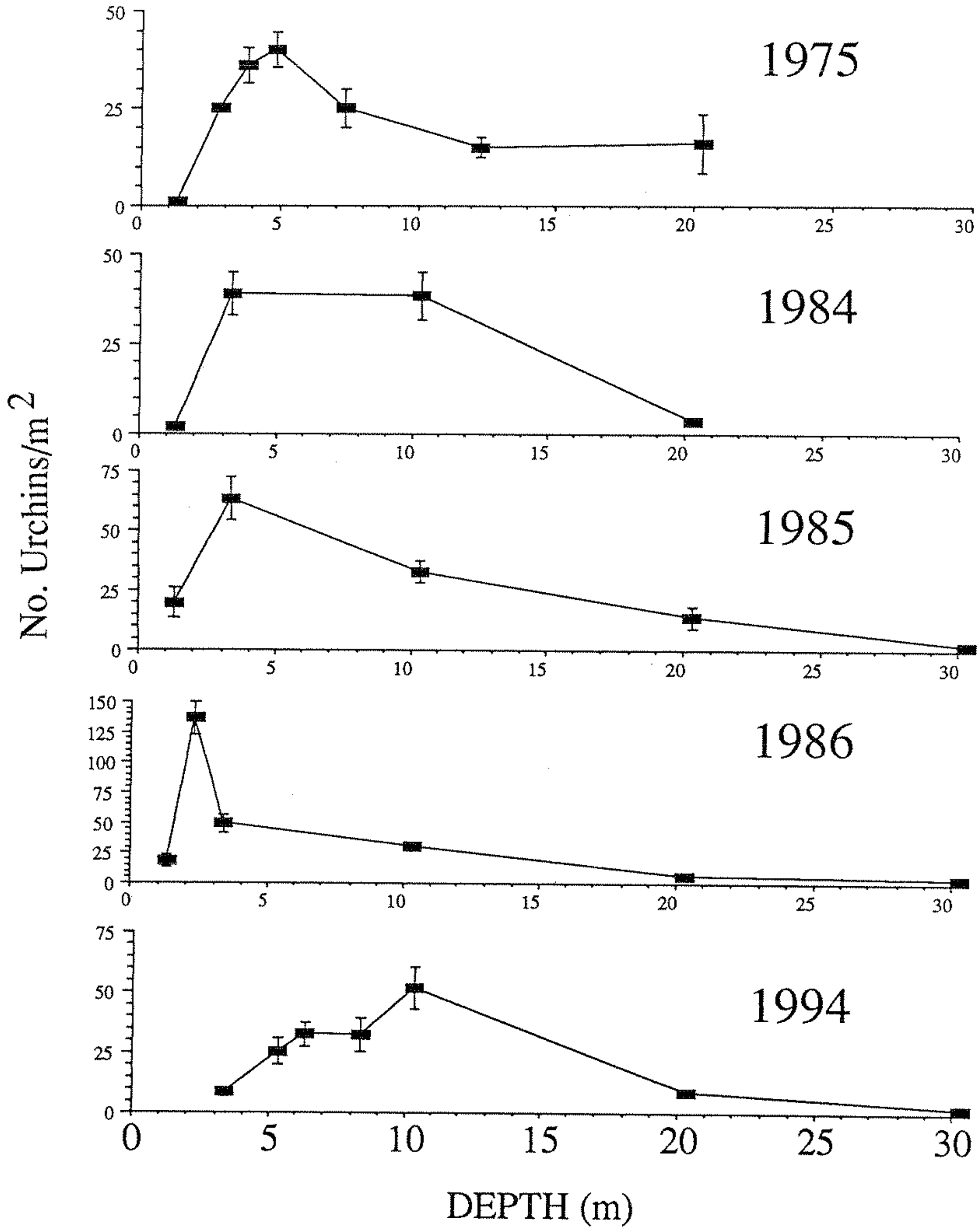
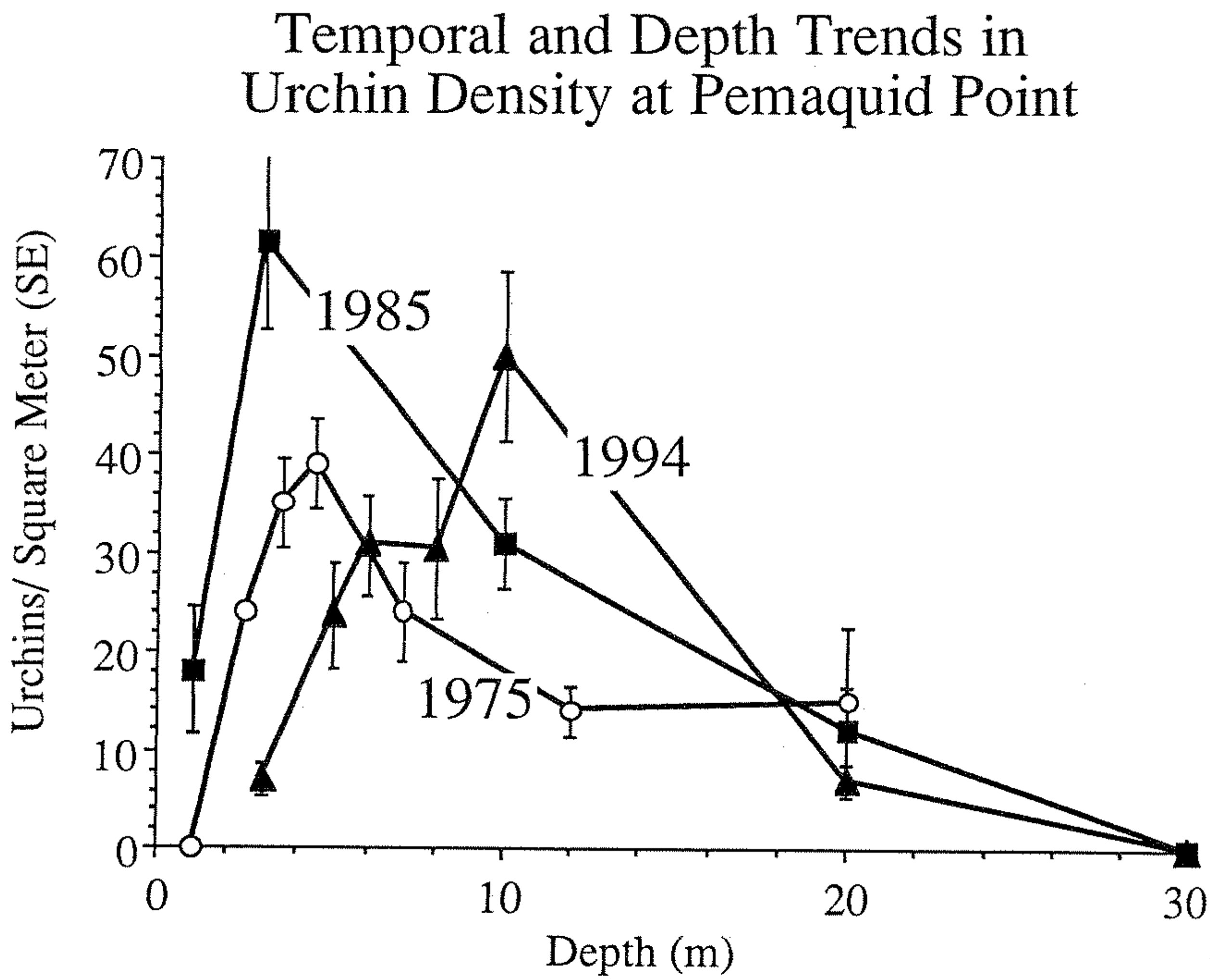
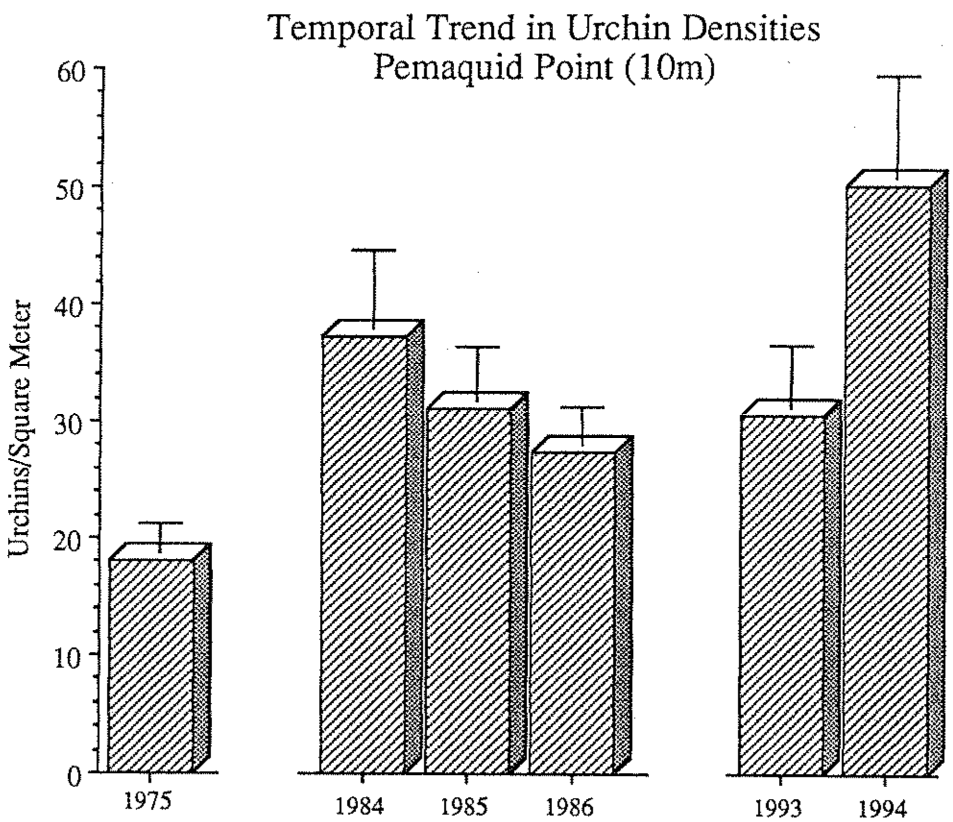
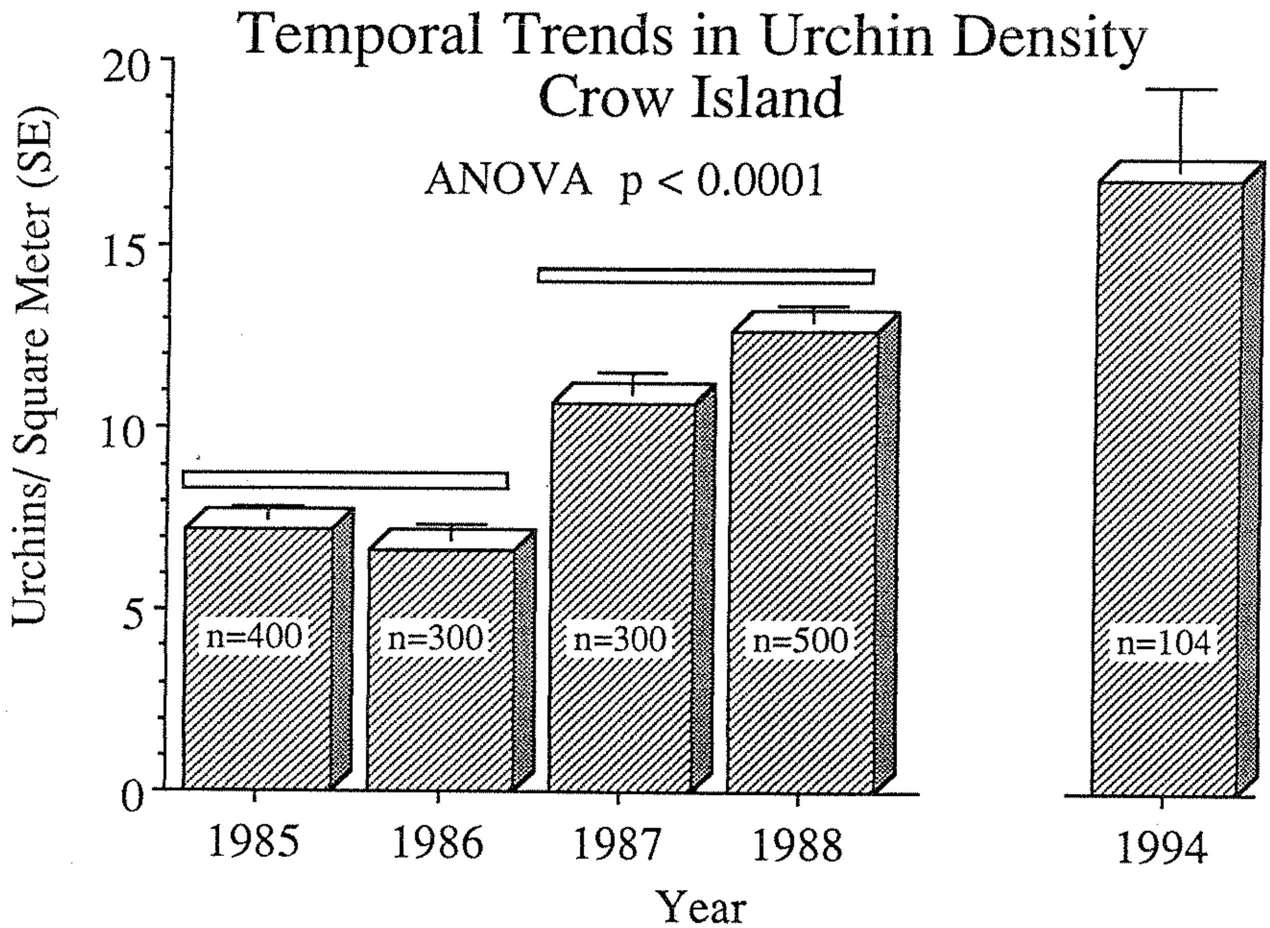


Fig. 11


Temporal and Depth Trends in
Urchin Density at Pemaquid Point
Urchins/ Square Meter (SE)
70
60
50
40
30
20
10
0
0
10
20
30
Depth (m)
1985
1994
1975


Temporal Trend in Urchin Densities
Pemaquid Point (10m)
Urchins/Square Meter
60
50
40
30
20
10
0
1975
1984
1985
1986
1993
1994


Temporal Trends in Urchin Density
Crow Island
ANOVA p < 0.0001
Urchins/ Square Meter (SE)
20
15
10
5
0
n=400
n=300
n=300
n=500
n=104
1985
1986
1987
1988
1994
Year

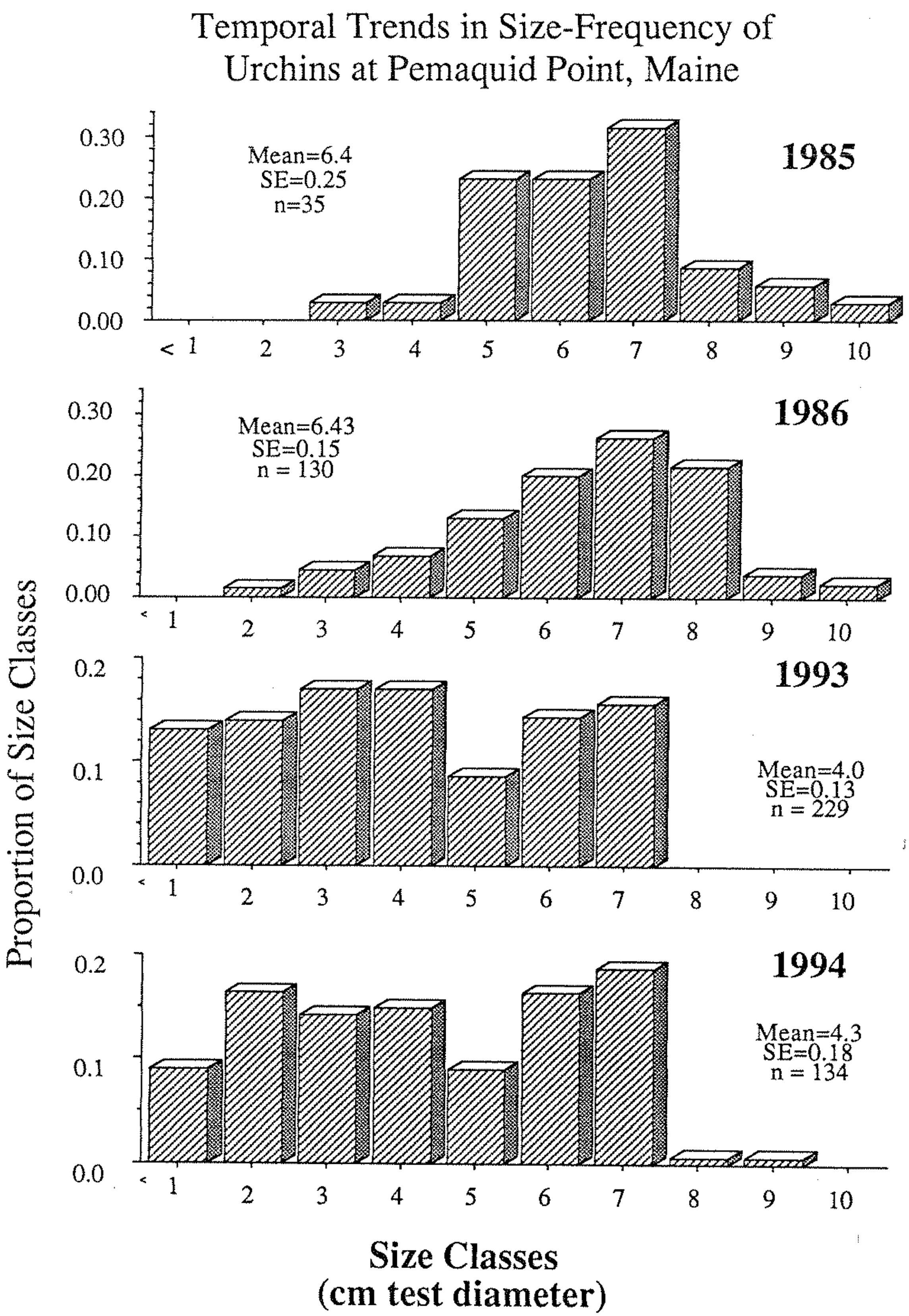

Temporal Trends in Size-Frequency of
Urchins at Pemaquid Point, Maine
Proportion of Size Classes
1985
Mean=6.4
SE=0.25
n=35
0.30
0.20
0.10
0.00
< 1
2
3
4
5
6
7
8
9
10
1986
Mean=6.43
SE=0.15
n = 130
1993
Mean=4.0
SE=0.13
n = 229
0.2
0.1
0.0
1994
Mean=4.3
SE=0.18
n = 134
Size Classes
(cm test diameter)

Fig. 15

Temporal Trends in Size-Frequency of Urchins Crow Island

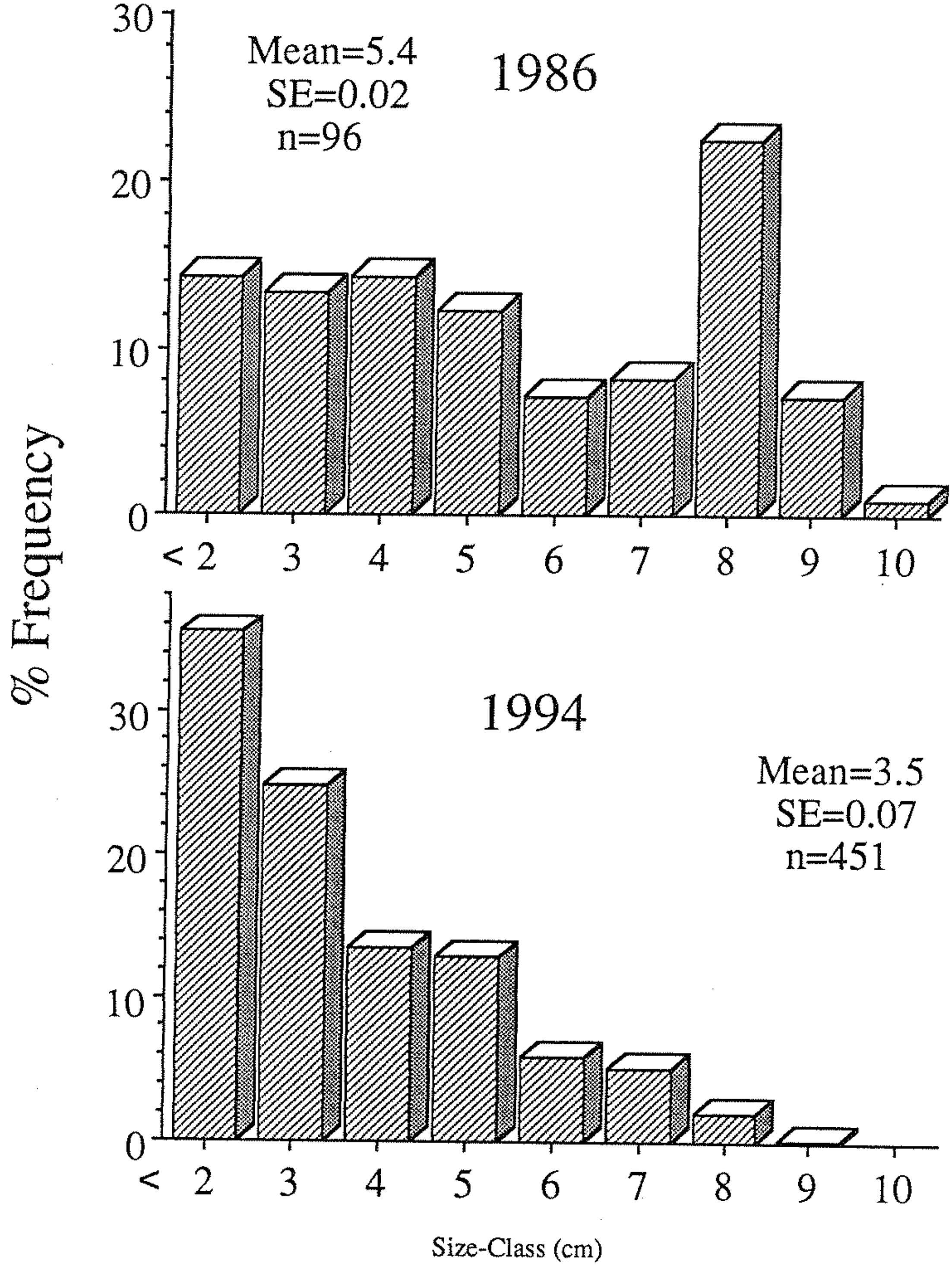
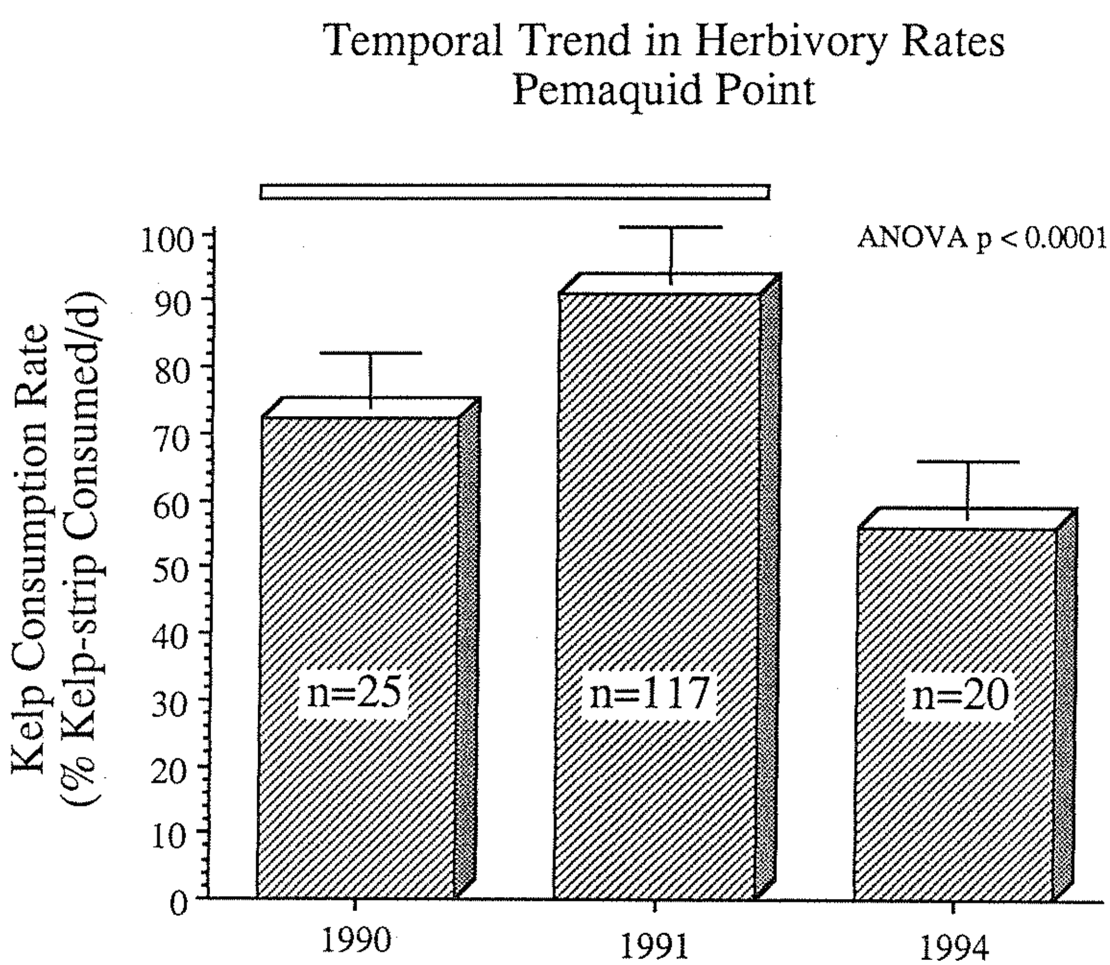
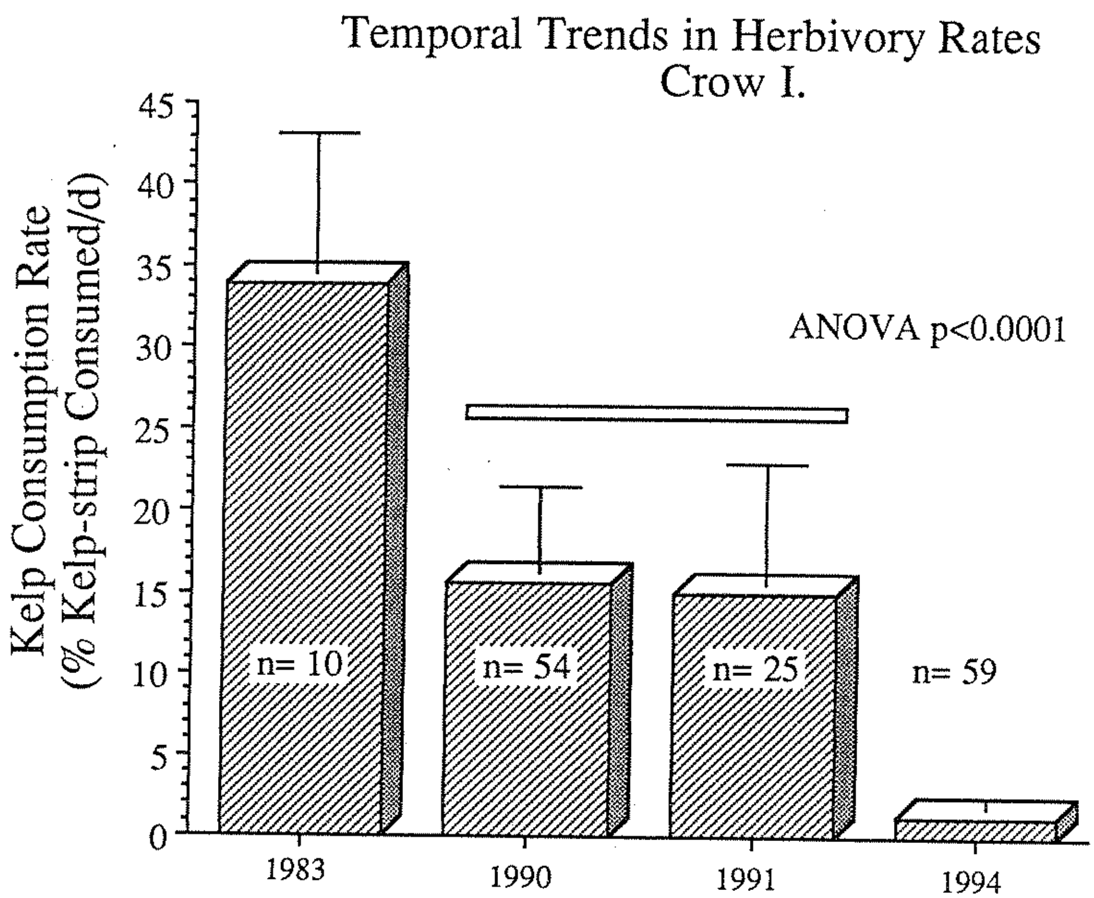


Fig. 16



Temporal Trend in Herbivory Rates
Pemaquid Point
ANOVA p < 0.0001
Kelp Consumption Rate
(% Kelp-strip Consumed/d)
0
10
20
30
40
50
60
70
80
90
100
n=25
n=117
n=20
1990
1991
1994


Temporal Trends in Herbivory Rates
Crow I.
Kelp Consumption Rate
(% Kelp-strip Consumed/d)
45
40
35
30
25
20
15
10
5
0
ANOVA p<0.0001
n= 10
n= 54
n= 25
n= 59
1983
1990
1991
1994

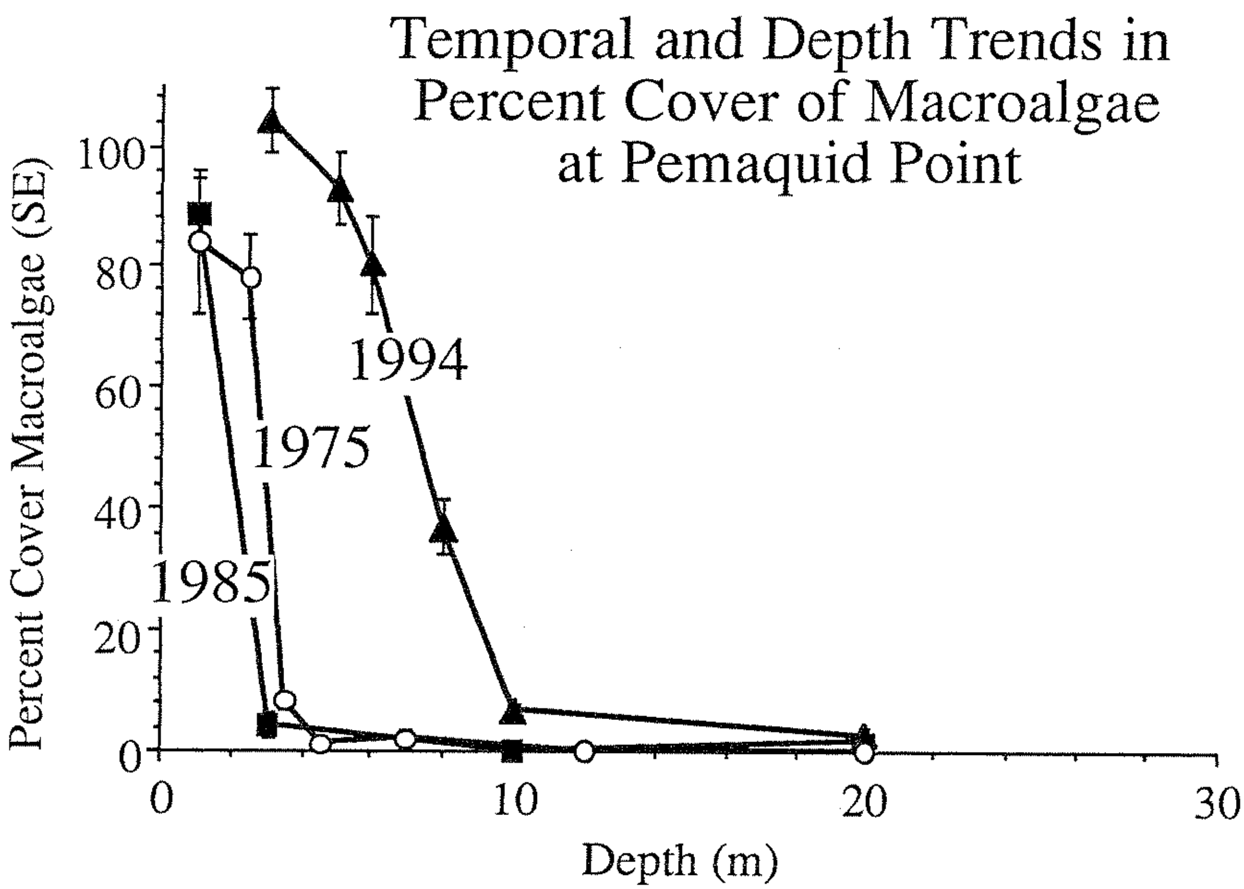

Temporal and Depth Trends in
Percent Cover of Macroalgae
at Pemaquid Point
Percent Cover Macroalgae (SE)
100
80
60
40
20
0
0
10
20
30
Depth (m)
1994
1975
1985

Fig. 19

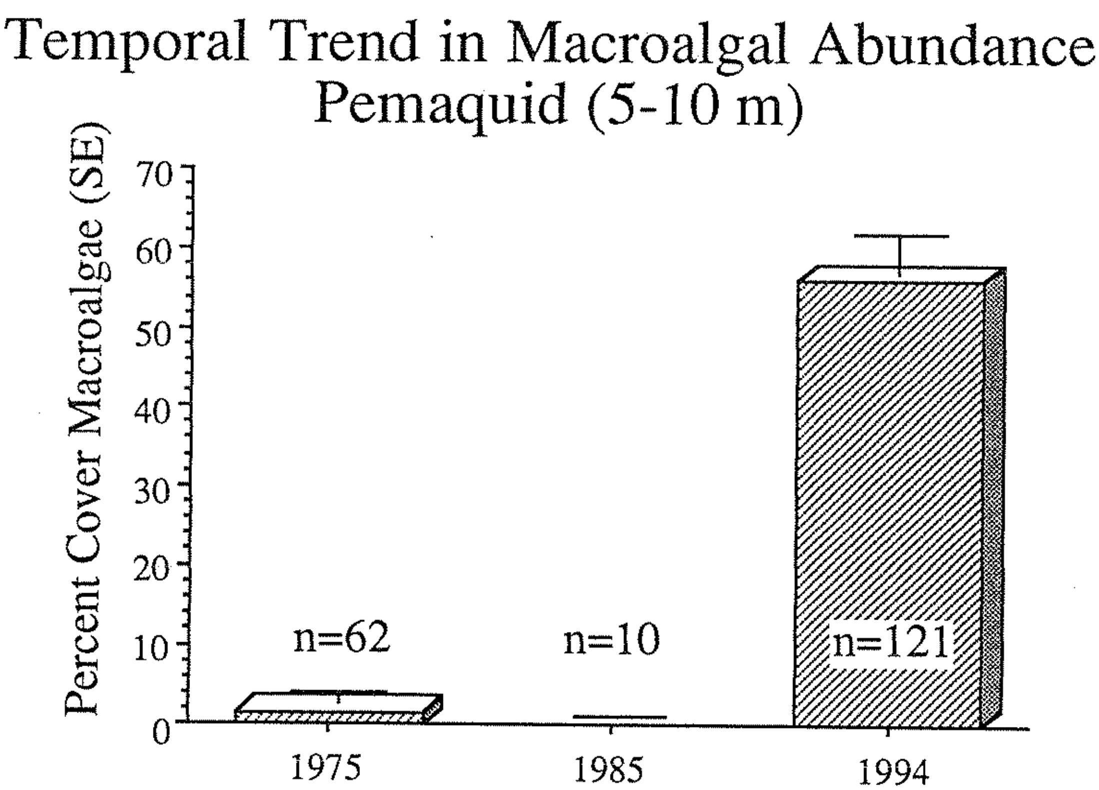
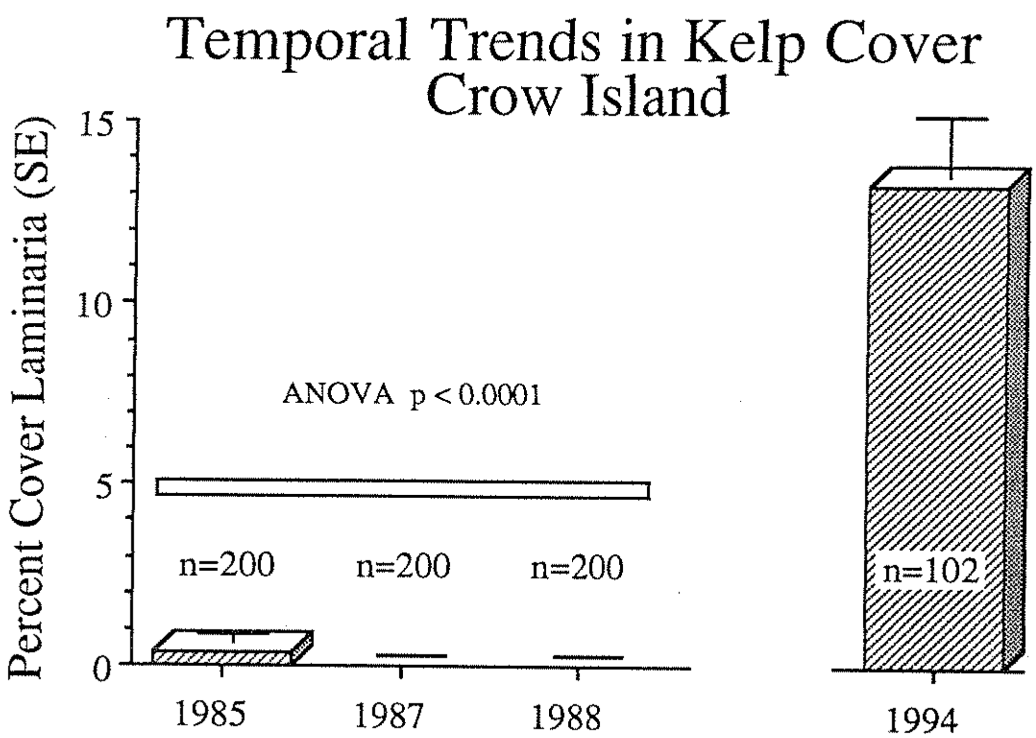

Temporal Trend in Macroalgal Abundance
Pemaquid (5-10 m)
Percent Cover Macroalgae (SE)
70
60
50
40
30
20
10
0
n=62
n=10
n=121
1975
1985
1994

Fig. 20

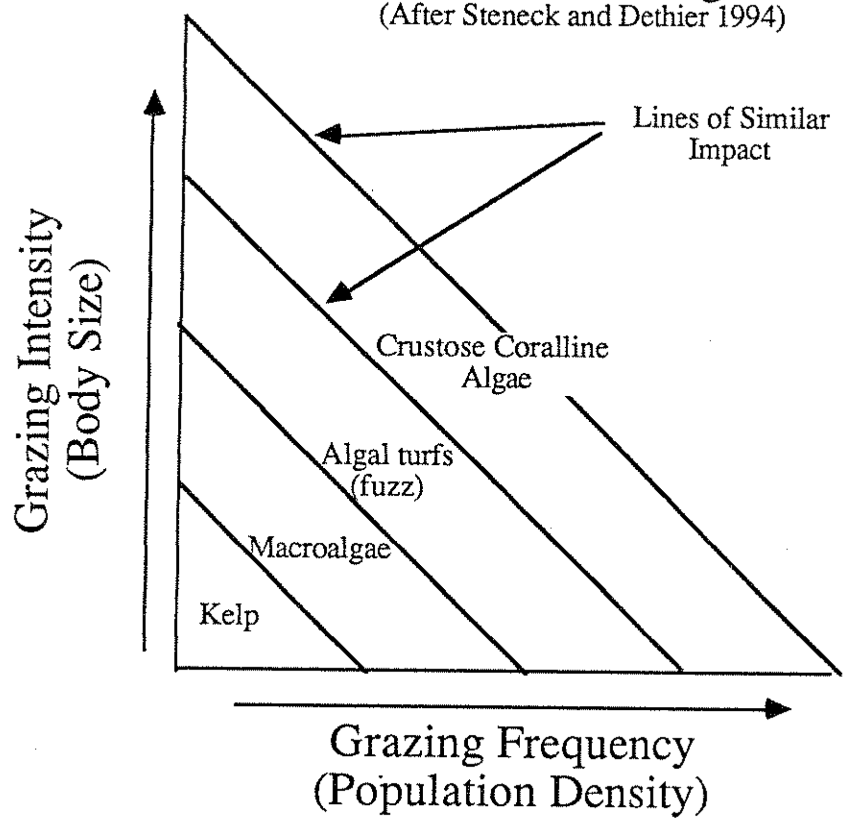


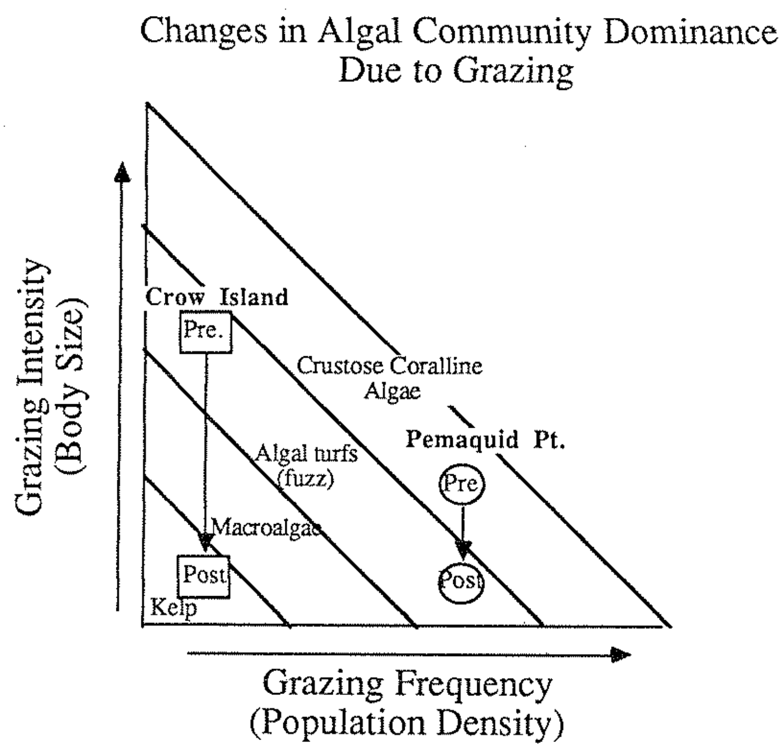
Temporal Trends in Kelp Cover
Crow Island
Percent Cover Laminaria (SE)
15
10
5
0
ANOVA p < 0.0001
n=200
n=200
n=200
n=102
1985
1987
1988
1994

Fig. 21

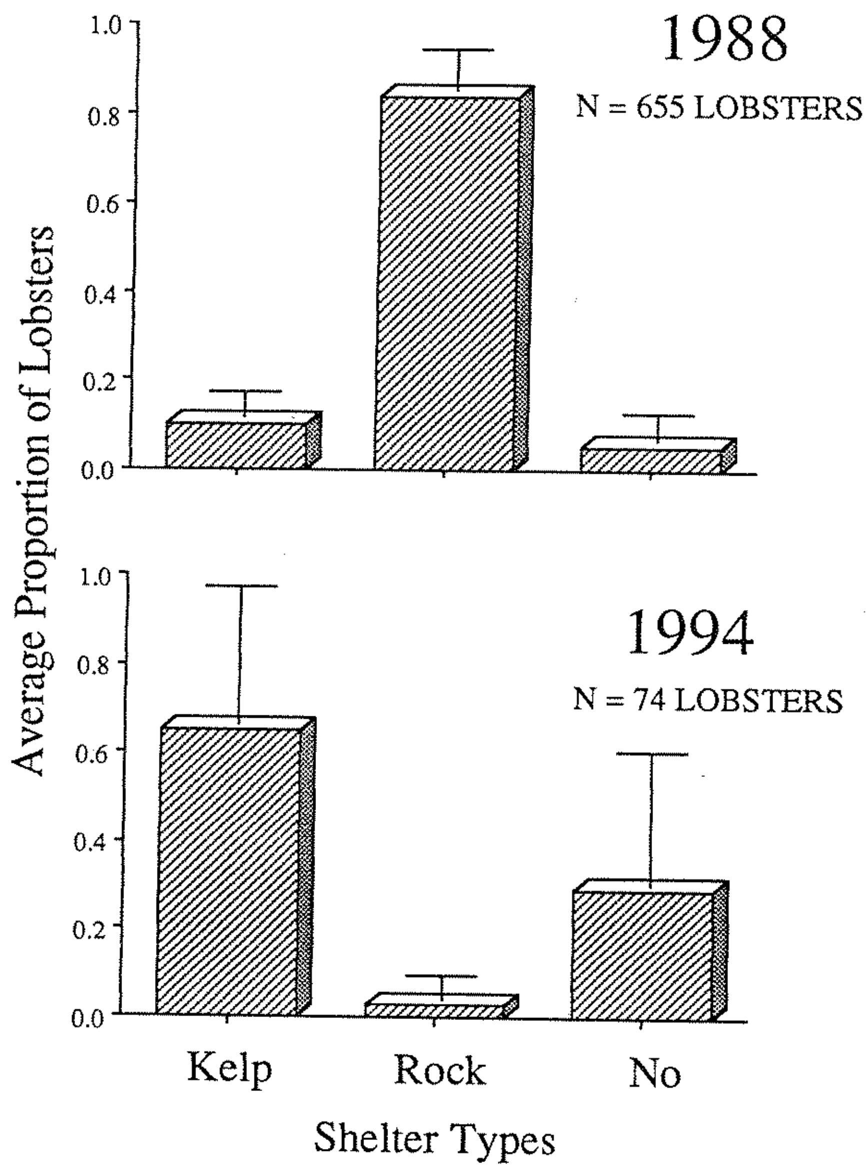
Changes in Algal Community Dominance Due to Grazing

(After Steneck and Dethier 1994)




Changes in Algal Community Dominance
Due to Grazing
Grazing Intensity
(Body Size)
Crow Island
Pre.
Post
Kelp
Macroalgae
Algal turfs
(fuzz)
Crustose Coralline
Algae
Pemaquid Pt.
Pre
Post
Grazing Frequency
(Population Density)

LOBSTER SHELTER USE



Spatial and temporal variability in reproduction and spawning in green sea urchins in Maine.

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Department of Plant Biology, University of Maine, Orono Maine.

Abstract

Green sea urchins, *Strongylocentrotus droebachiensis* were sampled monthly during 1977-88 from 10 sites along the Maine coast to determine changes in gonad weight. Density of sea urchins and habitat characteristics were assessed qualitatively during the year and quantitatively during late spring. Gonadal indices from three sites, Joneport, Owls head and Boothbay Harbor were sued to represent the eastern central and western regions of the coast. Patterns of gonad change were analyzed by analysis of variance. Specifically, a priori, planned contrasts enabled us to separate seasonal and monthly patterns, These data reveal that gonadal cycles vary seasonally and spatially and that at least two temporally significant ($P \leq .0.05$) gonad index levels can be found in most populations. Gonad indices correspond to the general temperature ranges for the three regions with lower gonadal levels from Ma or June through November and significantly higher levels from December through April or May. Spawning is variable and can begin as early as February but most populations appear to release gametes in March or April. These findings are relevant to possible management strategies currently being developed by fishermen and resource biologists.

Studies on the effects of depth, water flow amd diet on settlement, recruitment and grouwth of the gree sea urchin *Stongylocentrotus droebachiensis* in the Gulf of Maine.

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Abstract

Recent studies on early benthic phase populations of the green sea urchin Strongylocentrotus droebachiensis in the southern Gulf of Maine have indicated much variation in recruitment and growth within communities. Settlement of urchins occurs in June and early July and is predictable in timing over a 12-year period. Settlement density decreases with increasing depth and also is reduced in areas of low water exchange. New evidence also suggests that settlement is much less predictable in the northern Gulf of Maine. Survival of urchins past three months is unpredictable in space and between years and it may actually improve with increasing depth. Growth rates are also highly variable within populations and growth is best on an omnivorous diet. Urchins reach sexual maturity at about one inch in diameter and well-fed urchins may reach harvestable size of two inches in about two and one-half years. Settlement density, survival and growth rates all appear to be improved in areas with good water flow. The implications for management of an urchin fishery in the Gulf of Maine are discussed.

Introduction

In the late 1960"s, increased populations of the green sea urchin Strongylocentrotus droebachiensis were noted along the eastern coast of Nova Scotia (Breen and Mann, 1976a; Pringle, et al, 1980). The most conspicuous result of this sea urchin buildup was the removal of shallow water seaweed populations, particularly beds of the kelp Laminaria spp. Associated with the disappearance of kelp beds was a drop in lobster fisheries (Breen and Mann, 1976b). The increase in sea urchins and formation of "barren areas" extended almost the entire length of Nova Scotia, and similar outbreaks of urchins have been documented in Newfoundland, Prince Edward Island, Passamaquoddy Bay, and the Gulf of Maine (Pringle, et al, 1980; Neish, 1973; Larson, et al, 1980; Witman, 1985). In many areas, lobster fishing has decreased dramatically as lobsters tend to avoid urchin barrens. While there has been a die-off of urchins off the coast of Nova Scotia (Miller and Colodey, 1983; Scheibling, 1985), no similar die-offs have occurred in the Gulf of Maine. Certain areas, such as Passamaquoddy Bay, have contained urchin barrens since before 1970 (Neish, 1973; Harris, unpublished observations).

Sea urchin populations may be controlled by several factors including predation (Estes and Palmisano, 1974; Cowen, 1982), protistan disease (Pearse and Hines, 1979; Miller and Colodey, 1983) and commercial harvesting (Tegner and Dayton, 1977). Predation and disease are easily documented sources of mortality in urchins in Nova Scotia, but there is no evidence that either of these phenomena control urchin populations in the Gulf of Maine. Commercial harvesting of sea urchins has become a major industry on the temperate coasts of North and South America and Japan (Wilson and Gorham, 1982; Sloan, 1985; Freeman, 1987; Tegner, 1992). Analyses of the economic feasibility of urchin harvesting in the Gulf of Maine were conducted by Neish (1973) and Nieder, et al (1985). Beginning in 1987, commercial harvesting of urchins in Maine and New Hampshire has expanded rapidly to the present state where the urchin fishery in Maine is the second largest behind lobsters. Harris and his students have been conducting studies on sea urchin ecology and the potential for a fisheries since the late 1970"s (Harris,1982; Witman, 1985, 1987; Harris, et al, 1985, Martin, et al, 1988; Truchon, 1988; Nieder, et al, 1985). We have found that settlement of young *Strongylocentrotus droebachiensis* is predictable, intense and non-selective for about 6 weeks in June and July and at no other time (Harris, et al, 1985; Harris, et al, 1994). Further studies have shown that astroturf is an excellent settlement collector and that survival of newly settled juveniles is the key determinant to recruitment (Harris, et al, 1994). Growth rates of urchins can vary considerably depending on food availability and composition (Nestler, et al, 1994; Simoneau, et al, 1994).

The purpose of this report is to summarize observations and studies on urchin settlement, recruitment and growth of the green sea urchin S. droebachiensis in the southern Gulf of Maine. The results presented here will include experiments that were conducted during the summer of 1994 that are still being analyzed and/or are still underway. This is to provide the most recent knowledge available to a workshop focusing on synthesizing the available knowledge of green urchin biology in order to formulate recommendations concerning gaps in our knowledge that need to be addressed and areas of concern relating to the management of the fishery in the Gulf of Maine.

Materials and Methods

Current studies of settlement and recruitment of S. droebachiensis involve the use of pieces of astroturf attached to plasticized lobster trap wire panels placed on the bottom at a variety of depths and locations. The panels were set out in late May and the first week of June at the Isles of Shoals, 10km off the New Hampshire coast, at Cape Neddick, Maine, and in Casco Bay, Maine (Figure 1). At the time of placement, quadrat photographs of the adjacent bottom were taken with a Nikonos V camera and a 3:1 framer which takes approximately 104cm2 area. Newly settled urchins can be counted from these photographic quadrats. One half (10 replicates) of the astroturf substrates were collected in the middle of July and the adjacent bottom was again photographed. Each panel was placed in a plastic bag and returned to the laboratory where it was measured and placed in alcohol for 10 minutes. The materials extracted from the panel was filtered through a fine mesh screen and placed in a bottle of alcohol for subsequent counting of all newly settled urchins.

At the time of the workshop (27, 28 September, 1994) eight out of ten replicates from each site had been analysed and the photographic samples from Cape Neddick in July had also been completed. The second half of the samples were collected and processed on 26 September. The second astroturf and photographic samples from each site will allow for a comparison of survival or recruitment of urchins after three months. The results of a previous recruitment study are discussed below.

One long-term and several short-term growth studies have been conducted in the last few years. Approximately 200 newly settled urchins were established at the Coastal Marine Laboratory at the mouth of Portsmouth Harbor in late July, 1992. The urchins have been fed a diet of Laminaria spp. and the surviving urchins are measured on a monthly basis. The results of short-term growth studies comparing diets and the effect of water flow will also be summarized (Nestler and Harris, 1994; Simoneau, et al, 1994).

Results and Observations

The establishment of *Strongylocentrotus droebachiensis* -dominated communities began in the late 1970"s in the southern Gulf of Maine. Subtidal sites at Cape Neddick were converted before the fall of 1979 (Harris, 1982), while a study site at Star Island at the Isles of Shoals was transformed in 1980 (Witman, 1985; Martin, et al, 1988). Portions of Casco Bay contained well-established urchin barrens in 1985, but lobstermen had been complaining about sea urchins for several years at that time (Bruce Chamberlain, DMR, personal comm.) I observed urchin barren communities in the summer of 1970 in Eastport, Maine and Neish (1973) described urchin-dominated communities on Grand Manan Island from the same period, which would suggest that the transformation of shallow-subtidal communities from Chondus-Laminaria-dominated systems to urchin barrens proceeded from the northern Gulf of Maine to the south. As in other regions, the study of sea urchin settlement and growth began following the transformation of kelp beds to urchin barrens about 1980.

Settlement and Recruitment Studies.

The timing of settlement of S. droebachiensis at study sites at Cape Neddick and the Isles of Shoals has been consistent since observations began in 1981 (Harris, 1982; Harris, et al, 1985; Harris, et al, 1994). Newly settled urchins appear about the first week of June and continue to settle until at least the middle of July. The types of experiments conducted over the years has varied, but densities greater than 10,000/m2 have been consistently recorded from the first quantitative studies at the Isles of Shoals in 1982 until the present studies conducted in June and July, 1994.

There appear to be several factors that influence the density of accumulated settlement between sites. Depth of sampler has been shown to be important and the exposure to water motion also seems to influence density. Harris, et al, (1994) reported an approximate order of magnitude decrease in densities of newly settled urchins from stations at Star Island along a transect from 8m to 20m to 30m. Figure 2a summarizes the results of studies comparing settlement at the same depths in 1994. The pattern of decline in accumulated settlers by depth has been consistent over four separate years (1990, 1992, 1993 and 1994). There are large aggregations of urchins in both the 20m and 30m depth zones (Martin, et al, 1988; B. Bryant, lobsterman, personal comm.) and this may indicate that there are either differences in settlement by site and/or that survival or recruitment is higher at deeper sites.

There are substantial differences in settlement densities between sites at the 8-10m depth and these seem to be influenced by water motion or current. Figure 3 shows the partial results of panels set out at different sites at the Isles of Shoals, Cape Neddick and Casco Bay. This is the first year that comparisons between sites have been conducted that indicate water motion is a factor influencing settlement densities, though one set of results from studies done in 1993 suggested this pattern. Sea state consisting of 4 to 8ft long period swells out of the northeast dictated the experimental design that resulted in these findings. The sea conditions on the day panels were set out were too rough at the Star Island site where my students and I normally work (Witman, 1985; Martin, et al, 1988, Harris, et al, 1994). The panels for Star Island were therefore placed about 500m more to the west of the normal site near the southeast point of Star Island (Figure 1). On the day that the panels were retrieved, it was apparent that hydrographic conditions at this site were very different than those at the normal Star Island site - there was so little water motion that floculent material and urchin feces were accumulated in piles, which had never been observed at the normal site. Therefore, a set of panels from the barrens site at White Island was also collected as a comparison, for previous studies had indicated that this site was very similar in conditions and settlement patterns to the regular Star Island site. Figure 2b shows a comparison of the densities of new settled urchins at the alternate Star Island site and the barrens White Island site; the densities at the White Island site (30,237.8/m2) were more than 4 times the densities at the alternate Star Island site (7372.5/m2).

There are other indications that hydrographic conditions at the alternate Star Island site are different than those at the White Island site. On 26 September 1994, recruitment panels were collected at both sites and a sample of adult urchins was also obtained. In the prior week, there had been a northeasterly storm that passed through the Gulf of Maine. All of the urchins at the White Island site were covered with drift algae that they had trapped with their spines and pedicellaria, while no drift algae was observed at the Star Island site. Gonad indices for the urchins at the White Island site had a mean value of 14.69% while those at the alternate Star Island site had a mean value of 6.91%. This suggests that water motion can influence the number of larvae passing over a site that will be available to settle as well as the amount of drift algae that is an important source of nutrition to urchins in established urchin barren communities.

Previous results from Star Island show the effect of water motion, but were not interpreted as such at that time. Figure 4 shows the results of three years of sampling settlement at Star Island. The 1990 results show that panels placed on the bottom receive higher numbers of settling urchins than suspended panels. The densities for 1992 are comparable to the values observed at White Island in 1994. In 1993, a storm removed settlement panels from the 8m site at Star Island. A set of panels from just inside the Gosport Harbor side of Star Island was substituted and the densities on those panels was much lower (about 8000/m2) than seen in previous years at the normal Star Island site. The original assumption was that these lower densities might indicate that overfishing of S. droebachiensis was impacting the reproductive potential of the stocks. The results from 1994 suggest that differences in larval supply due to water flow are a more likely explanation.

The results from settlement panels in Casco Bay shows a similar pattern of lower densities of newly settled urchins on panels from the Cliff Island site relative to the densities on panels from Inner Green Island (Figure 5). The site at Inner Green Island is more exposed to water motion in the form of currents and surge and the bottom had much less accumulated fine materials than the site at Cliff Island.

Early Recruitment.

Numerous observations over the years has shown that while settlement is high and predictable in shallow depths, survival of newly settled urchins is unpredictable and mortality is high. In August 1983, the densities of young-of-the-year S. droebachiensis at the 8m Star Island site was 133.6/m2, based on counts from photographic quadrats; at Cape Neddick, the density was 1458.0/m2. At both sites, the settlement densities had been above 10,000/m2 though the settlement at Cape Neddick may have been lower than at the Star Island site as is indicated in the 1994 results shown in Figure 3. Harris, et al (1994) presented data that suggested that survival in astroturf panels is significantly greater than on adjacent substrate after three months, but this must be tempered by the fact that it is also higher at the immediate end of the settlement period in July. Only one set of photographic samples has been completed for the July 1994 settlement experiment, but the densities of newly settled urchins on substrates adjacent to the astroturf panels at Cape Neddick gave a mean density of 593.3/m2 versus over 18,000/m2 on the astroturf panels.

Growth Studies.

Harris, et al, (1985) analysed photographic quadrats taken at the Star Island and Cape Neddick sites from August 1983 to July 1984 and calculated a mean size for one year-old urchins of 4.1mm at both locations. A review of those photographs and numerous observations suggested that growth was highly variable within populations and that some animals grew much faster than the mean value. Figure 6 shows the present state, as of September 1994, of a growth study begun in 1992 with newly settled urchins. The urchins have been fed Laminaria spp. The largest urchin was 48mm in diameter, mean size was 38mm and the smallest individual was 18mm. Most urchins sampled have viable gonads by the time they reach 25mm in diameter and the fastest growing animals in this study should reach a harvestable size of 51mm in approximately two and one half years and will have reproduced at least once. However, the majority of this population will not be ready to harvest until the following year.

A diet of kelp is not the best diet for these omnivorous animals. A diet of Laminaria spp. encrusted with the bryozoan Membranipora membranipora has been shown to produce faster growth in short term growth experiments (Nestler and Harris, 1994; Simoneau, et al, 1994). A recent experiment has indicated that increased water flow results in faster growth rates in young urchins fed on bryozoan encrusted kelp

(Simoneau, et al, 1994). Further studies will need to be conducted to elucidate these findings, but the positive influence of increased water motion on growth is consistent with results that show higher settlement densities and improved gonad indices in habitats with greater water motion.

Discussion and Recommendations

The great interest in the ecology and fisheries of Strongylocentrotus droebachiensis in the Gulf of Maine is a very recent phenomenon. Neish (1973) evaluated urchin populations in New Brunswick relative to a possible commercial fishery at the beginning of the 1970"s, but studies of urchins in the southern Gulf of Maine only began after they altered communities on a massive scale (Harris, 1982; Witman, 1985; Martin, et al, 1988). Interest in an urchin fishery began shortly after the appearance of high densities of urchins (Neider, et al, 1985). A fishery started to grow in 1987, but any real effort to manage it is much more recent (Creaser, 1993a, b). By 1993, only Massachusetts was experiencing increasing fishing pressure as most of the waters off of New Hampshire and the southern portion of Maine were already overfished.

This report focuses on recent studies of settlement, recruitment and growth of S. droebachiensis in the southern Gulf of Maine. The results of these studies do suggest some implications for the fishery as it is currently functioning. This section will discuss those results in the context of managing the urchin fishery.

Twelve years of studying settlement and recruitment of urchins at the Isles of Shoals and Cape Neddick show a very predictable pattern of settlement in June and July. Results from 1994 also suggest that this pattern of predictable settlement extends to Casco Bay (Figures 3 and 5). Factors that influence the density of settlement at any given site in this region are depth and hydrographic conditions with settlement being greatest in areas with higher water flow and less than 10m in depth. The results concerning the influence of hydrographic factors are new and future studies will focus on this phenomenon. The results also confirm the suitability of astroturf panels as substrates for collecting new settled urchins.

The results to date all suggest that recruitment or survival of settling juveniles is much less predictable in space and time. It is possible to enhance survival for several months by leaving astroturf settling panels in place for additional time (Harris, et al, 1994), but analysis of samples from 1994 will determine if this is consistently effective and how factors such as depth and water motion affect this strategy. The implications for an urchin fishery in the southern Gulf of Maine are positive in that a large supply of urchin larvae will settle every year and certain areas at the Isles of Shoals are currently showing signs of recovery from previous overfishing.

Results presented at this workshop by Robinson, et al and personal observations from Passamaquoddy Bay suggest that neither settlement nor recruitment is predictable in the northern portion of the Gulf of Maine. If these results are correct, then the fishery in the northern region may be very difficult to sustain even with strict management procedures.

Studies to date show that growth is highly variable within populations and that it can be very slow under field conditions in urchin barrens (Harris, et al, 1985). Current studies have demonstrated that growth is faster on an omnivorous diet (Nestler and Harris, 1994; Simoneau, et al, 1994) and that increased water flow also increases growth rates (Simoneau, et al, 1994). Further studies are underway to confirm the influence of water flow on growth as are new studies to test an artificial diet, but the results to date do allow some conclusions concerning the dynamics of natural populations. Individuals of S. droebachiensis reach sexual maturity by the time they are about 25mm in diameter so all members of a population should be able to reproduce one or more times prior to reaching harvestable size of 51mm. Under good conditions of water flow and diet, some animals may reach harvestable size in two and a half years, but most members of such a population will probably take three or more years to reach the minimum size of 51mm. Field conditions are seldom as favorable as laboratory conditions so these growth projections are probably optimistic. Monitoring of field populations in areas free of harvesting will be required before accurate data on growth is obtained. My experience with poaching in an area protected by a research permit suggests that such studies will be very difficult to obtain.

There are conclusions that can be made from these studies that directly impact on management of the urchin fishery in the southern Gulf of Maine. Settlement of juveniles is predictable and heavy and recruitment can be enhanced by manipulations to make it reasonably predictable. Growth of field populations might be conservatively placed at four years from settlement to harvestable size in habitats with adequate food and water flow. It could be much slower in areas of low food availability and flow. Since roe content is directly proportional to food availability, conditions for the highest settlement rate and fastest growth will also provide the best roe content. It should be possible to assess the population dynamics of specific areas by using settlement density in July, population structure and roe content in the fall as indicators of the potential of an area to sustain different levels of fishing pressure. Future studies need to be conducted to confirm the potential of these parameters as management tools.

In summary, there is much that we know about the biology and ecology of Strongylocentrotus droebachiensis in the Gulf of Maine as is indicated by the presentations in this report. There is still much to learn, but it is my belief that the necessary information is available to begin to make some very difficult and unpopular management decisions. If these decisions are not made soon, there will be a rapid decline in the fishery for this species and some areas may lose the fishery for a very long time. The two most obvious problems are that the season is too long and there are too many fishermen. The most serious threat to the fishery is the number of harvesters. There is no way that urchin populations can sustain the present level of harvesting and a survey of Casco Bay will indicate the future of the fishery if nothing significant is done. The potential for a sustainable urchin fishery in the southern Gulf of Maine is great, but it will have to be organized and managed in a much different manner than the present system. Time will tell if the potential is realized.

Acknowledgements

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FIGURE LEGENDS:

Figure 1. Map of the southern Gulf of Maine showing the locations of urchin settlement experiments. The black circles on the blowups of each locality indicate the approximate positions of the experimental arrays.

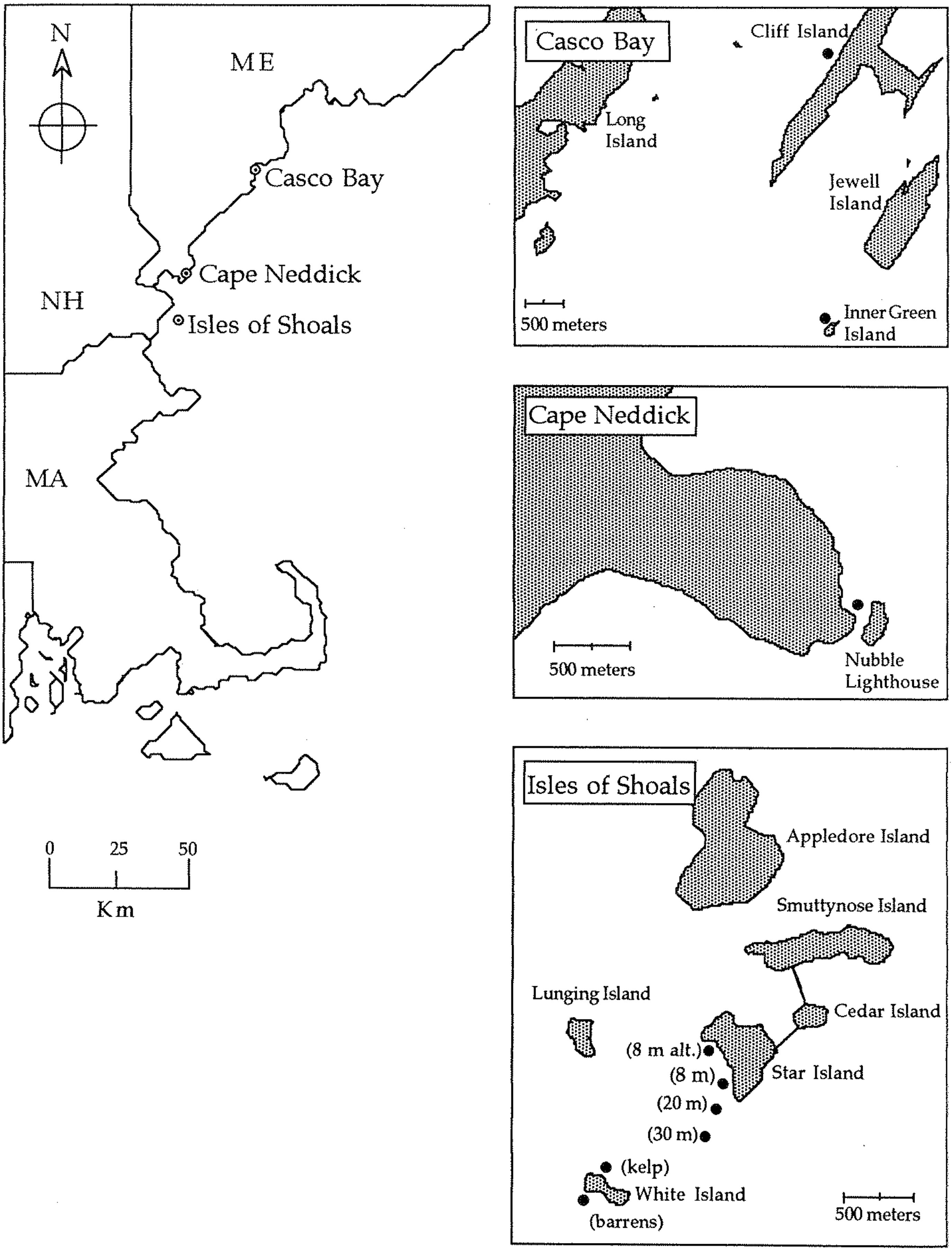
Figure 2. A summary of urchin settlement densities for sites at the Isles of Shoals comparing depth and also location. A. Compares densities of newly settled urchins at 30ft, 60ft and 90ft depths along a rocky slope on the southern side of Star Island. B. Provides an additional comparison between a 30ft site on the south side of White Island with the densities for the 30ft site used at Star Island. Past studies indicated that the White Island site is similar to the normal 30ft site on Star Island as compared to the more protected alternative 30ft site used in this study.

Figure 3. A summary of urchin settlement densities from five 30ft sites at the Isles of Shoals, Cape Neddick and Casco Bay. Differences in densities between sites may be due to the relative degree of exposure and water flow at each site

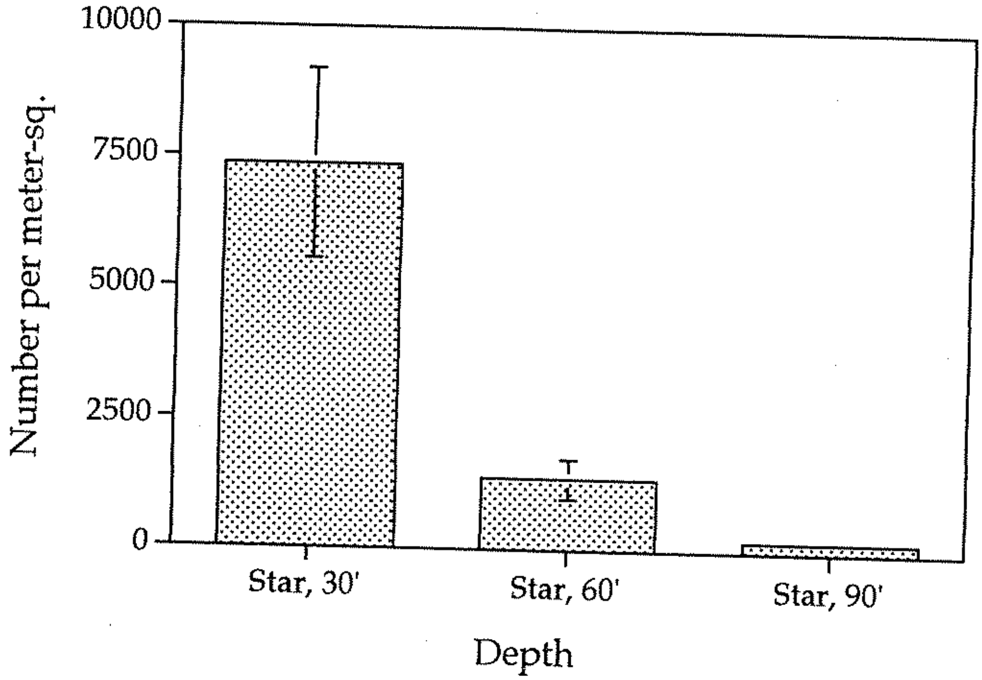
Figure 4. A comparison of settlement densities between years at 30ft at Star Island, Isles of Shoals. The two 1990 densities indicate that bottom-set panels receive a higher settlement than similar panels suspended off the bottom. The 1993 results were taken from panels in Gosport Harbor because the panels at the normal Star Island site were lost due to storm surge.

Figure 5. A comparison of settlement densities of urchins at two sites in Casco Bay. The Green Island site is more exposed and within a kelp bed than resulted from overfishing of an urchin barrens. The Cliff Island site is in a silty rubble habitat that is sparsely populated by urchins and algae.

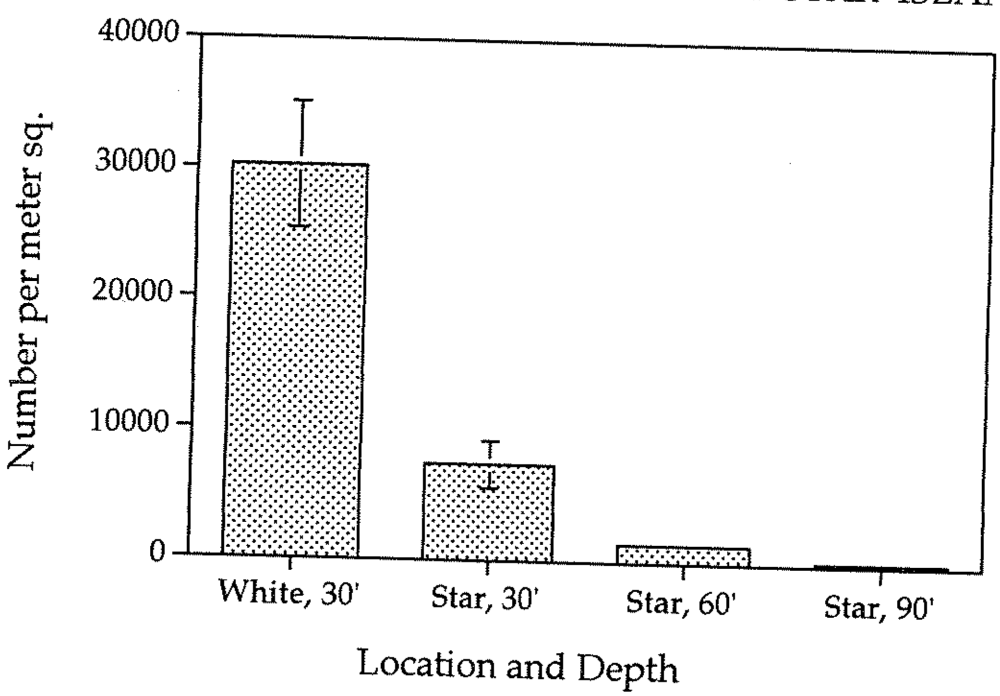
Figure 6. Results through September 1994 of an on-going growth study of *Strongylocentrotus droebachiensis* fed a diet of Laminaria spp.. The experiment began in July 1992 with newly settled urchins and is intended to provide information on the variation in growth of a population of urchins kept under identical conditions. The graph shows the size of the largest and the smallest urchin at each sampling period as well as the mean size of the population.


N
ME
Casco Bay
Cape Neddick
Isles of Shoals
NH
MA
0
25
50
Km
Casco Bay
Cliff Island
Long Island
Jewell Island
500 meters
Inner Green Island
Cape Neddick
500 meters
Nubble Lighthouse
Isles of Shoals
Appledore Island
Smuttynose Island
Lunging Island
Cedar Island
(8 m alt.)
(8 m)
Star Island
(20 m)
(30 m)
(kelp)
White Island
(barrens)
500 meters

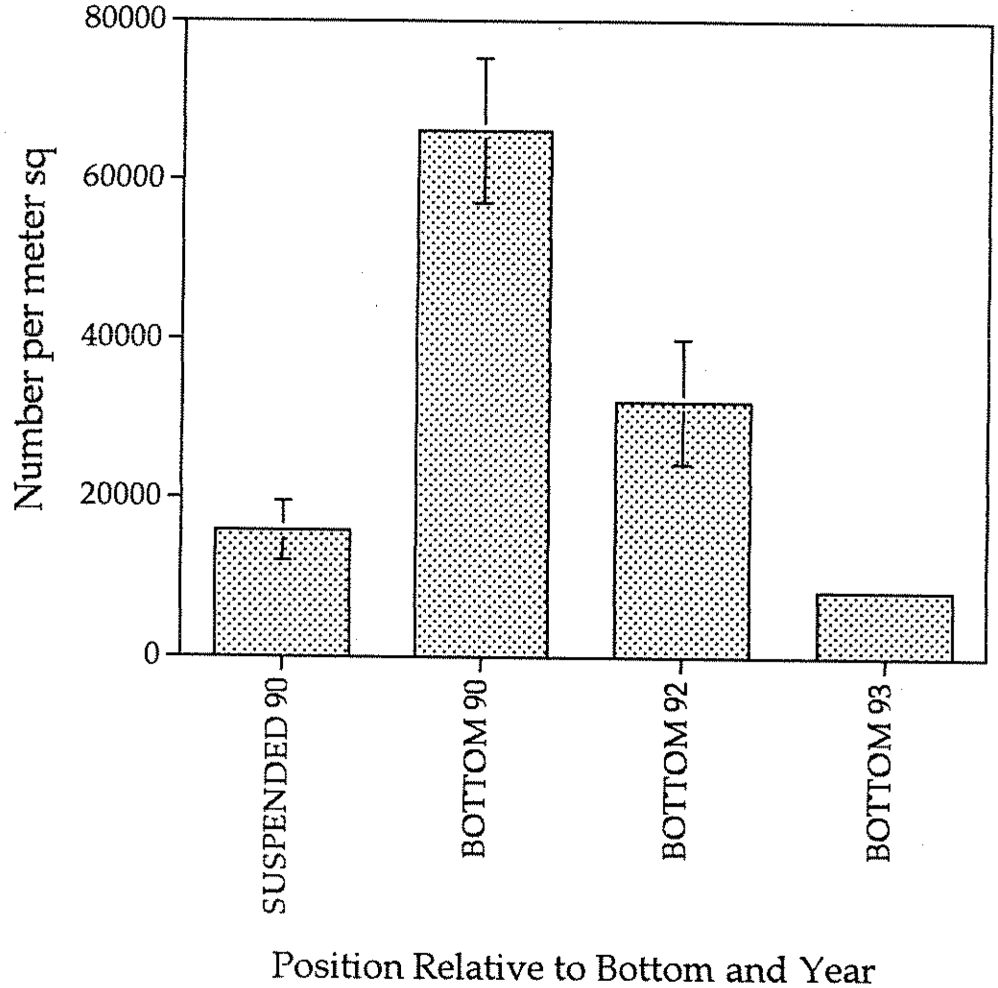
A. COMPARISON OF SETTLEMENT BY DEPTH



B. URCHIN SETTLEMENT AT WHITE AND STAR ISLANDS



COMPARISON OF SETTLEMENT BY POSITION AND YEAR



URCHIN SETTLEMENT WITHIN SOUTHERN GULF OF MAINE

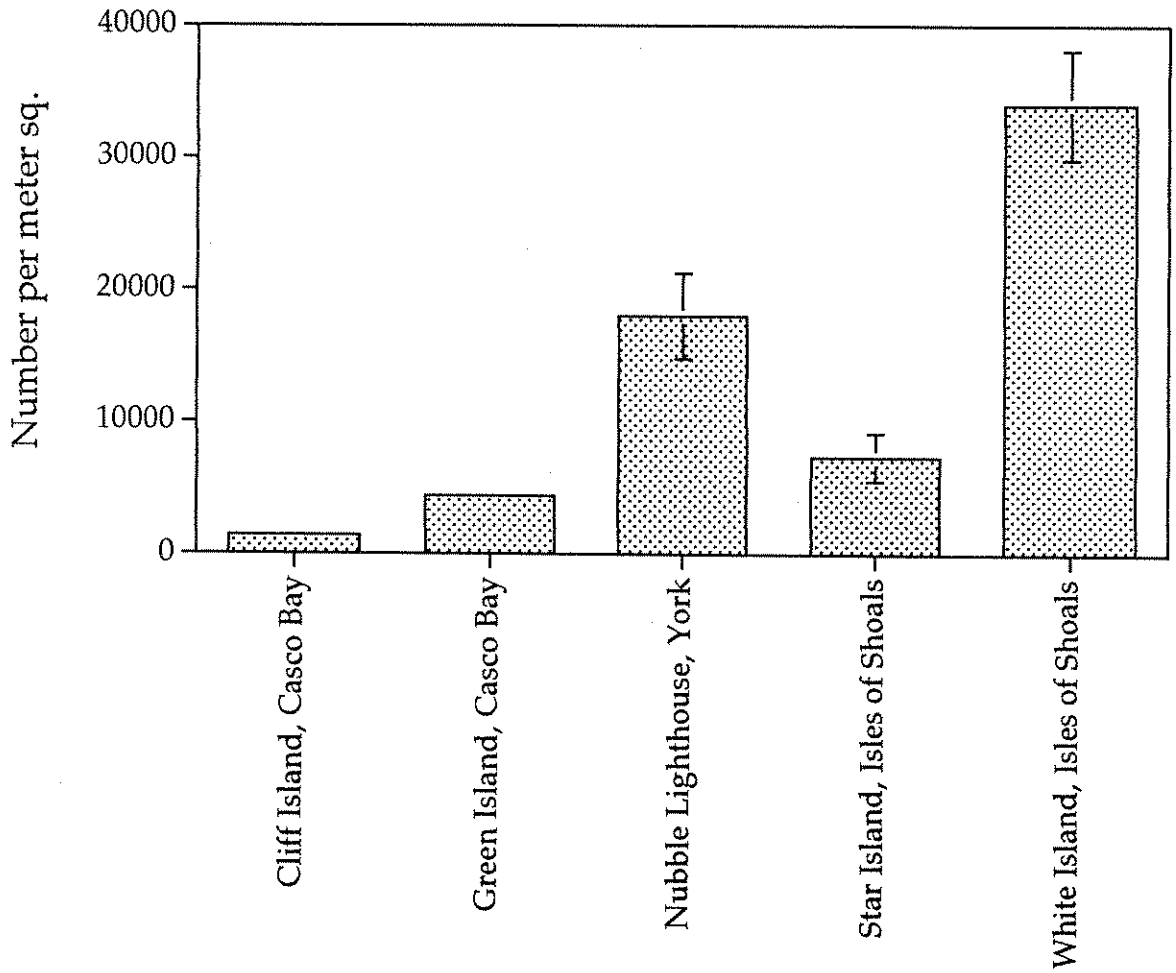
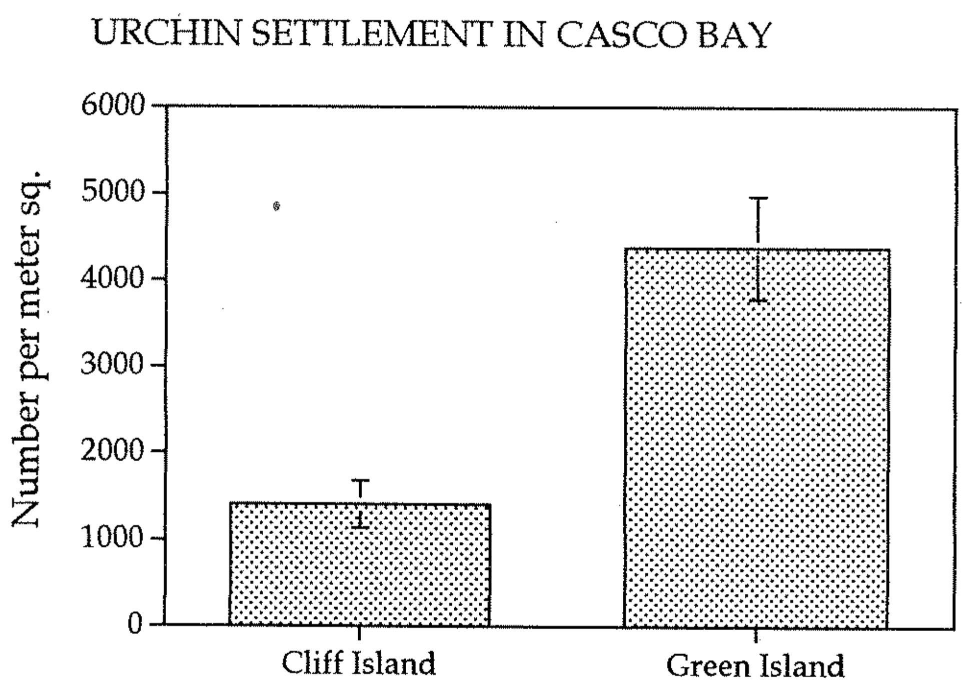
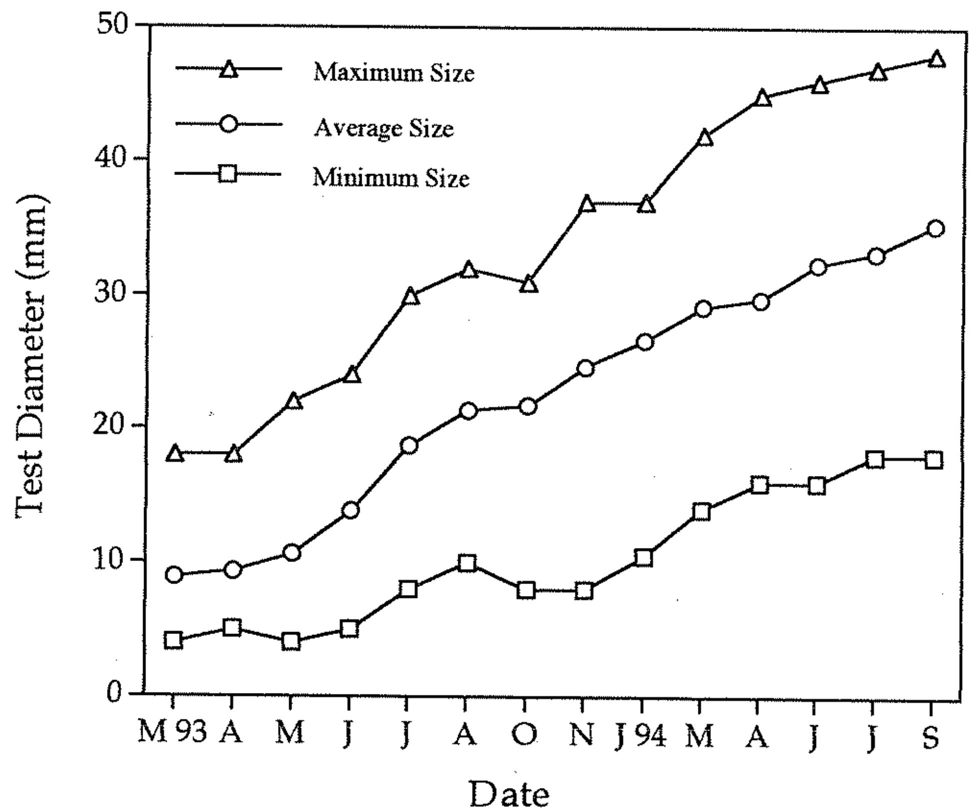


Fig 5


URCHIN SETTLEMENT IN CASCO BAY
Number per meter sq.
6000
5000
4000
3000
2000
1000
0
Cliff Island
Green Island

97

URCHIN GROWTH AT COASTAL MARINE LAB, NH



Strategies and life-history characteristics as criteria for evaluating the suitability of sea-urchin species for fisheries and aquaculture

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Abstract

Evolutionarily derived strategies involve a suite of life-history characteristics associated with the intensity of environmental stress (resulting in low production of biomass) and disturbance (resulting in loss of biomass including death) experienced by a species. These characteristics include capacity to obtain food; rate of growth; rate of respiration; resistance to starvation; the relative allocation of resources to protection and reproduction; and the quality of the gametes. An *a priori* evaluation of the environment and life-history characteristics of *Paracentrotus, Strongylocentrotus, Loxechinus, Anthocidaris, Evechinus, Heliocidaris, and Tripneustes* can be used to predict their suitability for fisheries and aquaculture.

A primary interest in fishing is the selection of species. A variety of criteria are used, but a key one is high productivity. This is important both in growth to a marketable size and in reproduction. These two factors combine when the product marketed are the gonads themselves, as is the case with sea-urchin fisheries. A large variety of species of sea urchins are fished (Sloan 1985). The primary ones are *Paracentrotus lividus*, several species of *Strongylocentrotus*, and *Loxechinus albus*; with secondary species being *Heliocidaris erythrogramma, Tripneustes gratilla, Anthocidaris crassispina, Evechinus chloroticus* and even *Heterocentrotus mammillatus*.

Introduction

Studies on the biology and ecology of some of these species, particularly the strongylocentrotids, have been numerous. But it seems to us the information has not been fully integrated into a concept of the species' life-history. Is it possible to use knowledge about the biology of sea urchins to evaluate their suitability for fishery or aquaculture? We suggest the life-history strategy of the species can be used for evaluation.

Discussion

The ways the environment impacts an organism have been divided into two categories that have been given various terms. We shall use Grime"s (1979) system which designates them as *disturbance*, an environmental effect involving the loss of biomass up to death, and *stress*, an environmental effect involving a decrease in production that can lead to death if sufficiently extreme. Grime proposed species have life-history strategies based on the levels of these two environmental variables, and that a suite of adaptive life-history characteristics are associated with them.

At extreme conditions, primary strategies are found for *competitive species* adapted to environments with a low level of stress and disturbance; *ruderal species* adapted to environments with a low level of stress and a high level of disturbance; and *stress-tolerant species* adapted to environments with a high level of stress and a low level of disturbance. Secondary strategies are found for species adapted to intermediate levels of stress and disturbance. No species are adapted to extreme levels of both stress and disturbance as their production is too low from stress for them to respond to disturbance. An abbreviated list of life-history characteristics associated with the three permissible primary strategies is given in Table 1.

If high productivity is the primary criterion for selection of species for fisheries, ruderal species would be the best choice as they allocate the least resources to protection. Stress-tolerant species would be the worst choice as they allocate the most resources to protection.

The ability to obtain resources is basic to life-history strategies. A species suitable for fishing should have a high capacity to feed. *Loxechinus albus* has a greater feeding capacity than *Tetrapygus niger* (Contreras & Castilla 1987). The continued increase in gonad index in *Strongylocentrotus franciscanus* past the size at which it no longer increases in other strongylocentrotids may be due to the greater allometric coefficient of the lantern (Lawrence et al., in press). Species found where food is not abundant or not accessible should be more stress tolerant. This fits the greater capacity to feed Ebert (1975, 1982) has provided data on basic life-history characteristics of growth rate, mortality, and longevity that show basic differences among species. These (Tables 2, 3) suggest a basic difference among the species. Lawrence (1987) reviewed the energy budgets of sea urchins. Few have been done and none provide data in similar units making direct comparisons difficult. This is unfortunate as reproductive effort (the relative amount of energy absorbed used for reproduction) is of prime importance in evaluating life-history strategies. The basic rate of metabolism should be an innate characteristic and reflect life-history strategy. The respiratory rate of *Tripneustes ventricosus* is greater than that of similarly sized *Strongylocentrotus droebachiensis* (Lilly 1979). A fundamental stress is starvation that should be related to this basic rate of metabolism. The time to death from starvation differed among *Lytechinus variegatus, Echinometra lucunter,* and *Eucdidaris tribuloides*, in that sequence which fit the life-history strategies predicted for the species (Lawrence & Lares, unpub.).

Lawrence (1990) evaluated sea-urchin species in terms of their probable life-history strategies based on their known life-history characteristics. *Heterocentrotus mammillatus* was suggested to be a stress-tolerant species; *Tripneustes ventricosus*, a ruderal species that can grow to 40-50 mm in one year; and strongylocentrotid species, *Paracentrotus lividus, Loxechinus albus, Heliocidaris erythrogramma*, and *Evechinus chloroticus* as CSR species. CSR species should be found where resources are relatively abundant and have an active mode of disturbance. The presence of predators may restrict access to resources even when they are available. Strongylocentrotid species are associated with lush algal floras of temperate waters. They have delayed maturity followed by annual reproduction for a number of years, a low gonadal: somatic production but a high potential maximal rate of feeding and production. Their protection against predation is not very effective and their life-history characteristics are greatly affected by the intensity of predation.

The various species of strongylocentrotids off Kamchatka have characteristics that vary in different habitats that suggest this secondary strategy (Bazhin, unpub.). These are summarized in Table 5. In sub-optimal conditions, individuals assume characteristics reminiscent of other strategies. Abundant food and low predation are necessary for populations appropriate for fishing. High fishing pressure would simulate high predation and result in populations of small individuals even if food were abundant.

We suggest the data accumulated for fished sea-urchins can be profitably interpreted and evaluated in terms of life-history strategies. It could aid in deciding on their suitability for fishery and aquaculture and the appropriate way of management and cultivation. If the interpretation of the strategies is correct, *Tripneuestes ventricosus* would be most suitable for fisheries and for aquaculture. The strongylocentrotid species are also suitable as they seem to have a high maximal relative potential for resource capture, growth and reproduction. However, I suspect their production efficiency is less. *Evechinus chloroticus* seems to have a heavier body and may have an even lower production efficiency. The soundness of these suggestions requires testing.

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Table 1. Abbreviated list of life-history characteristics associated with primary strategies. (modified from Grime 1979).			
Strategy	**Competitive**	**Stress-tolerant**	**Ruderal**
Longevity of established phase	Long or relatively short	Long to very long	Very short
Maximum potential relative growth-rate	Rapid	Slow	Rapid
Maximum potential relative reproduction	High	Low	High
Response to stress tolerance	Moderate	High	Low
Physiological adaptability	Low	High	Low

Table 2. Observed values of *p*, the probability of annual survival. (from Ebert 1982)	
Heterocentrotus trigonarius	0.971
*Echinometra oblonga**	0.649, 0.686, 0.868
*Heliocidaris erythrogramma**	0.964, 0.964
*Tripneustes gratilla**	0, 0, 0.508
*values for different populations	

Table 3. Growth rate (K) and mortality rate (M) for echinoids. (from Ebert 1975)		
	K	M
Cidaridae		
Eucidaris tribuloides	0.67	0.43
Toxopneustidae		
Lytechinus variegatus	0.95	
Tripneustes ventricosus	1.24	0.95
Strongylocentrotidae		
Strongylocentrotus droebachiensis	0.66	
Strongylocentrotus franciscanus	0.26	
Strongylocentrotus intermedius	0.33	
Strongylocentrotus nudus	0.36	
Strongylocentrotus purpuratus	0.22	

Table 4. Approximate horizontal body-size (mm) at which relative gonad production (gonad index) ceases to increase with a further increase in body size in strongylocentrotid species.

Species	Relative body size	Reference
S. franciscanus	125	Bernard & Miller 1973, Kramer & Nordin 1975 Tegner & Levin 1983
S. intermedius	35	Fuji 1967
S. purpuratus	40-50	Gonor 1972
S. droebachiensis	35-40	Fletcher et al. 1974

Table 5. Variations in characteristics of strongylocentrotids off the coast of Kamchatka in relation to habitat. + indicates positive effect; - indicates negative effect.

Habitat	Optimal[1]	Suboptimal			
		Biotic Stress[2]	[3] Biotic disturbance: mortality of large individuals	[4] Biotic and abiotic stress	[5] Abiotic stress: mortality of small individuals
Ecological Factors					
Salinity	+	+	+	+	±
Temperature	+	+	+	±	±
Exposure	+	+	+	±	+
Substrate	+	+	+	+	±
Food	+	-	+	-	+
Predation	+	+	-	+	-
Competition	+	-	+	+	+
Gonad produciton	good	poor	good	poor	good
Feeding behavior	semi-passive foragng	active foraging	passive "sit and wait"	active foraging	passive "sit and wait
Body size	normal s.f.d or large	small, intermediate	small, intermediate	small, intermediate	large
Density	dense	very dense	dense or very dense	low	low
Allocation of energy	reproduction, somatic growth	maintenance	reproduction, somatic growth	maintenance	reporduction, somatic growth
"Strategy type"	"C"	"S"	"R"	"S"	"SC"/"RC"
Population type	Flock of gluttons	Crowd of hungry and and angry dwarfs	Crowd of chubby babies	Opressed dwarfs	Long-time survivors

[1]Low predation, abundant food
[2]Sea-urchin barren grounds
[3]Habitats with high predation pressure from large predator (e.g. sea otter)
[4]Habitat too shallow or deep, or near geographical limit of distribution
[5]Low salinity. polluted or eutrophic habitats or high predation from small predator.

The Impact of Scallop Drags
on Sea Urchin Grounds

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Introduction

When a new species is chosen for exploitation, the selection of the gear used for harvesting is often the gear that the fisher is most familiar with. This is because the learning curve to master the harvesting methods is relatively short and because the fisher may already own the piece of gear and can easily make any required modifications. The problem with this type of development is that the original type of gear was designed (often by trial and error over decades) for a specific type of environment and the fishing characteristics and impacts may differ in other environments. This potential impact is one of the issues that must be addressed when a new fishery is developing. Specifically, new developments should be concerned with overharvesting the resource; incidental damage to the target populations; habitat impacts; and indirect impacts on other species.

The fishery for the green sea urchin *Strongylocentrotus droebachiensis* is relatively new in southwestern New Brunswick, having only begun in earnest in 1987. However, it is developing quickly as landings have been doubling each year for the last five years. Several different types of fishing gear have been used to harvest sea urchins including: scallop drags, box frame drags, Irish (or Green) sea urchin drags with chain sweeps, air lifts with divers, Venturi-type suction harvesters with divers, and simple hand harvesting techniques.

One of the objectives of this study was to study the effect of Digby scallop drags (with attached teeth) on the sea urchins and the associated species and habitat. Two additional sections have also been added to document some of the other fishing characteristics of towed gear.

Dragging Impact Study

Two sites were chosen to conduct this study. One around Grand Manan, in Cheney's Passage (Fig. 1) and the other one off Minister"s Island, Passamaquoddy Bay (Fig. 2). These two different sites were set up in the same manner. Each site was composed of two rectangular plots; one as a control and the other where the dragging took place and is referred to in this report as the experimental plot. The Minister"s Island site had 2 plots measuring 200 m long by 50 m wide, in a depth of 4m to 12m at mean low water. The site in Grand Manan had 2 plots of the same dimensions; 100 m long by 50 m wide, in a depth of 5 m to 10 m. All plots were parallel to the shore, in shallow water. Two divers would dive and attach each end of a 50 m transect line (marked at every meter) to the two main lines (Fig. 3). Each diver had two slates and one quadrat measuring 1m long by 0.5m wide and would survey one side of the transect by laying his quadrat every two meters along the transect starting at 10 m from where it was attached to the main line. All species of invertebrates were inventoried and recorded on a form printed on waterproof paper. The percentage of bottom covered by macrophytes and the relative percentage of bottom type (granulometry) were also recorded. Each diver assessed 15 quadrats for a total of 15 m^2 of sea floor surveyed along one 50 m transect by the team of two divers. After the first transect was done, it was moved 40 meters to the next mark on the main lines. Five transects per plot were made in the same manner. The survey was done in the experimental plot prior to, during and following the dragging, and in the control plot prior to and following the dragging of the experimental plot. These surveys were performed again after a period of 3 months and 6 months.

The Grand Manan site had much larger sea urchins present than the Minister"s Island site (Fig. 4). This difference has been documented before (Robinson and MacIntyre, 1992). Over the course of the dragging operation, there was a decrease in the densities of sea urchins in the experimental site over the control site in Grand Manan, but no real difference was observed at Minister"s Island (Figs. 5, 6). This may have been due to the small sizes of animals at the Minister"s Island site where they were not as vulnerable to the fishing gear. The densities of urchins in the experimental plots at both study sites remained relatively stable over time. The number of broken sea urchin tests were observed to increase over the period of dragging at Minister"s Island and at the interim period in Grand Manan (Fig. 7). The drop in density of broken urchin tests at the post survey in Grand Manan was probably due to the removal of tests by the current as it can exceed 3-4 knots in the passage at full flood or ebb tide. Due to a storm at the conclusion of our final dragging trials, we had to wait for a day before we could dive on the site to compete our survey. therefore, the tests were probably washed out of our study area before we could return.

Visually, the effects of the drags on the habitat were the disruption of the bottom substrate as many boulders has been turned over and dislodged from the sediment. There was no macro algae found at the Minister"s Island site, but the Grand Manan site showed some loss of macro algae due to the dragging. Dragging also had an impact on the lobster populations at the Minister"s Island site as the density of lobsters in the experimental plot decreased to zero over the course of the dragging while the control plot remained constant (Fig. 8). No remains of any lobsters were found during the surveys so it is presumed that the lobsters moved rather than died. The Grand Manan site had no resident lobster population.

Another impact of the scallop drags was to increase the density of the mobile predators in the experimental plots (Fig. 9). Hermit crabs, starfish, sculpins and whelks all responded to the damage to the benthic fauna caused by the heavy gear.

(A video was shown on the effects of the dragging operation on the bottom)

Observations of the Green Drag

To date there has been very little formal work done on the impacts of the Green (or Irish) drag on the seabed and associated benthos, with the exception of a few observational studies. This is also an account of the after effects of the Green drag on the bottom. The observations were made in March 1994 near Richardson, Deer Island, New Brunswick approximately two days after the dragging had occurred. The bottom type was primarily soft sediments with exposed rocks and a few ledges.

The sea urchins were concentrated in the rock areas and the drags had been towed up and over the rocky areas from the softer sediments below. The efficiency of the drags were very high as there were no sea urchins to be seen in the drag tracks, but there were sea urchins in high densities outside the tracks on the rocks. Some sea urchins were observed to be buried in the soft sediment and were dead. Lower down in the soft sediments, there were well established tube-worm communities. The chain sweeps from the drags ploughed though the beds and left a light brown mud behind with no trace of the tube-worm community. (*Underwater photographs were shown to document these observations*)

Surveys of Commercially Fished Areas

The sea urchin fishery in southwestern New Brunswick has been intensifying since 1990. A biomass survey done in 1992 (Robinson and MacIntyre 1993) has given us a set of baseline data with which to compare areas after they have been intensively harvested. Four areas were chosen for this presentation to compare sea urchin populations before and after harvesting operations have been conducted; two on Deer Island and two on Grand Manan. The two sites on Deer Island and the two sites on Grand Manan differed in size frequency distributions as one site was composed of small animals and the other was composed of larger individuals (Figs. 10, 11). The top panels represent the initial state and the ones below show the size frequency distribution after harvesting. Basically, for each site there is no change in the size frequency distribution, but in the sites where the urchins are predominantly large, the densities have dropped by 60 to 70%. There was no real change in densities for the sites where the sizes of sea urchins were predominantly small.

Summary

The results of these studies and observations demonstrate there will be some effect of fishing operations on the bottom substrate and the benthos. The amount of impact will depend on the gear used and the method of fishing. Short-term impacts are often quite apparent, but some of the longer-term impacts may be more subtle. For example, dragging operations may not only remove sea urchins from the bottom, but macro algae as well. Continued harvesting in the area may drive down the productivity of the area even if the densities of sea urchins are reduced.

Therefore, the potential effects should be investigated early in the development of the industry in order to make a conscious decision on what we are willing to live with or risk.

Figure Captions

Figure 1. Location of experimental and control plots at Grand Manan, New Brunswick.

Figure 2. Location of experimental and control plots at Minister"s Island, New Brunswick.

Figure 3. Dive survey sampling protocol for the drag impact study at both Minister"s Island and Grand Manan.

Figure 4. Size frequencies of sea urchins harvested during the dragging of the experimental plots on Minister"s Island and Grand Manan.

Figure 5. Mean frequency of sea urchins per quadrat for experimental (A) and control plots (B) at Minister"s Island 1993/1994.

Figure 6. Mean frequency of sea urchins per quadrat for experimental (C) and control plots (D) at Grand Manan 1993/1994.

Figure 7. Density of broken sea urchin tests per m^2 prior to the harvesting operation, midway through and after the dragging was completed (post) for control and experimental plots on Ministers Island and Grand Manan.

Figure 8. Mean density of lobsters per m^2 for the experimental and control plots at Ministers Island over the course of the dragging operation.

Figure 9. Mean density of predators per m^2 for the experimental plot on Minister"s Island over the course of the dragging operation.

Figure 10. Size frequency of sea urchins at two sites on Deer Island before and after harvesting operations had commenced. Density estimates are given in the upper right corner of each panel. The vertical line at 50 mm indicates the minimum legal test diameter.

Figure 11. Size frequency of sea urchins at two sites on Grand Manan before and after harvesting operations had commenced. Density estimates are given in the upper right corner of each panel. The vertical line at 50 mm indicates the minimum legal test diameter.

Fig. 1

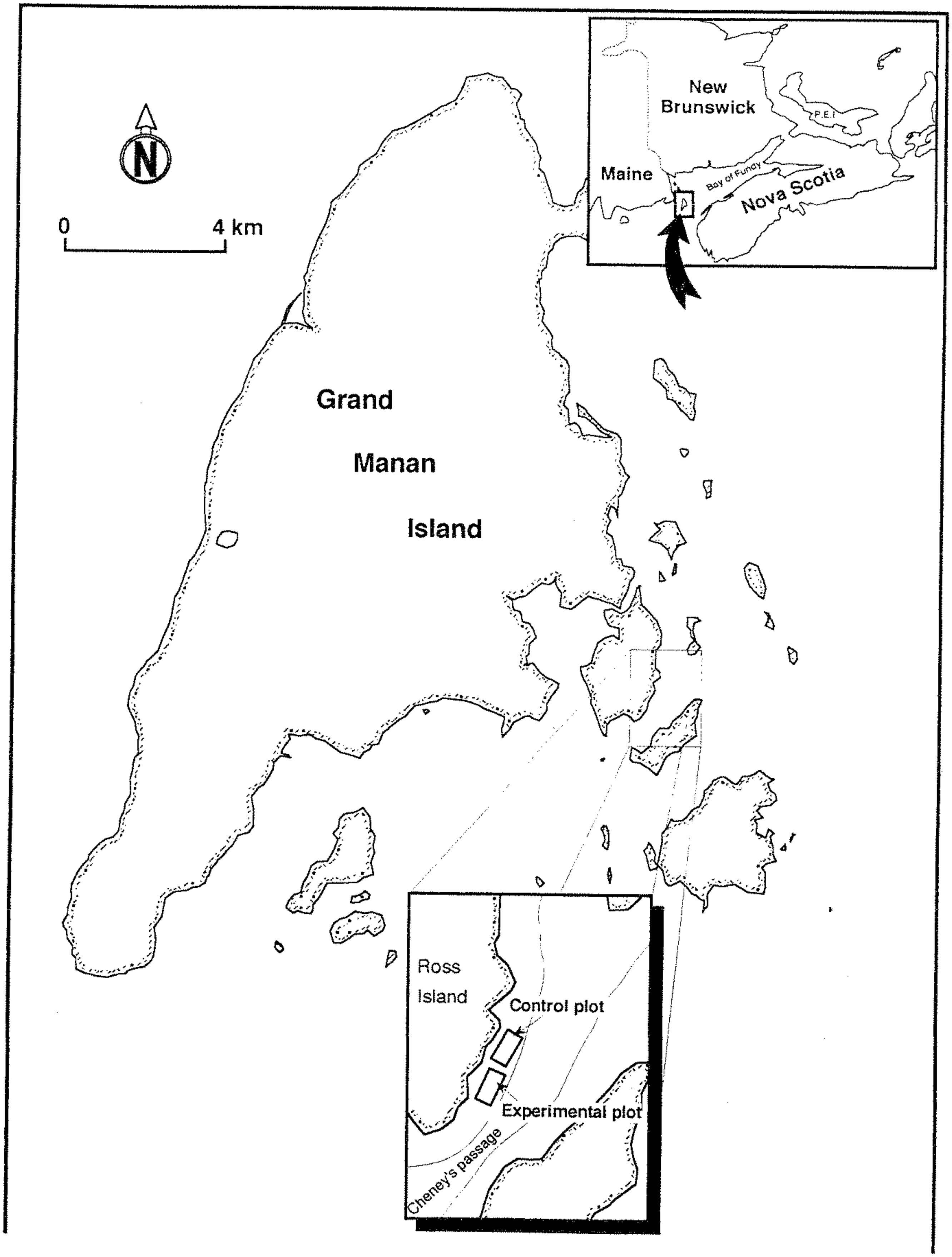

N
0
4 km
New
Brunswick
P.E.I.
Maine
Bay of Fundy
Nova Scotia
Grand
Manan
Island
Ross
Island
Control plot
Experimental plot
Cheney's passage

Fig. 2

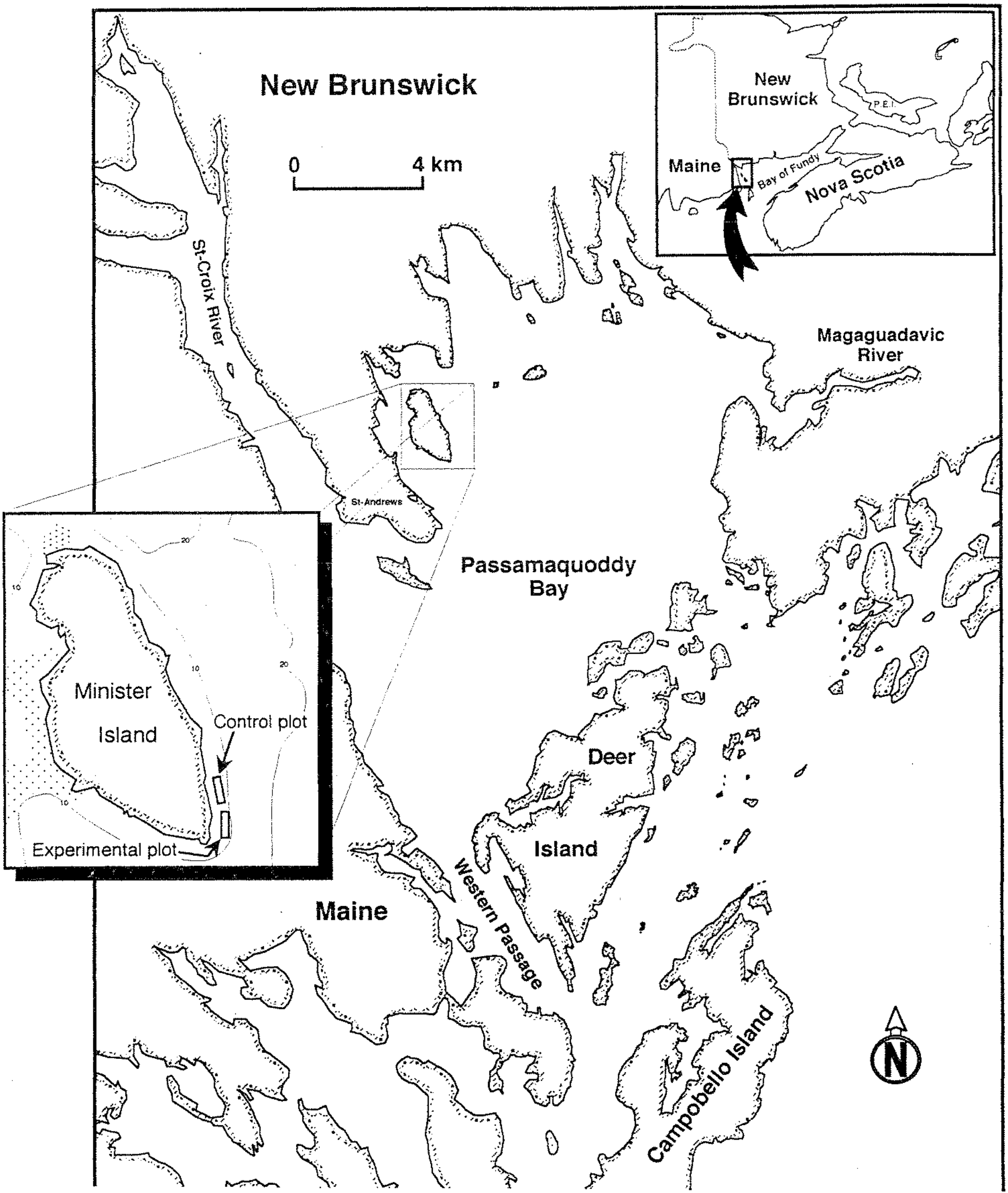

New Brunswick
0
4 km
New Brunswick
P.E.I.
Maine
Bay of Fundy
Nova Scotia
St-Croix River
Magaguadavic River
St-Andrews
Passamaquoddy Bay
Minister Island
Control plot
Experimental plot
10
20
Deer Island
Maine
Western Passage
Campobello Island
N

Fig. 3

Minister Island: Experimental plot
Survey #2,3,4,5

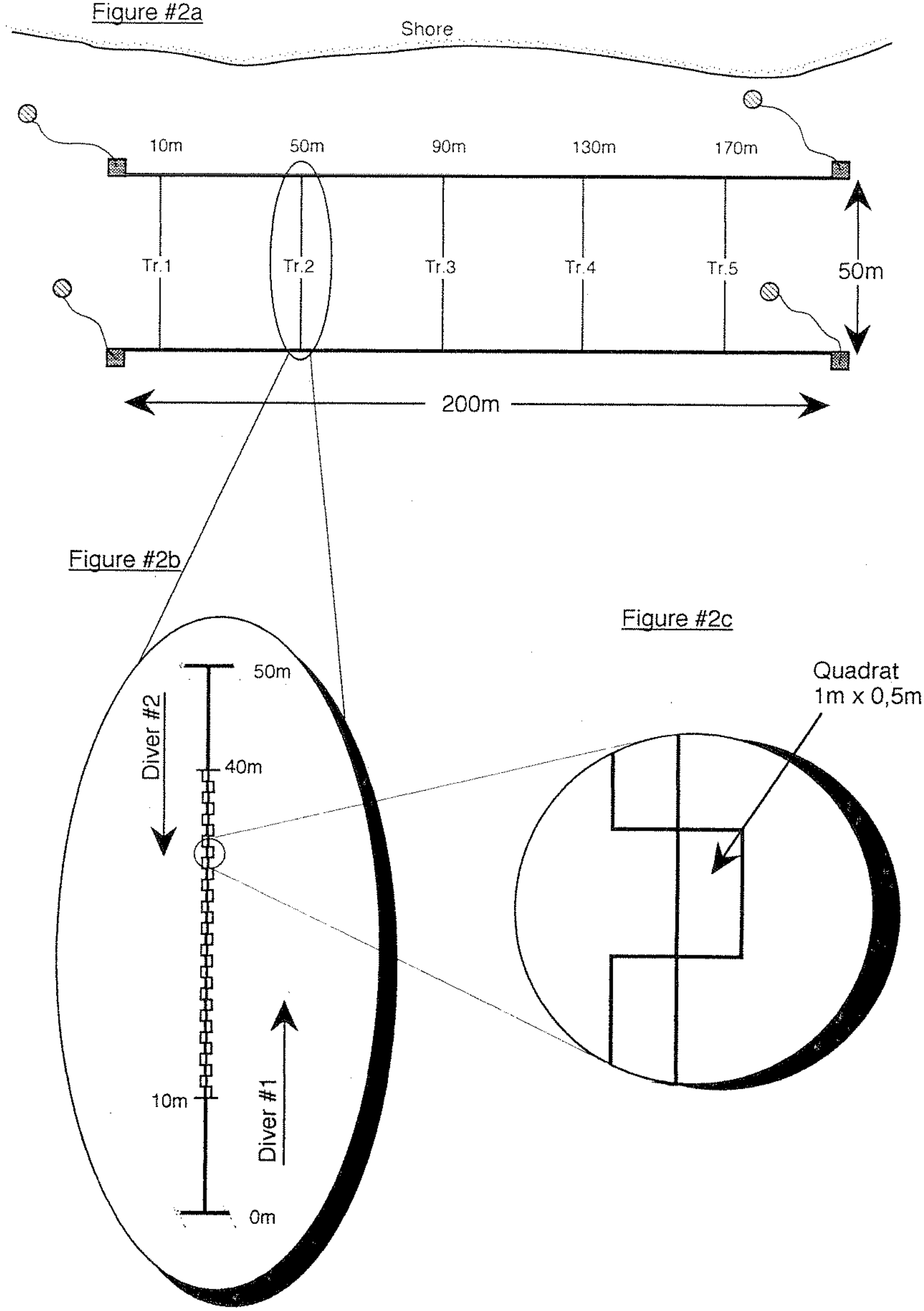
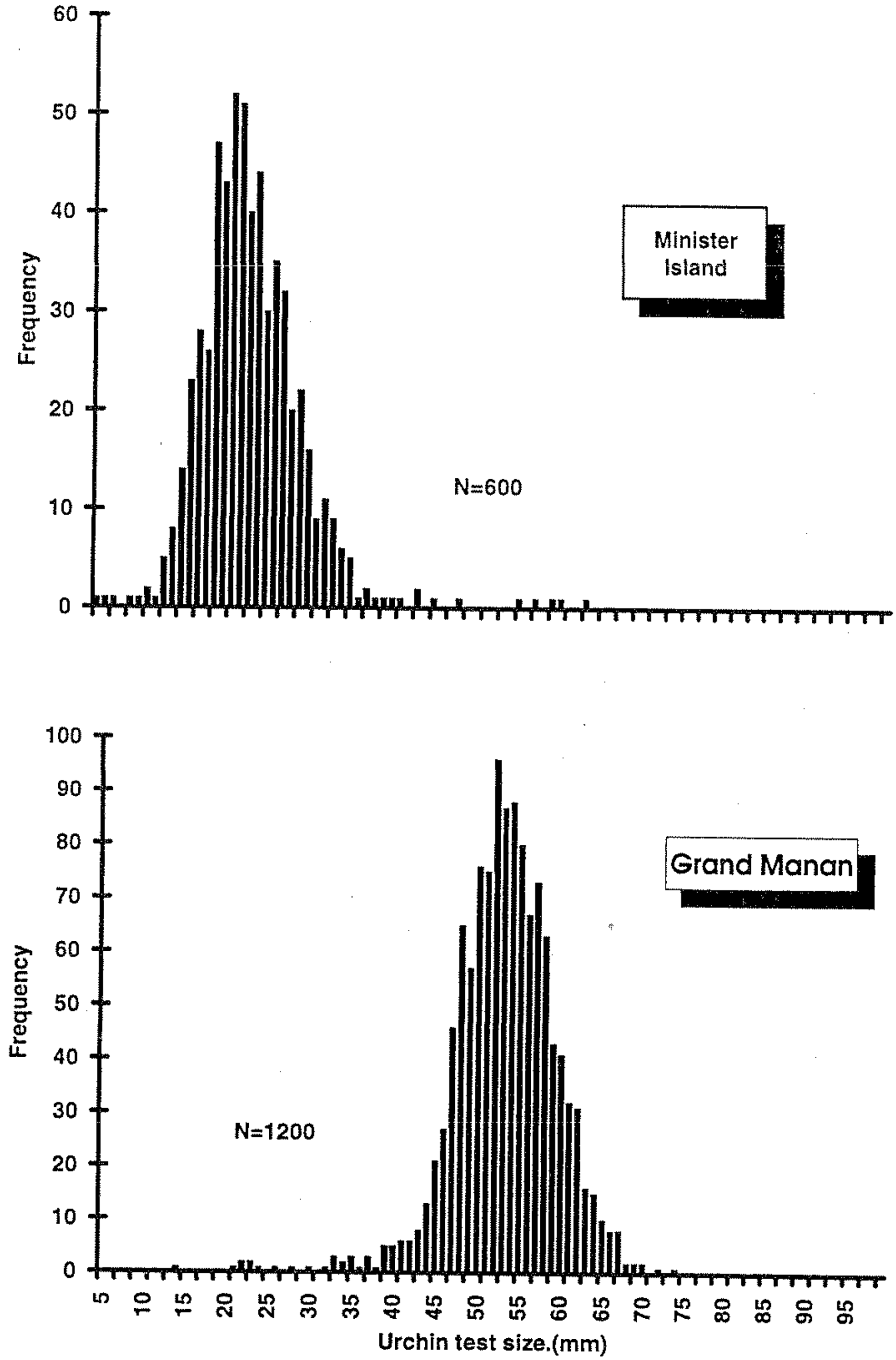


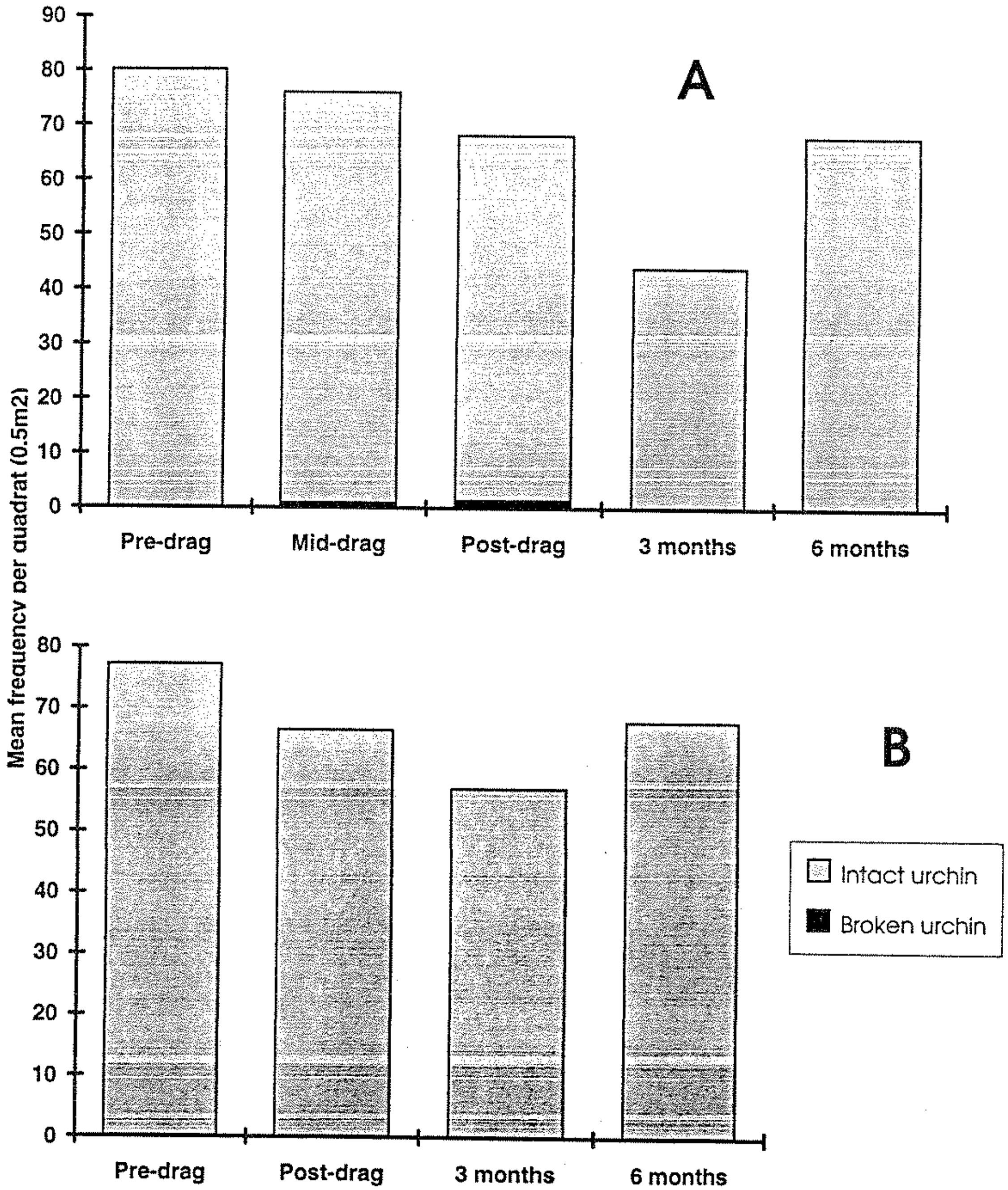
Fig. 4



Minister Island
N=600
Frequency
Grand Manan
N=1200
Frequency
Urchin test size.(mm)

111

Fig. 5



A
B
Mean frequency per quadrat (0.5m2)
90
80
70
60
50
40
30
20
10
0
Pre-drag
Mid-drag
Post-drag
3 months
6 months
Intact urchin
Broken urchin

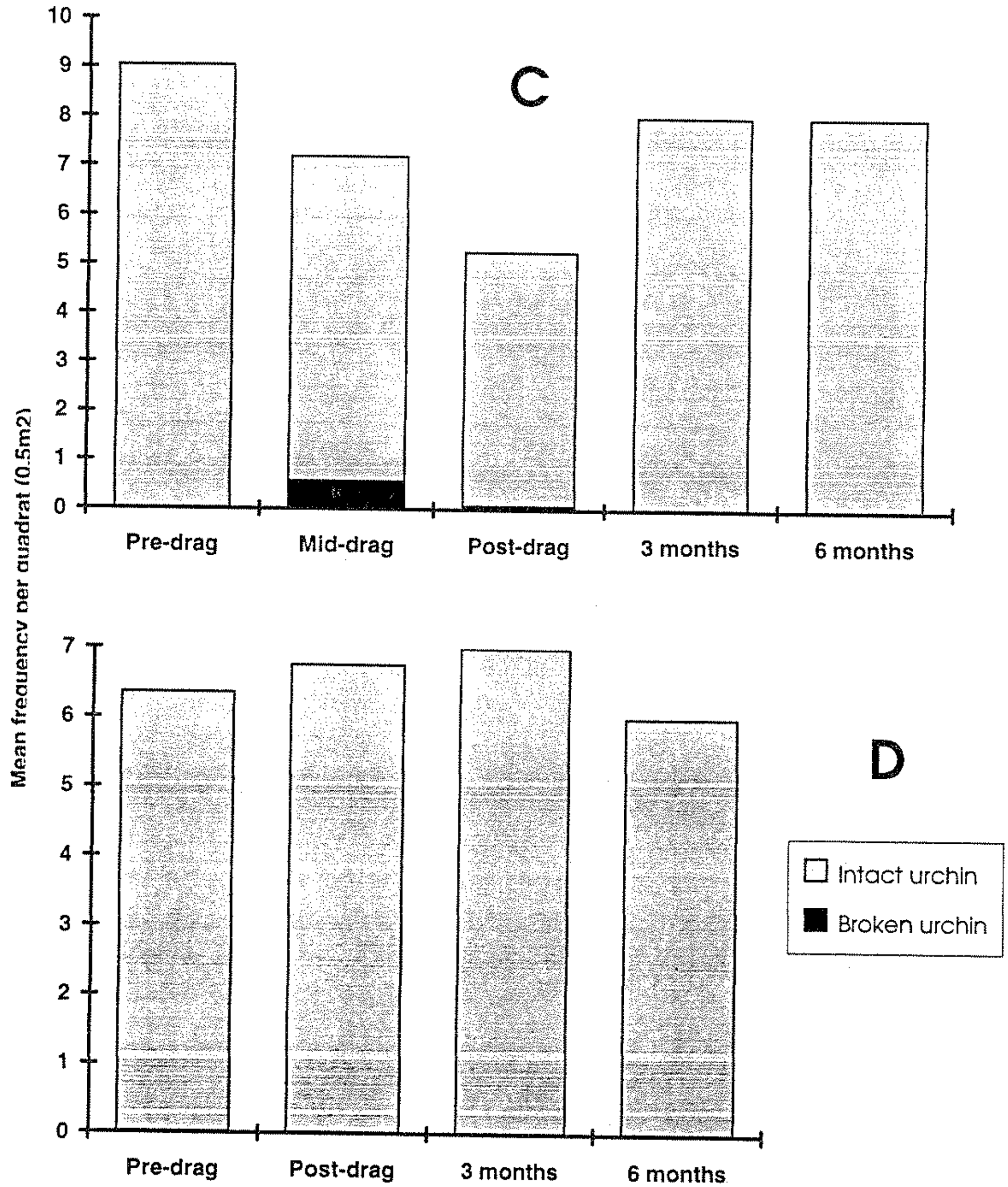
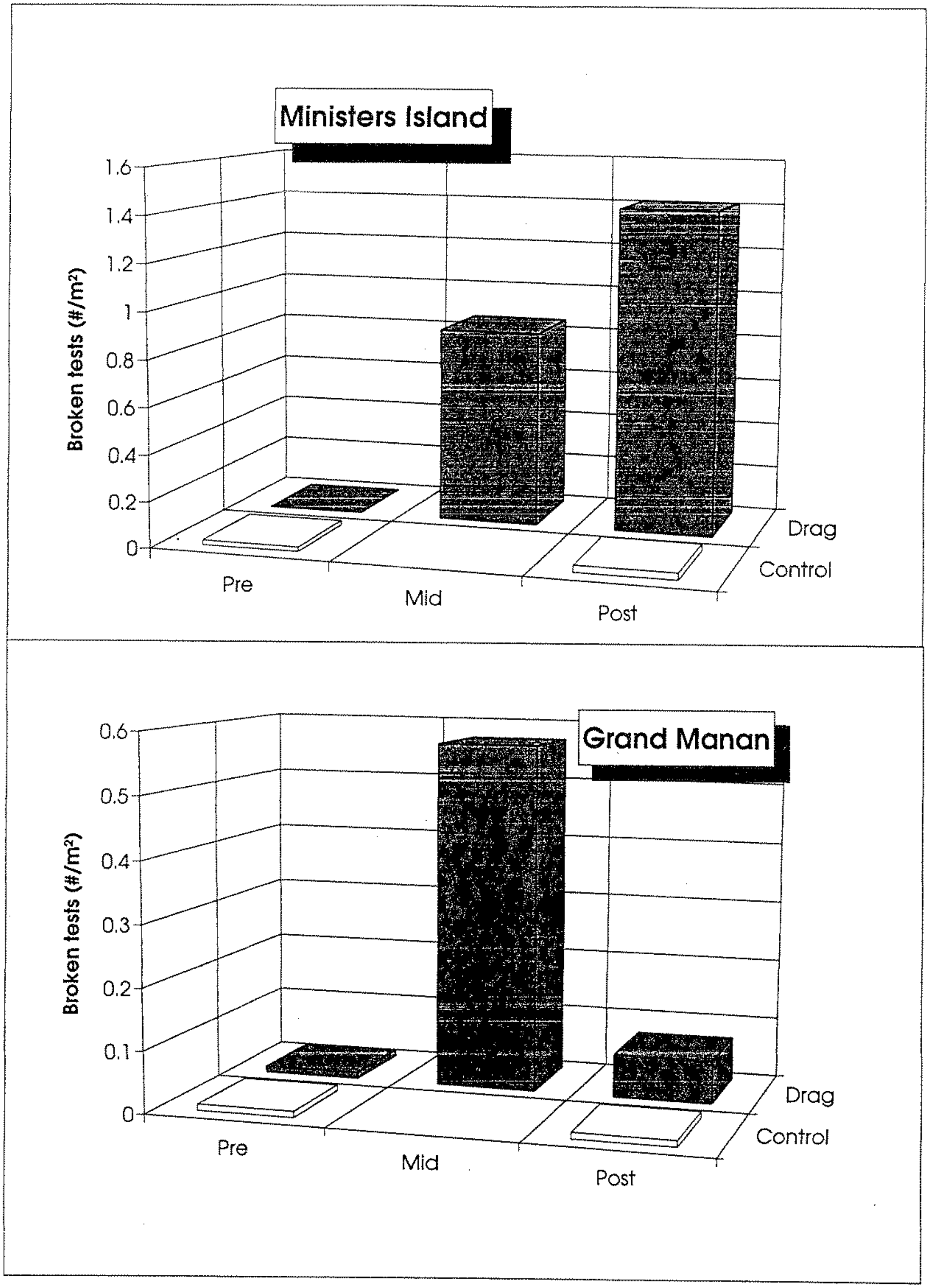

C
D
Mean frequency per quadrat (0.5m2)
Pre-drag
Mid-drag
Post-drag
3 months
6 months
Intact urchin
Broken urchin

Fig.-



Ministers Island
Broken tests (#/m²)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Pre
Mid
Post
Drag
Control
Grand Manan
Broken tests (#/m²)
0.6
0.5
0.4
0.3
0.2
0.1
0
Pre
Mid
Post
Drag
Control

Fig. 8

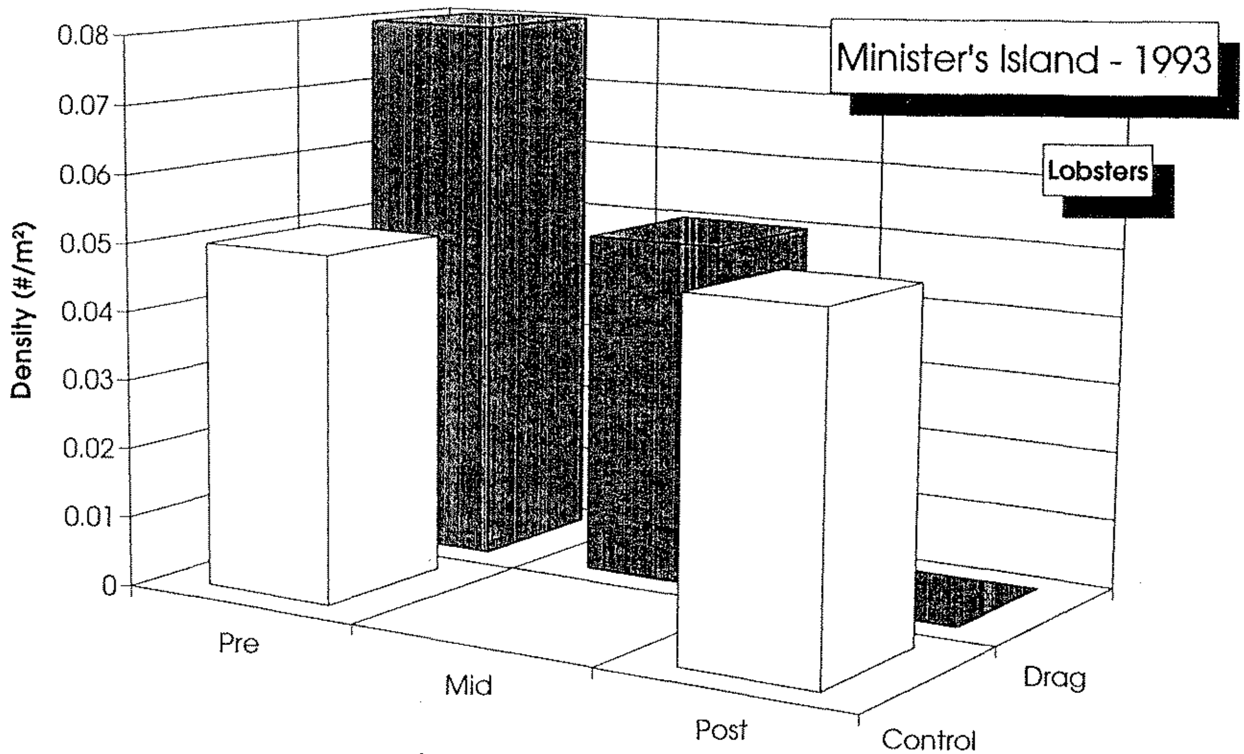
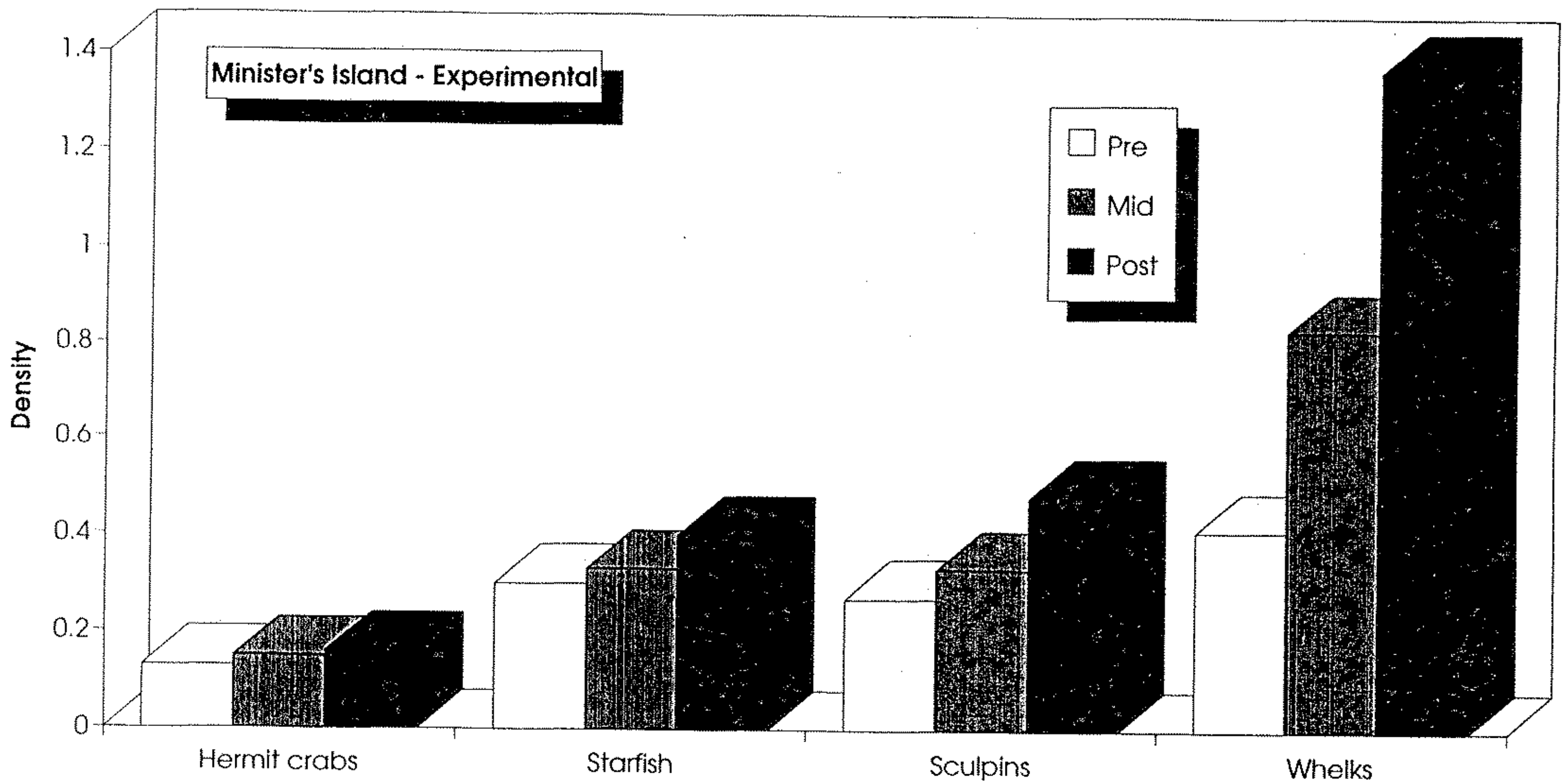
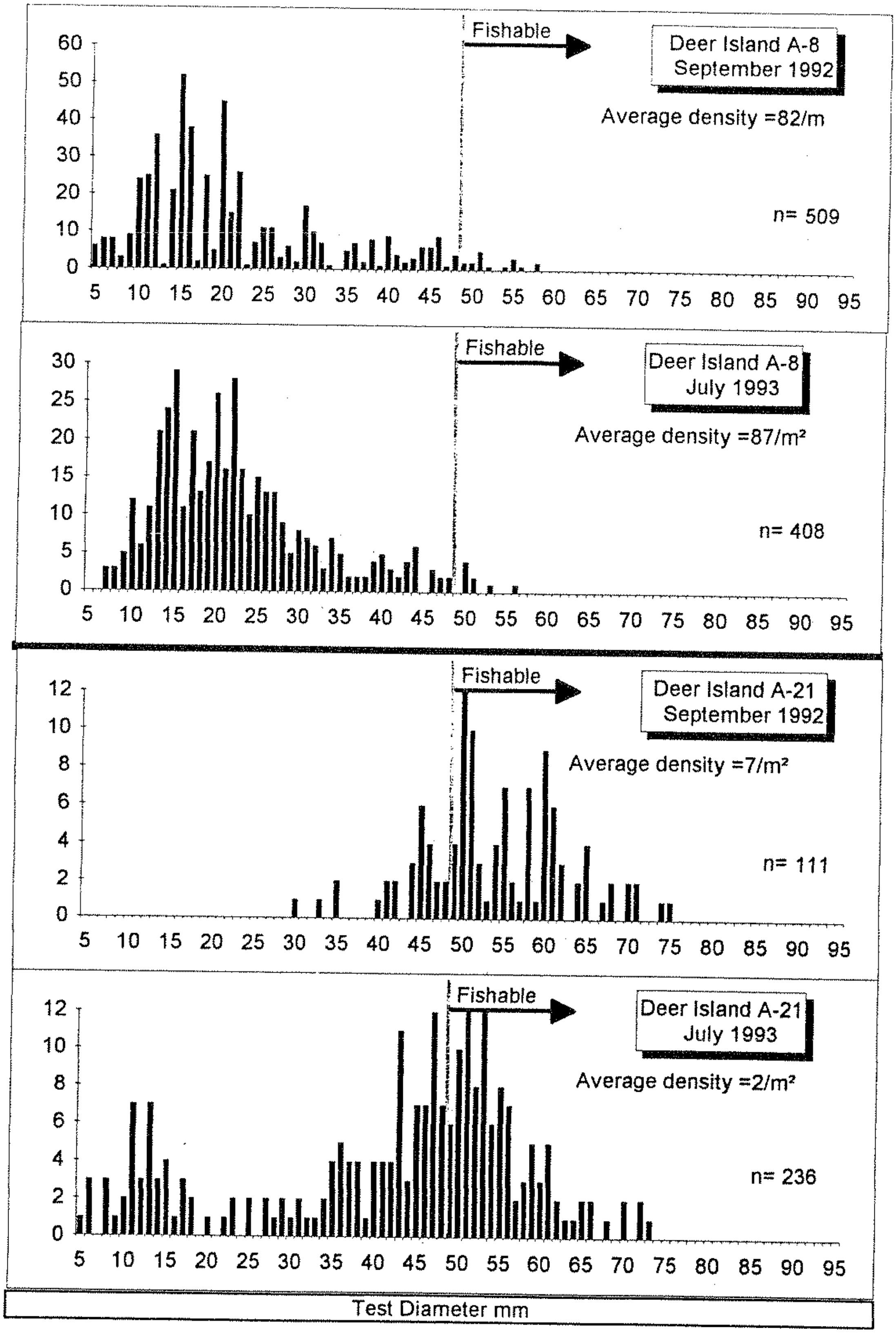

Minister's Island - 1993
Lobsters
Density (#/m²)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Pre
Mid
Post
Control
Drag

Fig.



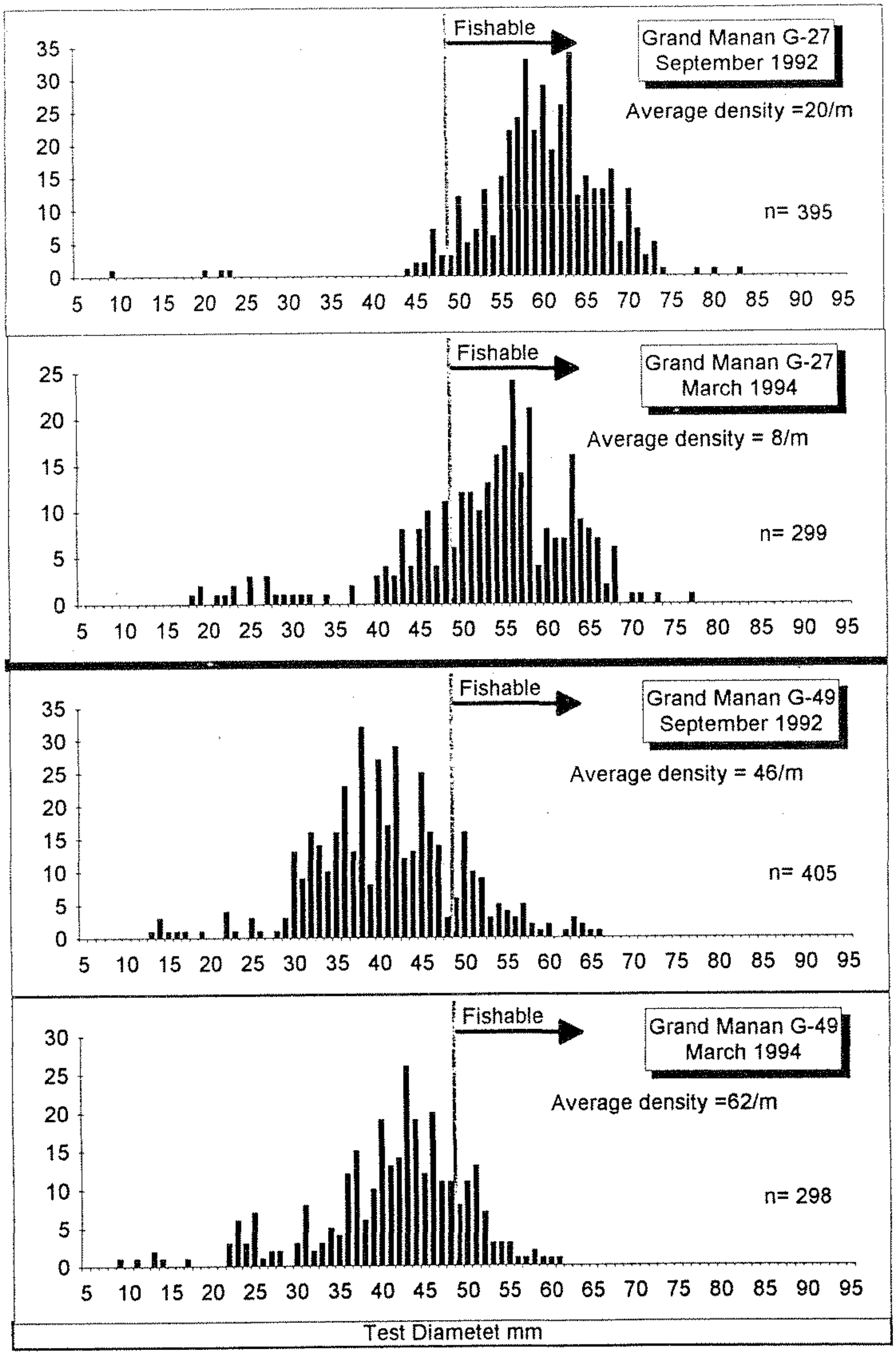
Minister's Island - Experimental
Density
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Pre
Mid
Post
Hermit crabs
Starfish
Sculpins
Whelks

Fig-1e



Fishable
Deer Island A-8
September 1992
Average density =82/m
n= 509
Fishable
Deer Island A-8
July 1993
Average density =87/m²
n= 408
Fishable
Deer Island A-21
September 1992
Average density =7/m²
n= 111
Fishable
Deer Island A-21
July 1993
Average density =2/m²
n= 236
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95
Test Diameter mm

Fig. 11


Fishable
Grand Manan G-27
September 1992
Average density =20/m
n= 395
Fishable
Grand Manan G-27
March 1994
Average density = 8/m
n= 299
Fishable
Grand Manan G-49
September 1992
Average density = 46/m
n= 405
Fishable
Grand Manan G-49
March 1994
Average density =62/m
n= 298
Test Diametet mm

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