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Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Region
Management Division
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TABLE OF CONTENTS

Introduction	1
Staffing	1
Objective A	2
Whiting	2
Bycatch Conference	7
ICES Meeting	7
Objective B	7
Sea Urchin drag impact	7
Objective C	8
Sea Urchin Workshop	9
1994 MTS paper	9
Other Meetings & Activities	10
Appendix I	Progress Report to the ICES Fish Technology and Fish Behavior Working Group - United States. April 1995
Appendix II	1994 Workshop on the Management and Biology of the Green Sea Urchin (<i>Strongylocentrotus droebachiensis</i>).
Appendix III	The Importance of Habitat in Fisheries Management

STATEMENT OF WORK

I. A. State: Massachusetts

B. Project Number NA46FI0268

C. Segment Number 1

INTRODUCTION

The Interjurisdictional Fisheries Management Support Program has been operating since 1988. Prior to 1992, the program had two components: Fisheries Technology and Fisheries Communication. Although these components were separate, they were consolidated to work together on a number of common objectives. The evolution of the program into a single entity reinforces the commitment of the Massachusetts Division of Marine Fisheries to the priority of fisheries technology and the utilization of this field as a means to further the conservation of the fishery resources and support sound fisheries management practices.

STAFFING

The Program staff consists of a Program Coordinator (Aquatic Biologist III), one Aquatic Biologist I and one Information Officer II.

As of November, the Information Officer II position is vacant; Mr. Charles Connor passed away.

Mr. Robert Bruce, who was previously on the program staff as a Information Officer II before his retirement, continues to be involved with the Program as a commercial fishing gear specialist. He is called upon when needed and is funded by state sources. The gear specialist aids the program by being an advisor and facilitator in the construction, repair and modification of nets and fishing gear components that this program uses in selectivity, bycatch reduction and discard and escapee survival investigations.

Program personnel continue to (1) identify and research fishing gear and practices that require greater conservation management, (2) assist in researching and promoting changes or modifications in fishing practices made necessary by action or intended action by the Division or Regional Council, (3) identify areas of potential gear and management conflict in or outside state waters, (4) acquire data on fishing efforts and practices, and (5) assist senior Division staff in communicating with industry and other various governmental agencies involved in fisheries management and conservation.

Three task areas that within the scope of project responsibility are: a) research on gear technology, b) data collection and analysis of current fishery activities, and c) technical assistance.

OBJECTIVE A: RESEARCH ON GEAR TECHNOLOGY

Research on gear technology concentrated on bycatch reduction, species and size selectivity, and gear

impact on the resources and the environment.

WHITING FISHERY BYCATCH REDUCTION AND SELECTIVITY

The ultimate goal of this work is to design an otter trawl for the directed whiting fishery which will selectively fish for whiting, substantially reducing the amount of groundfish and unmarketable size whiting.

The fishery in Cape Cod Bay

The fishery has been under severe scrutiny by the Massachusetts Division of Marine Fisheries because it is one known for high bycatch. During the past three years, the total discarded bycatch in this fishery ranged from 63-83% and the multispecies bycatch was 29-39% (Table 1). This far exceeds the 5% maximum permitted bycatch of the total catch that has become the standard on whether to permit small mesh fisheries.

In 1993, whiting fishermen were required to possess a state regulated fishery permit, a commercial fishing permit and a mobile gear coastal access permit. Fishermen were also required to remain within a geographic area west of Provincetown in Cape Cod Bay, defined by Loran lines and could possess up to 200 pounds of groundfish, but no lobster. There were no specific gear requirements, nor any mesh size requirements.

In 1994, new regulations were put into place which prohibited the retention of any multispecies when engaged in a small mesh fishery. Prior to the opening of the inshore whiting fishery, MDMF met with fishermen to discuss what must be achieved in bycatch reduction if a fishery was to be allowed. Among the issues discussed were a codend mesh size (stretched) of three inches, a reduction in the lengths of the legs and a lighter sweep. These actions were intended to reduce the catch of small whiting and herring, the herding of flatfish, and the catch of lobster and flatfish, respectively.

Fishermen convinced MDMF that they could sharply reduce bycatch by making the legs and ground cable of bare wire and not chain, limiting the length of the legs and ground cable to 25 fathoms, lightening the trawl sweep to a single chain sweep of 5/16" chain with no less than 18 links per foot, and using a 2.75 inch stretch mesh codend. Also agreed on was a minimum size for whiting of 10 inches with a 10% tolerance.

The fall fishery was conducted under these terms, except MDMF contracted one boat to use the MDMF modified whiting net. This net originated from a Wilcox whiting net. The prime difference is in the sweep and number of floats on the headrope (Figure 1). Bob Bruce, former MDMF extension agent, changed the sweep so that it had dropper chains and a sweep chain. The length of the sweep chain primarily determines how far that chain fishes behind the footrope. Although the length of the dropper chains aid in positioning the sweep chain, their main function is to allow the footrope to fish off the bottom.

MDMF contracted the commercial trawler F/V Northstar, owned and operated by Carlos Verde, a 40 year veteran of a variety of commercial fisheries, to use the MDMF experimental whiting net. The contract period was for a maximum of five days.

1994 Fishery Results

The MDMF experimental commercial whiting trawl, a modified Wilcox trawl with 3 - 5' dropper chains extending from the foot rope to a chain sweep, was fished on the state whiting grounds west of Provincetown, Massachusetts. Due to weather problems and the short season of this fishery only two trips and 10 tows were completed.

Four tows were completed on October 20, 1994 (Table 2). During the first tow the net had 6 floats on the center of the headrope and 3 floats on each wing, and the sweep was in front of the footrope. The tow was made on mud bottom and had to be towed at the surface to rid the net of mud. The catch was "dirty", or nonselective with 300 pounds of lobster discarded. To correct this, the sweep was lengthened by three feet on each side. After the second tow of the day, a 6" piece of chain was added to each wing to try to maximize the opening of the wings to herd the whiting towards the net while allowing the mouth of the net to continue to ride above the bottom and allow the escape of groundfish.

At the beginning of the day on October 24, one float was added to each wing and the first dropper chain on each wing was shortened by 6 links which approximately equals 6" resulting in these dropper chains being approximately 4.5' long. Two 2 hour tows were made and then a codend cover was placed on the codend to determine the amount of herring and small whiting that was escaping through the codend. Four one hour tows were made with the codend cover.

The configuration of the net on October 24 achieved the best reduction in groundfish bycatch, as low as .58% discard of regulated species (Table 2). By allowing the wings to achieve maximum vertical spread while keeping the mouth of the net off the bottom whiting loss appears to be minimized and bycatch loss seems to be maximized. An interesting result of this work appears to be a higher efficiency at one hour tow durations than two. The mean whiting caught per hour for one hour tows was 243 pounds versus 131 lbs. for two hour tows. The number of tows conducted does not allow for rigorous statistical analysis, however the results are promising and show that further work is both necessary and is likely to be successful.

Recommendations

The future of this small whiting fishery requires a sharp reduction in bycatch. This can be accomplished by establishing a series of regulations such as follows:

The trawl

The trawl must fish just off the bottom. To do this a chain sweep of the trawl must be modified by using a series of vertical chains, dropper chains, between the sweep and the footrope. This chain sweep must

be rigged to lie behind the footrope; therefore the chain sweep must be longer than the footrope. The headrope of the net must also have sufficient floats to compliment the sweep and keep the net fishing just off the bottom. Some improvements to this type of sweep are pending more work; for example, dropper chains may be sufficient with no chain sweep.

The legs of the trawl must be fashioned of bare wire and must have be no longer than 20 fathoms combined. The forward part of the leg must have a buntbobbin attached to lift the wire off the sea bottom.

The mesh of the net should be a minimum of three inches (stretched), except in the codend which will have 2.75 inches in 1995 and three inches in subsequent years.

A grate similar to one deployed by DFO Canada may be necessary when cod, haddock and pollock become abundant. The grate would provide further means to reduce the bycatch of larger fish that do not escape at the mouth of the trawl.

Bycatch

No lobsters, groundfish, sea herring or alewives shall be aboard - possessed or landed.

An active, random law enforcement presence is strongly encouraged to provide further incentive to reduce bycatch by modifying the trawl to fish dirty.

Whiting

The minimum size for the whiting should remain as it was during the 1994 fall season.

Table 1. Discards from the Provincetown fishery from data gathered by the MDMF Fisheries Dependent Investigations Project.

	1992	1993	1994
Weight of total sample and number of tows.	94,151 lbs. 31 tows	36,788 lbs. 17 tows	17,132 lbs. 20 tows
% Multi spp in catch (discards + kept)	51.28 %	33.98 %	32.34 %
% Discards (including all multi spp except whiting)	77.47%	74.55%	57.59%

Table 2. Comparison of the catch during the two sampling trips using the modified Massachusetts Division of Marine Fisheries modified Wilcox trawl.

	Oct 20, 1994	Oct 24, 1994*
Avg. Whiting per hour	80 lbs. (kept) 5.24 (discarded)	130.55, 243.05 lbs. (kept) 12.95, 22 lbs. (discarded)
Avg. Lobster per hour	15 lbs.	2.48, 2.23 lbs.
Avg. Am. Plaice per hour	14.23 lbs.	
Avg. Winter flounder per hour.	1.1 lbs.	
Avg. Sea Herring per hour	1.28 lbs.	
Avg. River Herring per hour	7.33 lbs.	2.25, 15.4 lbs.
Total Discards (%)	32%	23.43%
Discard of Multi Spp (except whiting)	6%	1.62%
Discard of Regulated Species	6%	.58%

* Two 2 hour tows were made and four 1 hour tows were made, the different numbers are from these different tow durations, respectively.

BYCATCH CONFERENCE

The Division assisted as a co-sponsor in convening the East Coast Bycatch Conference, which was held in Newport, Rhode Island between 7-8 April 1995. The primary convener was the University of Rhode Island. At the conference, IJFMSP personnel presented a paper on the recent whiting selectivity study. The paper will appear in the proceedings of the workshop which should be available in late spring 1996.

ICES TECHNOLOGY MEETINGS

The project leader attended the ICES Fish Technology and Fish Behaviour(FTFB) Working Group Meeting that was held in Aberdeen Scotland at the Scottish Aberdeen Marine Laboratory. While at the meeting he presented the U.S. report on gear technology which was a compilation of reports from agencies and institutions working on the subject(see Appendix I). All agencies and institutions that contributed to the US report were sent a list of papers that were presented at the meeting with a notation as to which were available from MDMF upon request. Also, participation involved the development of a report on "Unaccounted Mortality in Fisheries" by the designated study group. The report is presently in draft form pending further series of reviews. Next year MDMF will, with assistance from NMFS, host the ICES FTFB Working Group on Cape Cod.

OBJECTIVE B: DATA COLLECTION AND ANALYSIS OF CURRENT FISHERY ACTIVITIES

The Information Officer II frequently surveyed the commercial fishing ports, especially in the southeastern region of Massachusetts. He provided information on current activities, problems and trends to project staff and Division fishery managers. As appropriate this information was also passed on to other authorities. The Information Officer was also assigned to investigate activities at particular sites, for example, participating as a sea sampler in the special whiting fishery that was allowed near the boundary between state and federal waters in the northern area of Cape Cod Bay. He also surveyed the Boston area for large landings of lobsters by trawlers. This was during the fall, when hard shell and soft shell lobsters are known to be present in relatively high densities northwest of Provincetown. The purpose of the survey was to document the size and composition of the landings.

SEA URCHIN DRAGGING AND IMPACT

MDMF, specifically through this project, previously continued studying the dragging for sea urchins. MDMF sea sampled the inshore fleets and observed via video the action of various drags. The recent work involved investigating the impact of a drag on the benthos and on juvenile sea urchins. The work was accomplished in April 1995 with the assistance of a commercial sea urchin fishermen, and personnel and a vessel from Northeastern University.

The primary concerns expressed about dragging are as follows:

- survival of sublegal sea urchins discarded or encountered by the drag
- impact on the benthos
- impact on juvenile lobsters
- impact on kelp

The sea urchin drags that are used in both Boston Harbor and Salem Harbor are basically of one design with a variety of modifications. Characteristics common to these drags are a metal bale that leads the drag, a chain sweep that forms a grid with a series of openings roughly 6"x 6" square, and a bag that collects the catch. Variations in construction of the drag are usually associated with the design of the bale or with the weight of the drag.

Our initial surveys showed that the drag does impact the bottom to the level of rolling small rocks, some removal of kelp and some bycatch of flatfish, crustaceans and lobsters. Additional work done this past April using one drag in a designated harvesting area that had a bottom type primarily consisting of mussels, gravel and some rock, has shown little damage by the drag on the bottom. Sea urchins were collected from the discard, the swath track of the drag and from a control that represented untouched seabottom and held in situ. Survival of the sea urchins that were discarded or encountered the drag was excellent two weeks from the date of dragging.

OBJECTIVE C: Technical Assistance

Staff continue to assist and advise on commercial fishing activities and problems that appear to be of current or potential concern to state, council and federal management authorities. Much of this activity is done on a day to day basis and relates to verbal exchanges. The Information Officer answered a number of inquiries relative to the new summer flounder regulations. Information on the opportunistic sea urchin fishery was the most frequent subject of queries for all project staff.

The staff presented a seminar on trawl gear and measuring webbing to the Massachusetts Division of Environmental Law Enforcement. The seminar included each attending officer to work with the measuring devices and know the commercial gear.

The project maintains, and periodically expands, the video library. The library includes short study tapes on underwater observations including sea urchin harvesting, fish behavior in fishing gear, ghost fishing gear, and construction of prohibitive fishing gear.

THE SEA URCHIN WORKSHOP

On September 27 & 28, 1994 the Massachusetts Division of Marine Fisheries (MDMF) and the Maine

Department of Marine Resources (DMR) co-sponsored a conference on the biology and management of the green sea urchin (*Strongylocentrotus droebachiensis*). Impetus for the workshop was the sharp increase in the fishery along the Northeast U.S coast and Canada. Concern focused on what this increased effort could have on the resource, the benthos or bottom habitat, and the other important fisheries which occur in these areas.

More than 40 people from Maine, New Hampshire, Massachusetts, Florida New Brunswick and Newfoundland gathered to discuss sea urchin research and to discuss future research needs and approaches to management. A wealth of new information was presented and this sparked the need for further biological and ecological information. The information is needed in order for researchers, managers and fishermen to understand the implications of the commercial harvests of urchins - not only on the urchins themselves, but also on the benthic community of which they are a part.

The conference participants prioritized the information that needs to be collected with the emerging fishery in mind, dividing it into two categories, basic biological research and information on the current aspects and impacts of the existing harvests. Identified were three immediate priorities for management of the fishery:

- 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.
- The creation of no-harvest reserves, such as those Canadian researchers have found to be so valuable, to allow the comparison of unharvested to harvested areas; and
- The establishment of a fleet (including all types of harvesters), appropriate to the size of the resource was also considered a top priority.

Participants also agreed that it is important to further the understanding of spatial and temporal patterns of distributions in order to be able to distinguish impacts due to harvesting from naturally occurring fluctuations.

General agreement prevailed that a better understanding of larval supply, juvenile distributions, settlement and growth is necessary in order to figure out how many adult urchins can be harvested in a sustainable fishery.

A proceedings of the workshop is attached as Appendix II.

HABITAT RELATIONSHIPS TO FISHERIES MANAGEMENT

The role of habitat in regard to the success of particular life stages of marine groundfish has become an issue of increased awareness and interest. In response to this situation and several requests for discussion on this topic, project personnel authored a paper that was presented at the 1994 fall meeting of the Marine Technology Society (see Appendix III). The following section is taken from the abstract of the paper entitled "The Importance of Habitat in Groundfish Management":

Groundfish stocks in the Northwest Atlantic are at historically low levels. Historic management regimes have failed to maintain a viable fishery in this region. Benthic species of groundfish must pass through critical periods which affect year class strength. One such period occurs as pelagic juveniles settle to the benthos. Understanding the exact habitat requirements of juvenile groundfish at the time of settlement will lead to better predictability of year class strength and overall management.

Over the past decade an increasing number of studies have been conducted on the habitat requirements of fish species at critical times in their life cycles. These studies have used recent advances in undersea research technology to assess preferences for habitat characteristics. Studies have reported characterizing preferences for variables such as sediment, salinity and temperature regimes that are driven by factors such as predation and feeding. This paper reviews current knowledge of habitat requirements for the principal groundfish species in the Northwest Atlantic, the application of this knowledge to fisheries management and stock assessments, and highlights areas in need of further research.

OTHER MEETING AND ACTIVITIES

Project personnel have normally participated in the Maine Fish Forum and did so in March 1995. The Aquatic Biologist I attended the forum.

Project staff, as requested, reviewed various proposals that were submitted seeking funding. Proposals submitted for Fishery Industry Grants, Saltonstall-Kennedy Funding and Sea Grant Funding were among those reviewed.



Progress Report to the ICES Fish Technology and Fish Behavior Working Group, April 1995.

UNITED STATES

Massachusetts Division of Marine Fisheries Conservation Engineering Project

**H. Arnold Carr, Senior Marine Fisheries Biologist
Jessica Harris, Assistant Marine Fisheries Biologist**

Mitigation of Deck Discard Mortality and Survival of Codend Escapees in the New England Groundfish Fishery.

This two year study is an extension of our groundfish discard survival study completed in 1993. Three species of groundfish American plaice (*Hippoglossoides platessoides*), Yellowtail flounder (*Pleuronectes ferrugineus*) and Atlantic cod (*Gadus morhua*) were trawled for one or three hours and held on deck for ten minutes in one of three treatments. After sitting in either a wet tray, spray tray or dry tray the fish were put into a holding cage and returned to the depth from which they were trawled. The fish were soaked in the cages for 72 hours at which point they were retrieved and assessed for survival. There were no statistically significant treatment effects for either flounder species, although there were differences in survival due to tow duration and fish length with shorter tows and longer lengths producing higher survival. For cod there was no statistical effect due to the two tow durations, however there was statistical significance of the effect of length and of the interaction effect of length and treatment with large fish in the spray treatment having the highest survival.

Of the three species examined, cod showed the most potential for responding to a change in the way fish are handled on deck, however low sample sizes inhibited the statistical analysis of the data. Sample sizes for cod were low due to the drastically decreased abundance as a result of the stock collapse due to too many years of overfishing. In the future, when cod stock become healthier, it would be interesting to further investigate this issue.

All three species exhibited high survival for individuals that escaped through the codend. During the first year fish were held in the cover for 24 hours and then transferred to a cage for an additional 72 hours. During the second year fish were held in the codend cover/cage for 72 hours. Survival from the first to the second examinations went up for cod indicating that most of the mortality occurs in the first 24 hours, while survival decreased for both flatfish species. This latter result may indicate that either delayed mortality is a factor for flatfish or that flatfish are more susceptible to cage induced mortality.

The Use of a Species Selective Trawl in the Cape Cod Bay Whiting Fishery.

In the fall of 1994 a modified Wilcox trawl was used to catch whiting while excluding flatfish and lobster in the annual whiting fishery in northern Cape Cod Bay. The sweep of the net was modified by attaching 1 to 1.5 m dropper chains and adding floats to achieve a high opening off bottom trawl. This net was fished on a commercial trawler under commercial conditions. Unfortunately, only two sea days were possible resulting in 7 useable tows. Nevertheless some encouraging results were obtained. Combined mean discards of American plaice (*Hippoglossoides platessoides*), Yellowtail flounder (*Pleuronectes ferrugineus*) and Winter flounder (*Pseudopleuronectes americanus*) were below 10 lbs. per hour versus over 60 lbs/hour in the rest of the fleet fishing in the same area at the same time. Mean lobster catch (and thus discard as the landing of lobster was prohibited) 8 pounds per hour and was as low as 2.33 lbs. per hour versus over 40 lbs. per hour in the rest of the fleet. The loss of whiting is apparently minimized and bycatch loss maximized when the wings of the net have a maximum vertical spread and are tending bottom and the mouth of the net is off the bottom.

Selectivity of hook size and hook spacing for cod in demersal longlines.

This project is in its initial stages. We will be testing the difference between the size of Atlantic cod caught on 11/0 vs. 13/0 circle hooks and the difference between 6 ft. and 12 ft. spacings of a single hook size. All hooks will be baited with a single sized bait that is suitable for the 13/0 hook. Work will be conducted on commercial fishing vessels.

Modified Crucifier.

The project, which is also in its initial stages, aided a groundfish longliner in the construction of a roller/crucifier to try to mitigate damage caused to sublegal fish when snubbed during gear retrieval. The distance between the rollers, the angle and the length of the rollers are being modified to enable the fishermen more control when removing sublegal fish from the hooks.

THE IMPORTANCE OF HABITAT IN FISHERIES MANAGEMENT

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INTRODUCTION

Fisheries declines in the Western North Atlantic have reached crisis proportions. Canada has banned commercial fishing for several species along its maritime coast, and has challenged the internationally accepted 200 mile economic exclusive zone in order to protect its fishery resources. New England fisheries have come under strongly debated, restrictive fishery management regimes. There are many factors that have contributed to the failure of historical management strategies in these fisheries. These factors include over capitalization, inadequate effort control, and the politicization of management.

The science behind fisheries management has focused on the relationships between biomass, spawning stocks and the size of recruitment classes into a fishery on a species by species basis. This science has been well developed and executed, however, while the need to look at species complexes has been acknowledged, research examining the larger picture of the environment and habitat in which fish spawn, mature and reproduce has been overlooked by fisheries managers. In addition to controlling effort and determining spawning stock sizes, fisheries managers and scientists must gain a better understanding of the habitat and ecosystem influencing the groundfish populations so that we may be able to use the information to predict changes in population parameters and to protect critical times and areas in individual species' growth and development. This information must then be incorporated into fisheries management strategies in a proactive manner.

DISCUSSION

The bulk of the literature regarding the responses of marine fish to environmental parameters focused on one or two variables at a time. The investigators have searched for variables that have overriding influence on populations so that these variables could be used as predictors of stock recruitment. The investigations fall into two primary categories oceanographic and substrate variables. There is also a fair amount of literature regarding the interactions of biological variables. These investigations have focused primarily on the existence of density dependent responses to fluctuations in stock size.

Oceanographic variables

Research into links between reproduction and recruitment and environmental variables such as salinity, temperature, depth, turbidity and substrate, during the juvenile stages of groundfish development has been conducted. Results have shown links between individual variables or a subset of environmental variables and parameters such as recruitment and geographic distribution (Colton 1972, Colvocoresses and Musick 1984, Myers et al. 1993, Rose and Leggett 1989, Scott 1982b, Swain 1993, Walsh 1992), however they have not always proved consistent (Horne and Campana 1989). This view of the system however, suffers from the same problems that individual species assessment does, namely, that the focus is too narrow. The relative importance of the individual variables included in the set of habitat, environmental and biological factors

that determine recruitment success fluctuate from year to year in importance. For instance, Myers et al. (1993) showed that salinity plays an important role in recruitment success for the Northern Atlantic cod stock off Newfoundland. The authors proposed several explanations for the underlying mechanism such as larval freezing, advection related processes or stability arguments, however, no conclusions regarding the underlying mechanism could be made. Scott (1982a&b), Horne and Campana (1989), agree that it is absolutely necessary to look at the suite of biological and environmental variables in order to account for covariation among the variables.

Substrate

Preferences for specific substrate types have been described for several species of marine organisms. Associations of sediments and benthic invertebrates is well documents by Gray (1974), but have also been shown for finfish. The yellowtail flounder exhibits a strong preference for sandy bottoms, winter flounder are found on sand to sand-mud bottoms, cod and haddock prefer sand-gravel, silver hake prefer silts and clays etc. (Colton 1972, Scott 1982, Walsh 1992). Recently research into the underlying mechanisms and significance of these preferences has been conducted. Lough et al. (1989) overlaid distributions of juvenile cod and haddock over George's Bank in pre- and post-benthic stages. Pelagic juveniles were distributed fairly evenly within the gyre of the bank, however once these animals settled into their benthic stage they were located primarily over the gravel areas along the northeast peak of the bank, an area which corresponds approximately to statistical area 523 (Crecco and Overholtz 1990, Lough et al. 1989). The authors proposed that this may be due to differential survival of the juvenile fish on the different bottoms, with gravel offering more shelter against predators. This theory is supported by work conducted by Gotceitas and

Brown (1993) in which they placed juvenile cod in a tank with three substrates of varying rugosity and exposed them to a predator (larger cod). In the presence of a predator larger cod showed a preference for finer substrates while smaller cod showed preference for cobble which increased the probability of survival. When no cobble was present juvenile cod attempted to flee from the predator. This is also supported by work done by Keats et al. (1986) who examined one and two year old cod associated with fleshy macroalgae in Newfoundland. The authors proposed that, based on stomach content and behavioral observations, shelter from predators is the primary reason for the one year old cods' association with the macro algae. Carr (1989) found increased recruitment of temperate reef fish to areas with giant kelp (*Macrocystus spp.*) and attributed the results to differential settlement or post settlement mortality. Wahle and Steneck (1991 & 1992) proposed that habitat restrictions may exist for the American lobster (*Homarus americanus*) due to the vulnerability of early benthic phase lobster to predation in areas of insufficient shelter (cobble bottom) from predators. Shelter use has also been cited as the primary reason for the association of juvenile red hake (*Urophycis chuss*) with sea scallops (*Placopecten magellanicus*) (Steiner et al. 1982) and is an important factor in structuring some temperate and coral reef fish communities (Hixon and Beets 1993, Buchheim and Hixon 1992, Carr 1989&1991).

Density Dependence

Habitat that has specific benthic and oceanographic attributes can affect population sizes through density dependent mechanisms. Density dependent mechanisms have been identified in demersal species of fish. Ursin (1982) attributes the stability of recruitment of North Sea plaice to density dependent mortality in postmetamorphosis juveniles in the Wadden Sea. Myers and Cadigan (1993) showed that

juvenile mortality is density dependent within cohorts during the juvenile stage for cod, plaice, sole and whiting and among adjacent cohorts for cod. The authors proposed four possible explanations for the underlying mechanism, competition for food, cannibalism, prey switching by predators (including human) to abundant year classes and competition for critical areas of appropriate juvenile habitat. A particularly interesting outcome is that density dependence is much stronger in cod than in haddock, with benthic recruitment variability at the youngest age observed also being greater for cod than haddock. However, cod is considered to have less variable recruitment to the fishery than haddock (Ursin 1982, Myers and Cadigan 1993). This implies that the natural mortality due to density dependence is high enough to mask the variability of recruitment in cod. Cod and haddock are found in very similar bottom types, with both preferring sand-gravel substrates (Scott 1982), but do have different diets. Haddock are primarily benthic feeders while cod is largely piscivorous, which would contribute to its higher density dependence due to cannibalism of older year classes on younger ones (Bigelow and Schroeder 1953, Myers and Cadigan 1993). The effects of such a situation would be most noticeable during periods of high population densities. When populations increase they infiltrate areas of less favorable habitat in which natural mortality may be higher and reduce their ranges during episodes of low population size (Swain and Wade 1993; Rose and Leggett 1991; Crecco and Overholtz 1990). When a population is depleted and has retracted into the more favorable habitats within its range its vulnerability to fishing mortality increases (Crecco and Overholtz 1990, Rose and Leggett 1991, Winters and Wheeler 1985). Crecco and Overholtz (1990) predicted that under such conditions, unless fishing mortality could be restrained by a fishery closure or strict quota management, spawning stock biomass would be

steadily fished down, leading eventually to recruitment failure and collapse of the fishery.

Synthesis

Several states have implemented programs that attempt to address the problem of stewardship over environmentally sensitive or critical habitats. These programs and the research they support have focused on the shallow nearshore environments. These areas are more obvious to the general public and are much easier to sample. Off shore areas are significantly impacted by human endeavors, yet our knowledge of these areas pales in comparison to the nearshore environment.

The Commonwealth of Massachusetts created a program in 1975 called Areas of Critical Environmental Concern or ACEC's. Habitats in a broad range of categories including coastal, fishery, agricultural and inland wetlands can be designated as an ACEC. While no specific protection is afforded an ACEC, it does require any proposed development that might affect the area to withstand extra scrutiny. The program acknowledges the existence of areas that are critical to the survival of important species and the responsibility for stewardship of the state's resources. Massachusetts provides separate protection under the Division of Marine Fisheries regulations for cases such as the winter flounder spawning closure that lasts from February 1 to May 31.

Maine has opted for a more systematic approach to addressing the stewardship of its marine resources. Brown (1993) catalogs habitats in a classification system developed for the state's marine and estuarine benthic habitats and identifies representative sites for these habitats.

While this catalog does not include terrestrial ecosystems, it creates a fundamental data base from which managers and scientists will be able to identify areas in need of further research, areas in need of management and protection

and from which assessments of human impacts can be made in the future. The habitats are divided into two large groups, marine and estuarine, defined by salinity (30ppt being marine). These are each subdivided into either intertidal and subtidal habitats, which are then differentiated primarily by depth and energy level. It is interesting, although not surprising, to note that the marine subtidal habitats are poorly documented and described in comparison to all the others in the catalog.

As researchers establish the importance of the various environmental factors affecting the ecosystem supporting commercial and recreational fishes, managers, scientists and industry participants will have the much more difficult task of establishing how this information can be incorporated into fisheries management. At a recent workshop on habitat sponsored by the Regional Association for Research on the Gulf of Maine (RARGOM), a fisheries resources working group tackled this problem (Langton 1994). They defined critical or essential habitat as "geographically and/or physically discreet areas that a species must utilize at some phase in its life history." The participants proposed a flow diagram which would allow fishery managers and scientists to work together to determine research needs, necessity of management action regarding the defined critical habitat and the direction of management strategies. These decisions would be based on a habitat-life history matrix that graphically represents the relationships of the variables which define a species' critical habitat. A multispecies model can be constructed by overlaying the life history matrices of species that co-occur.

The task at hand then, is to describe and map areas that previous work has shown are potentially critical habitats for valuable commercial and recreational fish. As habitat characteristics vary according to the unique biological, physical and chemical properties of an area, areas suspected of playing an

important role in fish ecology should be assessed individually and then integrated to look at larger scale effects. The existence and recent advances in technologies such as Global Positioning systems, computer mapping database facilities, remote operated vehicles (ROV's), video imaging systems, high resolution sonar and acoustic technologies, will enable the description of these areas. Uses of these technologies have increased within the past ten to fifteen years and as a result sampling and analysis techniques have improved tremendously, especially in the use of ROV's for scientific sampling (Barry and Baxter 1993, Michalopoulos et al. 1993).

SUMMARY

Enough evidence exists in the literature to say that demersal fish require specific types of benthic and oceanographic conditions at some stage in their reproduction and/or early development. The proportion of the numerous variables vary in importance by species and location, and by the interactions of the variables themselves. In order to better study and manage our living marine resources, we need to describe and identify those areas of the marine ecosystem that are critical to commercially and recreationally important fish species. This is a goal that is becoming technologically achievable as well as biologically and economically important.

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ROV, Divers, and Acoustics Team for Target Recovery

Teamwork Among Disparate Instruments, Equipment Enables Aircraft Location and Inspection.

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S ometime during the late evening on December 28, 1991, a training flight began making "touch and go's" at a small airport on the northeastern coast of the U.S. Its flight path took it several miles offshore on approach to the runway. The winds were light out of the west at 10-15 miles per hour and the air was clear.

Onboard the twin engine Beech 1900C Airliner were an instructor/trainer and two trainees. The plane disappeared from air traffic control radar while over the ocean at 9:18 p.m. By itself, this is not unusual because ATC radar does not always track low-flying planes. At 7:40 a.m. the next morning, however, a section of starboard wing, outboard of the engine, was located floating more than 10 miles from shore.

The debris was taken in tow by the U.S. Coast Guard while an air search was conducted to determine the position and classification of any further floating debris. Extended air search operations were carried out to locate any trace of the aircraft's occupants in the event they survived water impact.

The cause of the accident was not known. The crew had not put out emergency or distress calls. The exact location of the crash site was unknown. The debris floating on the surface included the wing portion, internal components, and small buo-

yant parts. After determining the crew was not alive or afloat, the most urgent task was to locate the wreckage of the aircraft, recover the remains of the crew if present, and recover the "black box" cockpit voice recorder (CVR) for analysis by the National Transportation Safety Board.

In search operations of this type, it is imperative that several steps be taken early in the planning stages to minimize time spent in the search phase.

Pinpoint Time, Location

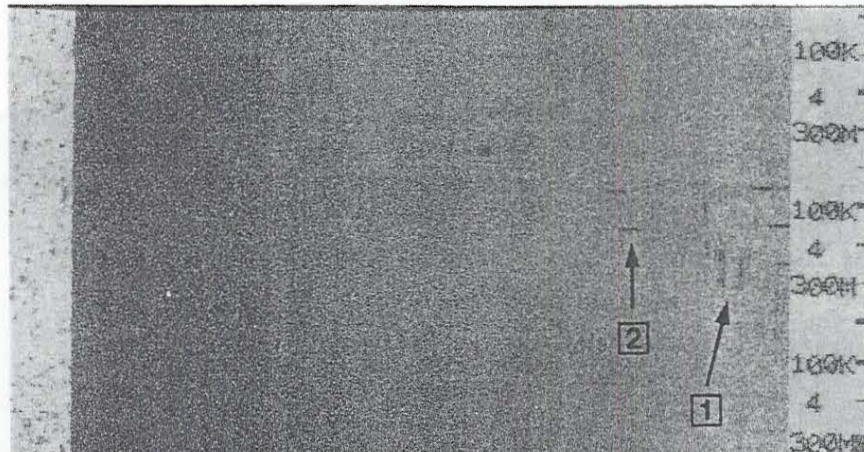
The first step is pinpointing the time and location of recovered floating or shoreline debris pertinent to the incident. Another important step is to determine the precise location of existing bottom obstructions, including all shipwrecks and pre-incident aircraft crash sites.

Analysis of available data was undertaken in an effort to produce an operational search plan in an area

with a 95 percent probability of containing the target aircraft. Information, including the position, time, and condition of the debris first sighted was gathered.

The 30-foot section of wing, floating vertically with about 6 feet extending above the water surface, had low windage and, thus, appeared to be a key piece for drift analysis. Data were collected on the wind speed and direction for every 20 minutes from the time of the last known sighting of the aircraft until debris was discovered. The NTAP air traffic control radar positions of the aircraft before the accident were gathered along with oceanographic data concerning wind-driven and tidal currents for the region.

These data were used by the search team to perform target area analysis and post-plot hindcasting to determine the origin of the floating debris. It was assumed that the origin of the debris was where most of the remain-



Portion of the EG&G side-scan sonar record shows what searchers thought was the first contact. While the anomaly making up most of the wreckage (1) can be recognized, output pulses from the aircraft cockpit voice recorder beacon are clearly visible (2) in the sonar data.

ing components of the aircraft would be located. Target area analysis provided a 12-square-mile search area with the highest likelihood of target location in a 1.5-square-mile section.

Computerized seafloor obstruction

research showed the exact location of all previously downed aircraft in the region as well as known and historically recorded shipwrecks in the area. Equipping the operational team with this data significantly reduces time spent examining targets with characteristics similar to the object of the search. Because of the possibility that ROV/diving operations would be required to complete site component recovery, all available seabed data were examined. Hazards in the area included a German "U-boat" sunk in 1945 with warshot-equipped torpedoes on board and several areas of unexploded depth charges. Obstructions in the region included a buried submarine cable.

Investigations into the structure of the CVR indicated that it was originally bolted to the aft bulkhead and

was equipped with a 37.5 kHz Dukane pinger. The pinger is designed to activate upon immersion and transmit a 100-millisecond pulse at a 1-pps rate. The unit has battery power for over 30 days. The exact duration is a function of the maintenance schedule of the pinger.

The depth of water when the floating debris was found averaged 40-50 meters. At these depths the pinger's source level would provide a range of about 1-2 miles.

The goal of the immediate operation was to locate and map the debris field of the aircraft in preparation for recovery of the CVR. A secondary goal was to recover crucial components of the target aircraft for analysis. A weather front traversing the search site precluded operations for the first 72 hours after the incident.

Equipment and personnel were moved into the region, ready to operate on the first weather break. The first potential weather window came January 1.

Equipment for the search operation included an EG&G model 260 digital side-scan sonar, model 272-TD dual frequency towfish, lightweight Kevlar®-reinforced tow cable, and an EG&G model 360 digital tape system.

Positioning was provided by a Magnavox MX-4200, a six-channel glo-



At upper left, diver using surface-supplied air prepares to deploy from barge for target recovery. (Photo by Jos. Amaral.) MiniRover Mk II vehicle above was search crew's "eyes" for following up targets mapped by the scanning sonar. Starr target (background) aided in positioning the vehicle in relation to surrounding debris field. Search area depths of 40-50 meters allowed use of Kevlar-reinforced, lightweight tow cable and manual launch and recovery of EG&G dual-frequency side-scan sonar towfish.

bal positioning system receiver, and a Northstar model 800 Loran-C. These navigation sensors were integrated by an SAIC PINSS (portable integrated navigation and survey system) using a 386 laptop computer. The navigation sensors and the PINSS were interfaced directly to the side-scan sonar system.

Target Confirmation by ROV

In the event that the aircraft experienced in-flight breakup, which often results in a debris field comprised of small pieces, a Benthos MiniRover Mk II, supported by a 180-meter tether assembly, was included for target confirmation. Color video data was recorded on multiple VHS video recorders.

Power was provided by 100-220 volt generators and 12/24 volt lead-acid storage batteries with inverters for power backup. A Dukane model N-30-A5B hydrophone was used to determine if the aircraft recovery pinger was present and operational. The target area was within 20 miles of port allowing the use of small, easily mobilized vessels for search. The R/V *Magic*, a 31-foot Blue Hill Marine boat specifically set up for coastal research and survey operations, was used as a support craft.

The operation used a non-adjacent-track, target-prioritized sonar search layout. The preliminary search process used 100 kHz side-scan frequencies. Because the sonar operator had an extensive background in locating downed aircraft and the seabed was relatively smooth, it was determined that the target could be detected and recognized using 300-meter-per-side sonar ranges.

The long range also decreased the time required to cover the search area and allowed the search team to utilize the short weather window currently available. Although vessel tracking was stable, lane spacing was 450 meters. This tight lane spacing brought targets in the outer ranges on one pass closer to the center of the sonar record on successive passes, thus enhancing target classification.

Upon arrival at the start of the first lane, the pinger receiver (tuned hydrophone) was lowered. The directional capabilities of the hydrophone had been disabled so bearing information was unavailable. The signals received indicated a faint but discernible output from the pinger. This provided the search team with the

"The key in minimizing the time to complete the entire job was the effective use of the three integrated tools. The combination of the ROV, scanning sonar, and divers—working in concert—resulted in a complete coverage of the site and allowed the client to optically examine even the smallest portion of debris."

knowledge that the pinger was functioning and that the survey vessel's current position was within a 2-mile radius of the acoustic source.

The search pattern was set up along the calculated flight path of the lost aircraft. On the second lane, within two hours of search commencement, a debris field was seen in the sonar data at a range of 275 meters on the starboard channel. The debris field was long and narrow, lying along an approximate heading of northeast-southwest. Detail mapping sonar runs were made, confirming that it contained targets consistent with a broken-up aircraft. Sonar data were generated to assist in the construction of a seafloor mosaic to be used in planning any recovery efforts.

The debris field was approximately 250 meters long and 40 meters wide. There were three or four areas containing larger pieces of debris with numerous small targets between them. Initial on-site analysis of the sonar data indicated a target characteristic of an aircraft empennage at the southerly end of the debris field.

Transducer Triggers 'Off'

Several runs were made at the site along the path of the debris field with the towfish transducer triggers turned off—to bypass the TVG circuitry and drive receiver gains higher. Further, the narrow receive beam angle of the transducers prevented the system from displaying the pinger's output until it was exactly 90° to the longitudinal axis of the towfish. This was done in an attempt to localize the pinger, which was likely to still be attached to the CVR.

The output pulses from the relocation pinger showed the source to be coming from the southwesterly end of the debris field.

The following day, the ROV provided immediate confirmation that the debris field was comprised of the aircraft's components. Within one hour, the serial number of the plane was recorded on videotape. The debris field was spread out far enough and there were multiple obstructions to the ROV tether that the confirmation

dives were made in several separate deployments back-to-back.

Repeated dives throughout the wreckage provided only traces of small pieces of debris. On the last deployment, the pilot of the ROV located and recorded video images of the nose landing gear (lowered and locked). Attached to this was the lower forward portion of the nose and cockpit. In one day, the site was confirmed and portions were mapped by the ROV.

Because of the lack of available weather windows in the winter season, operations to recover the crucial components of the downed aircraft had to be mobilized without delay. American Underwater Search & Survey Ltd. had designed and implemented aircraft recovery procedures for coastal zone depths that have been proven to be very successful. On an earlier operation, more than 95 percent of a badly broken-up and widely dispersed craft had been recovered.

A large, permanently moored, surface support platform, while able to withstand higher sea states, would be too difficult to move on- and off-station during winter gales common to the region. A mobile coastal platform would be able to respond more quickly and be able to take advantage of frequent, short weather windows.

The water depth allowed diving operations using air. The planned process for recovery would use a triad of tools. A scanning sonar would search for and "triage targets" of interest within the debris field. The recovery of objects would be effected by the following: divers for small objects; a steel basket on a winch for medium-sized objects; and a derrick for the heaviest components.

Remote sensing equipment included the same equipment suite used in phase I with the addition of an Imagenex model 855 high frequency scanning sonar.

Diving Operations

Diving operations utilized surface-supplied air to SuperLite diving hel-

"A scanning sonar would search for and 'triage targets' of interest within the debris field. The recovery of objects would be effected by the following: divers for small objects; a steel basket on a winch for medium-sized objects; and a derrick for the heaviest components."

ments with communications. Hot water suits received heated seawater from diesel-fired heaters on deck. A four-man, double-lock chamber was welded to the deck of the barge.

Weather forecasting became crucial to the operation. Because many of the weather pattern changes occurred in the early morning hours, personnel were often mobilized on the barge at 4:00 a.m. The weather rarely held for more than 10 hours so only one shift was used for the operation. If the weather was expected to hold for more than 12 hours, work sometimes continued in excess of 18 hours.

The support barge required a stable multi-point moor to allow it to be easily and reliably moved to a position directly vertical from any point within the debris field. Proper anchor placement is critical to allow the barge to be placed in the exact position required and permit the operation to continue as long as possible.

The sonar mosaic was used to outline operational parameters. A detailed map of the debris and surrounding topography was generated from the initial sonar runs as well as the mosaic. These records were critical in determining subsequent survey and recovery operations, placement of the anchors, and in the initial determination of the fate of the aircraft. In this case, the aircraft was severely broken up, but the first analysis of the spatial distribution of the aircraft, and its orientation, (that the tail section was the furthest down the flight path) was correct.

The Imagenex high frequency scanning sonar head was not mounted on the vehicle but rather on an independent stand on the seabed—offering several advantages. Under guidance from the sonar operator, it allows the vehicle pilot to move quickly to targets without having to stop his horizontal progress and reacquire the target on sonar. It allows the placement of the sonar head higher off the bottom to more fully insonify bottom depressions, which often held debris.

With the transducer on an independent stand, the target and divers

are very visible on the sonar display. And with the attachment of a passive STARR target to the vehicle, it helps to position the vehicle in relation to its surroundings.

The STARR target became a significant component for vehicle operations. It provided the strongest acoustic return within the debris field and permitted operations personnel to closely monitor vehicle progress.

The ROV operated in an area of high density, sharp-edged debris. As a result, the maximum tether length from the downweight was 50 meters. Once the sonar was placed on the seabed, the sonar display described a section of the debris field that could be worked thoroughly and effectively without gaps or holes.

Upon achieving operational status in specific areas of the site, the sector scanning sonar was deployed to identify on-bottom targets for survey. The sonar sweeps a 380° arc and can be programmed to sweep smaller sectors to focus on targets or the ROV as required.

During the survey for prioritized site components, the CVR was located and recovered. Surveys continued on a day-to-day basis to locate and recover the targets of interest. For recovery, the dive team and the derrick operator worked in concert with the remote sensing equipment operators.

The full extent of the area was mapped by moving the scanning sonar to new locations after each area had been covered. When a target was located for recovery, the vehicle pilot would remain at the target while a diver was deployed. The diver would descend to the bottom, follow the ROV tether to the target, and recover the item.

Large Object Recovery

The recovery of large objects was accomplished using the sector scanning sonar, surface-supplied divers, and the derrick mounted on the barge. The target would be illuminated by the sonar before deploying the surface-supplied diver. The ROV was recovered prior to heavy lift operations. Once the diver securely strapped the

target, it was lifted to the surface and placed on deck.

The crash site was spread along the flight path over 250 meters. The majority of the remains of the aircraft were in very small pieces with the exception of the empennage, which was badly distorted but still identifiable. Other large components included the cockpit, both engines, and the remaining wing.

During the operation, the owners of a submarine cable buried in the vicinity of the aircraft wreckage expressed serious concern for its condition. They purchased the mooring anchors, in-place, with an agreement that they would not be recovered.

The weather was the most significant factor in the amount of time required to complete the survey and recovery operation, but the platform chosen for the operation provided the stability needed during marginal sea states. The key in minimizing the time to complete the entire job was the effective use of the three integrated tools. The combination of the ROV, scanning sonar, and divers—working in concert—resulted in a complete coverage of the site and allowed the client to optically examine even the smallest portion of debris. /st/

John Perry Fish has extensive experience in survey and seabed search operations worldwide. His experience includes directing a search and survey



company, managing in-house submersible operations, and approving specific field operations using sonar, magnetometers, and a variety of ROVs. Fish teaches advanced survey techniques using side-scan sonar on a regular basis.

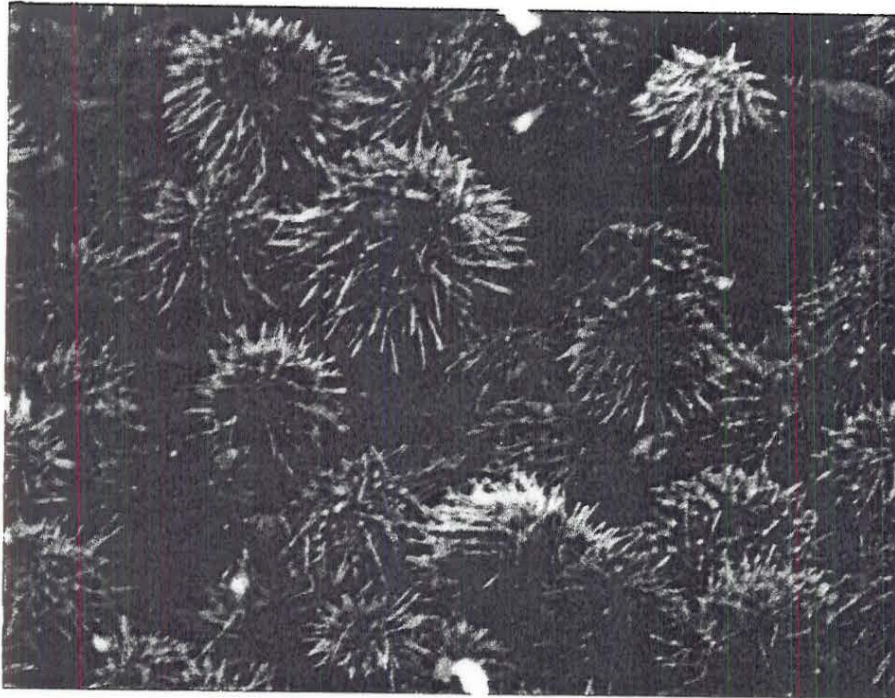
H. Arnold Carr has more than 30 years of experience working on undersea programs including surface-supplied manned diving, manned submersibles, and ROV operations. He has developed new



methods of deploying seabed inspection ROV systems for the state of Massachusetts and has organized and managed seabed search programs to locate and identify shipwrecks and other seafloor obstructions.

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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TABLE OF CONTENTS

Introduction	1
Workshop Summary	1
Presentations:	
Carr, H. Arnold, Daniel J. McKiernan, Peter Burns and Jessica Harris. The Sea urchin fishery in Massachusetts, current trends, concerns and research. Massachusetts Division of Marine Fisheries.	8
Robinson, Shawn and Hank Scarth. The green sea urchin fishery in southwestern New Brunswick. Department of Fisheries and Oceans, Biological Station St. Andrews New Brunswick.	18
Steneck, Robert, Douglas McNaught and Stephanie Zimsen. Spatial and temporal patterns in sea urchin populations, herbivory and algal community structure in the Gulf of Maine. Department of Oceanography, Darling Marine Center, University of Maine.	34
Vadas, R.L., B. Beal, S. Dudgeon, W. Wright. Spatial and temporal variability in reproduction and spawning in green sea urchins in Maine. Department of Plant Biology, University of Maine, Orono Maine. (abstract only)	74
Harris, Larry. Studies on the effects of depth, water flow and diet on settlement, recruitment and growth of the green sea urchin, <i>Strongylocentrotus droebachiensis</i>	75
Lawrence, John. Strategies and life history characteristics as criteria for evaluating the suitability of sea urchin species for fisheries and aquaculture.	94
Robinson, Shawn, Art MacIntyre and Sylvie Bernier. The impact of scallop drags on sea urchin grounds.	102
List of Participants	122

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).

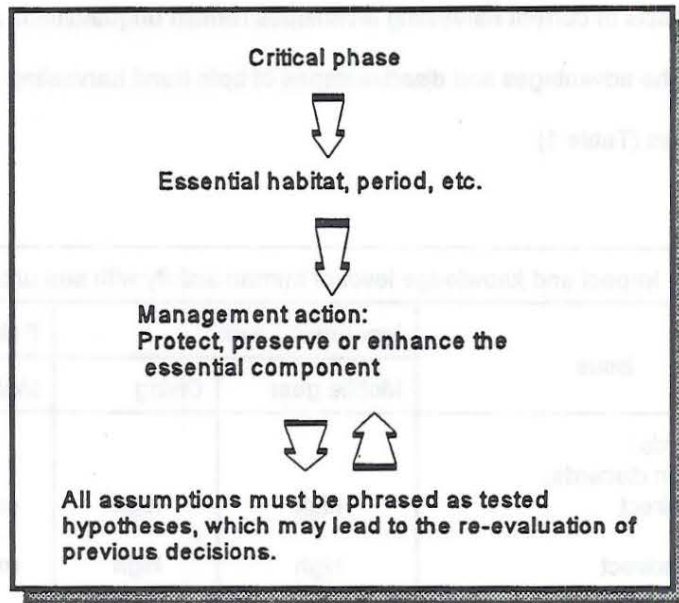


Figure 1

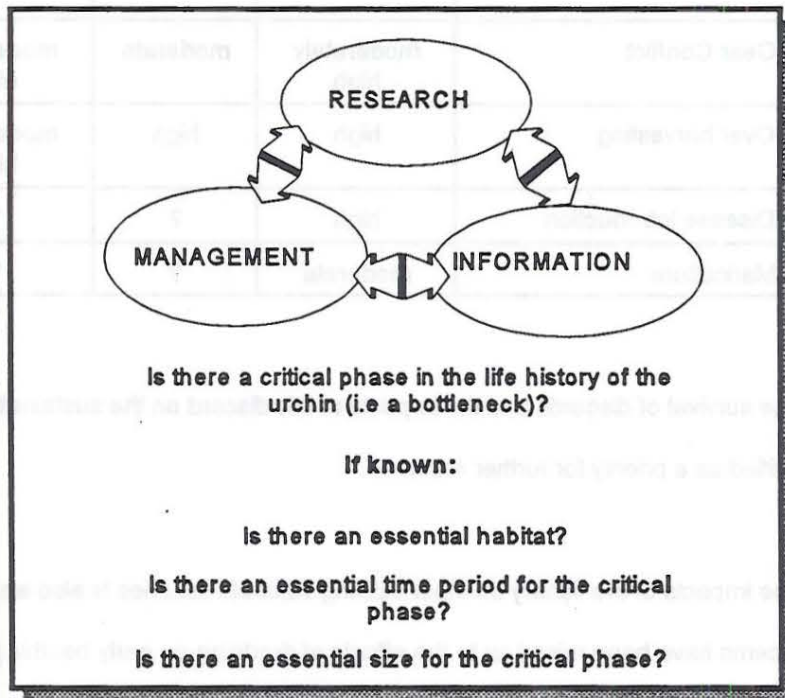


Figure 2

■ 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 by 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. DMF 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 not 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-jurisdictional 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.

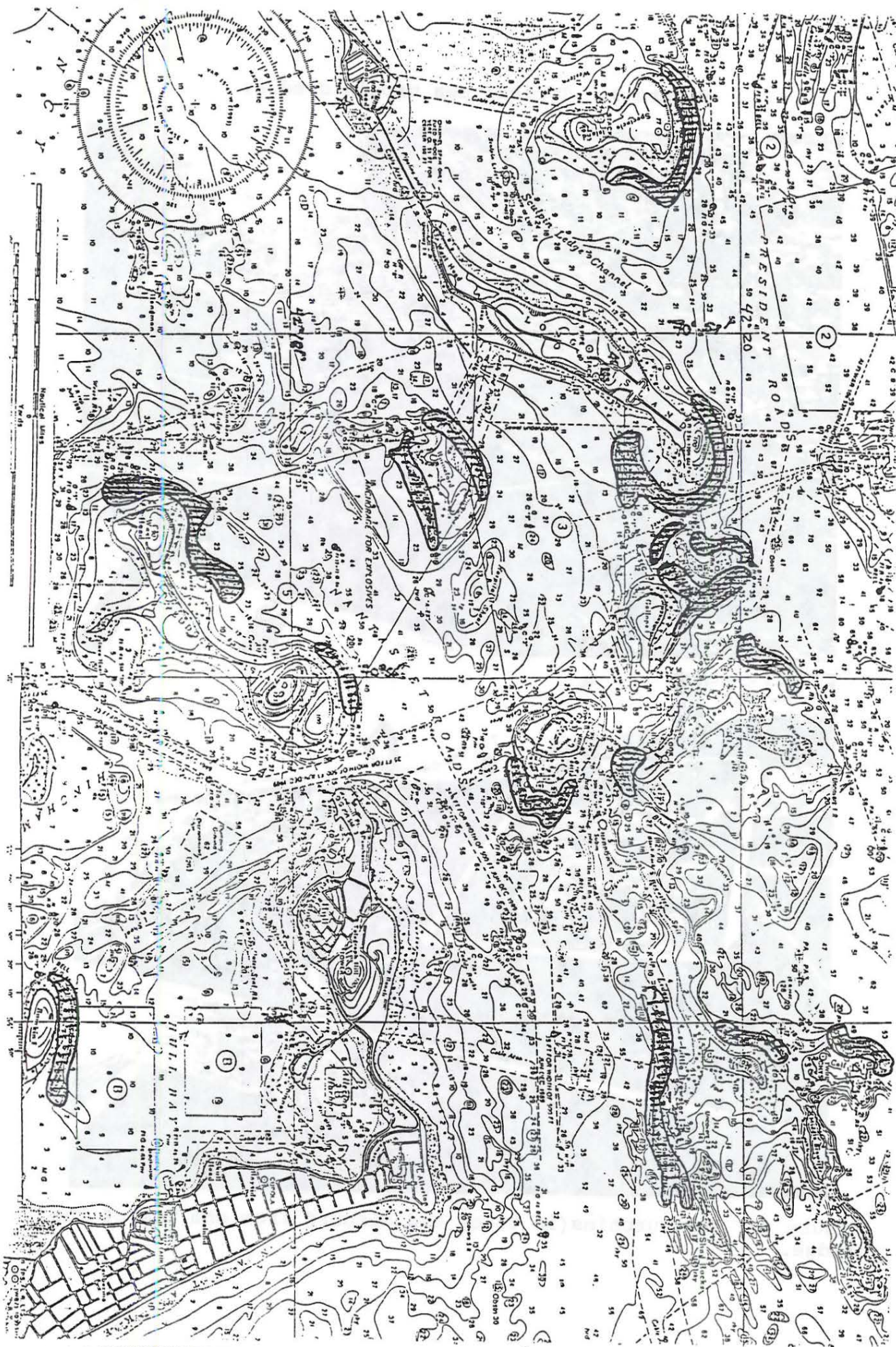


Figure 3. Typical sea urchin dredge.

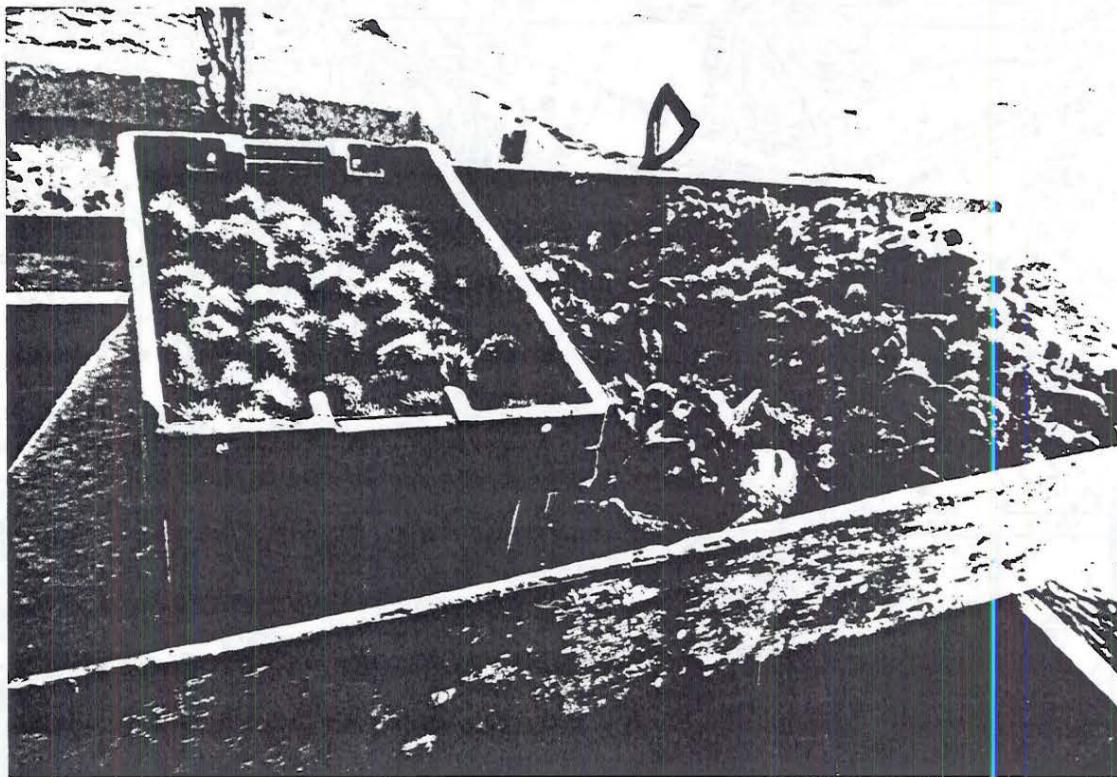
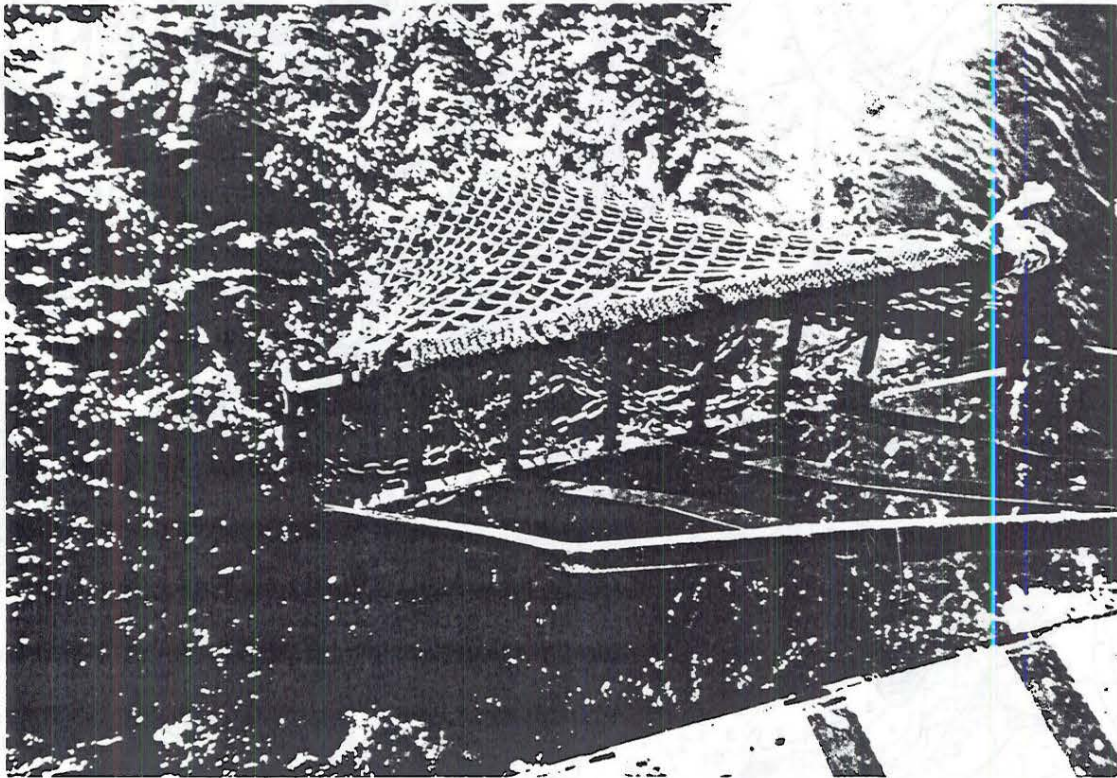


Figure 4. Kept urchins(in tote) and discard from one tow of the dredge.

**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 cm² 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 m² 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 demipyramid 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 cm² 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 cm² 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.

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.

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
Transshipping to or from unlicensed vessels	1 year, all fishing privileges
Size Limit	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
Not sorting/returning undersized to grounds	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

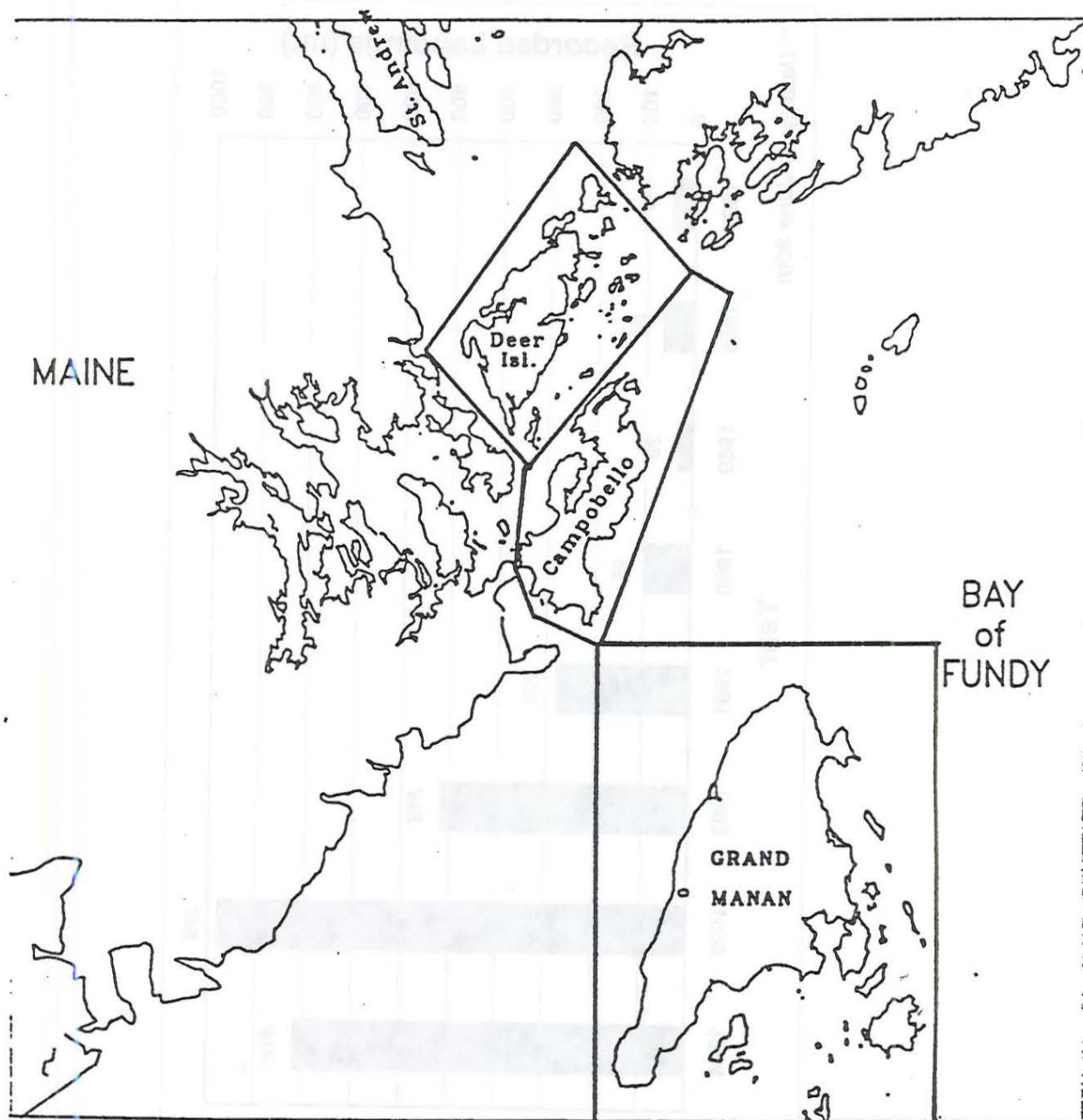
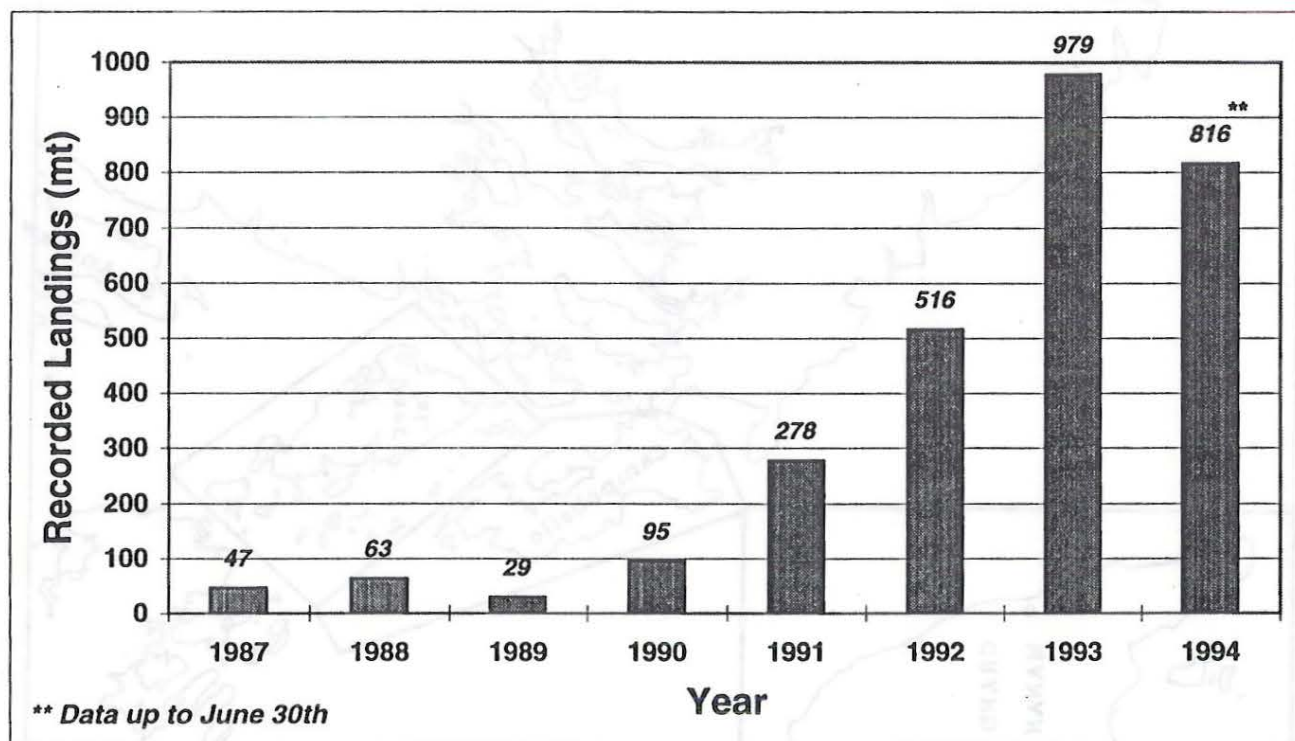
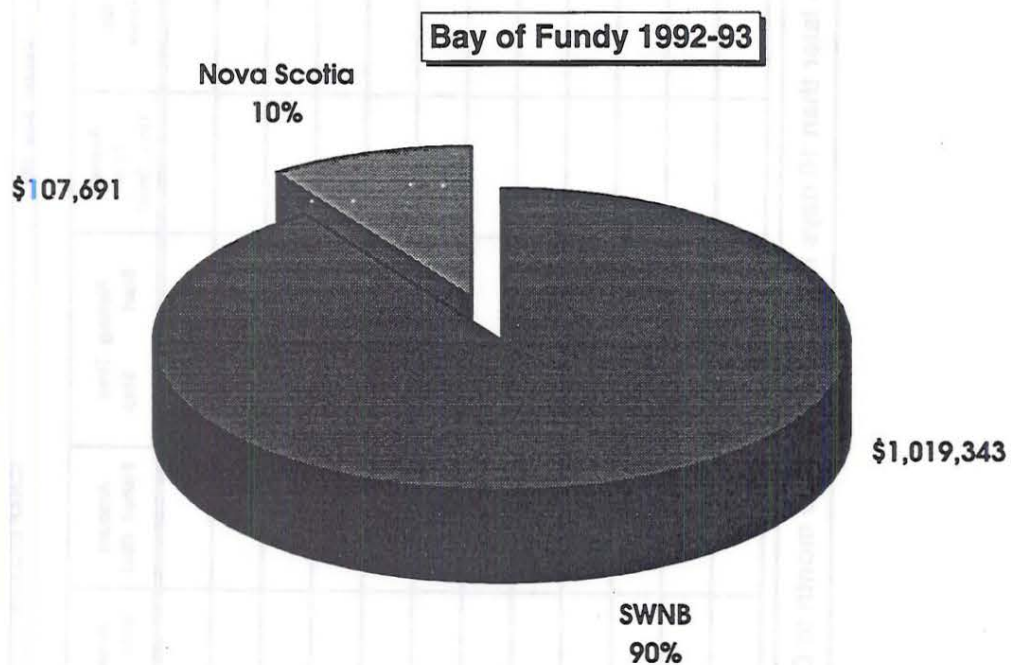


Fig. 2





4. 19

ICNAF Division: _____

Licensee Signature:_____

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: _____

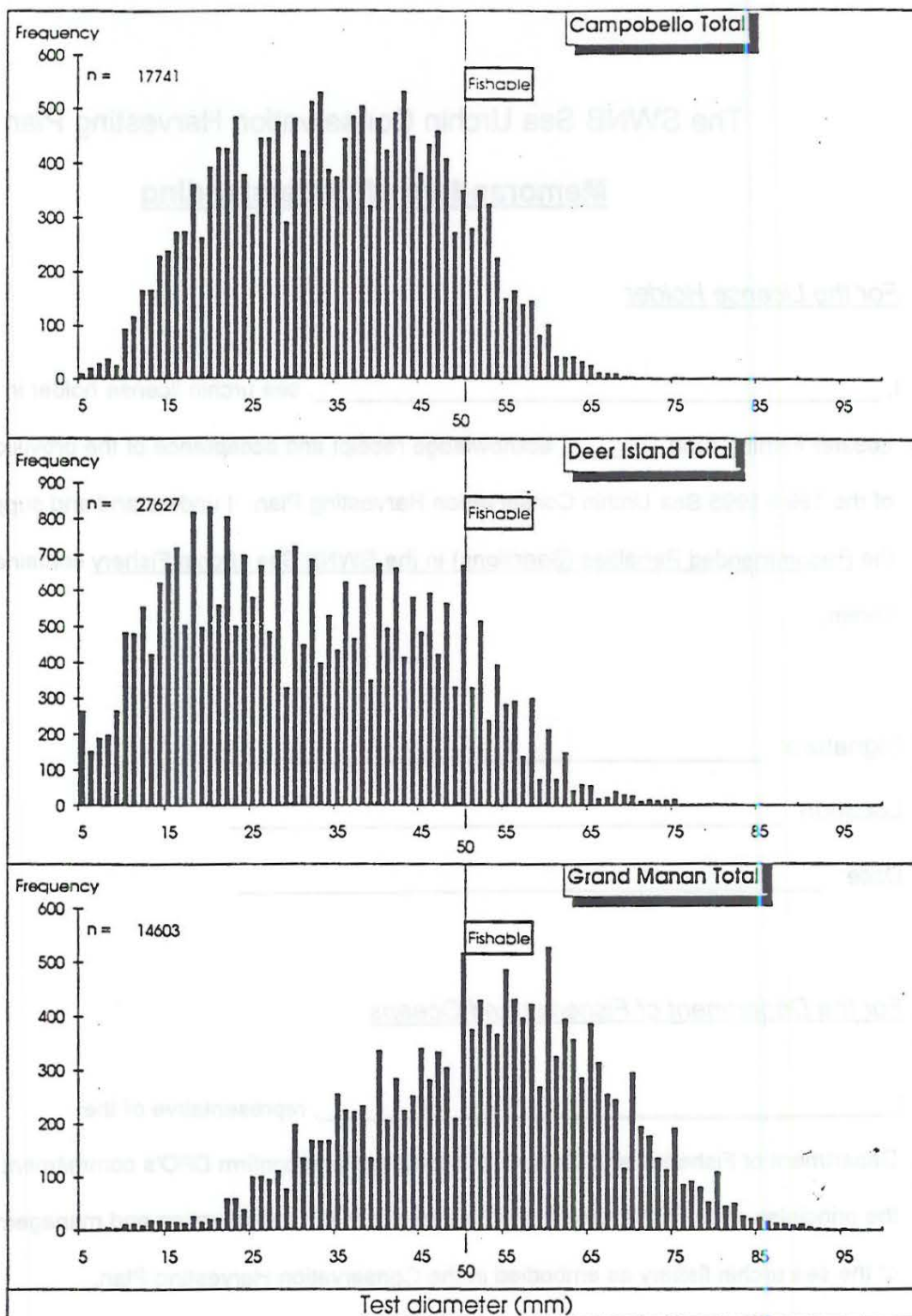
For the Department of Fisheries and Oceans

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: _____



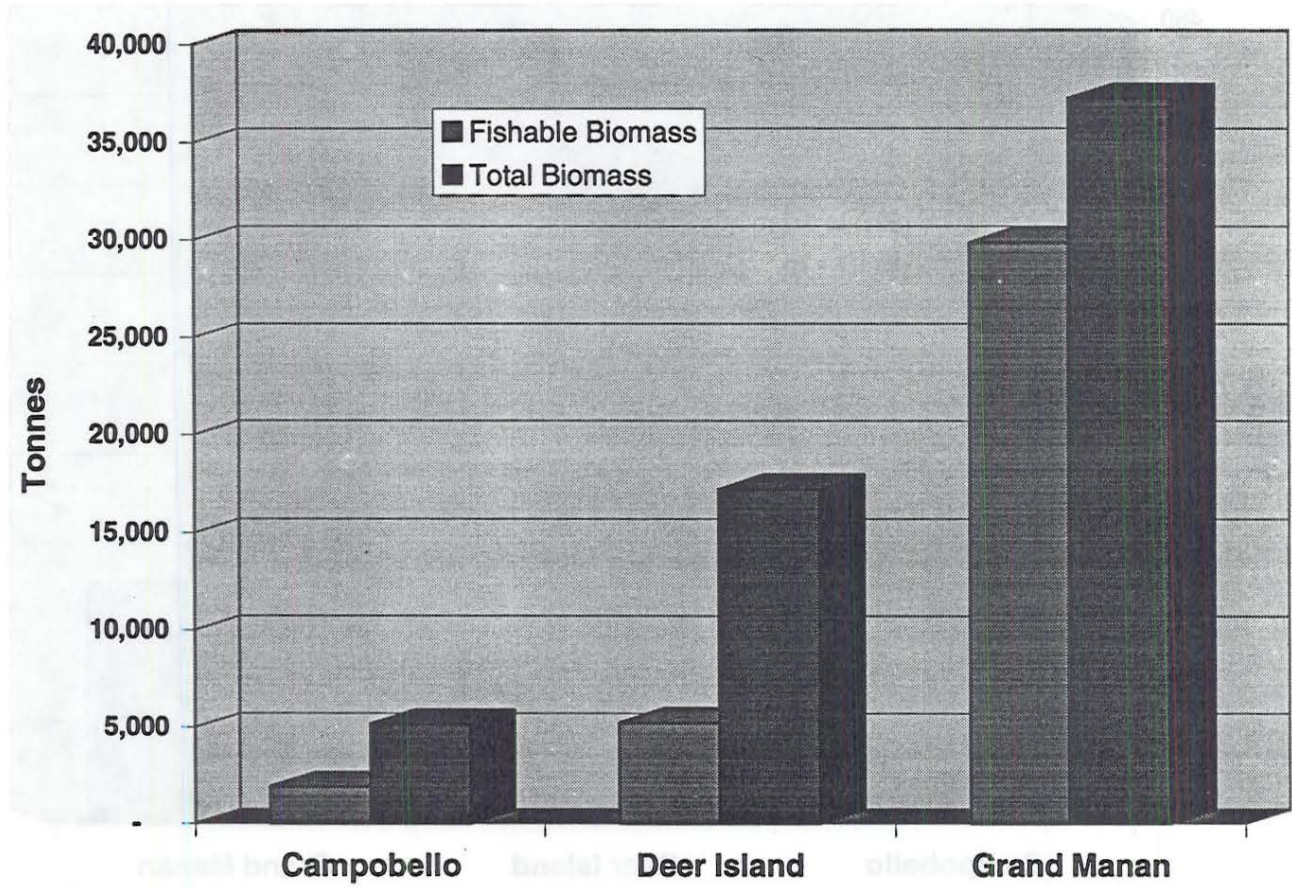


Fig-8

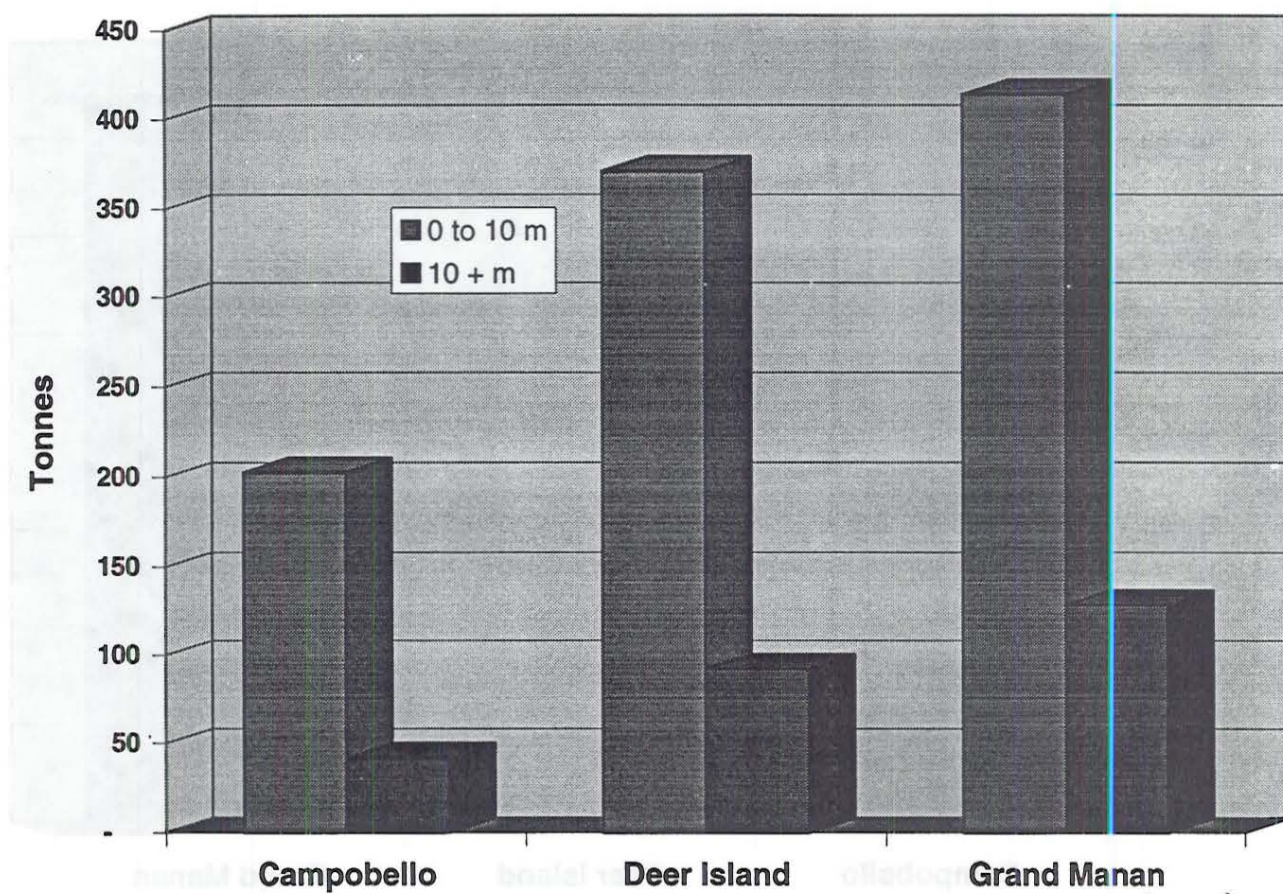


Fig. 9

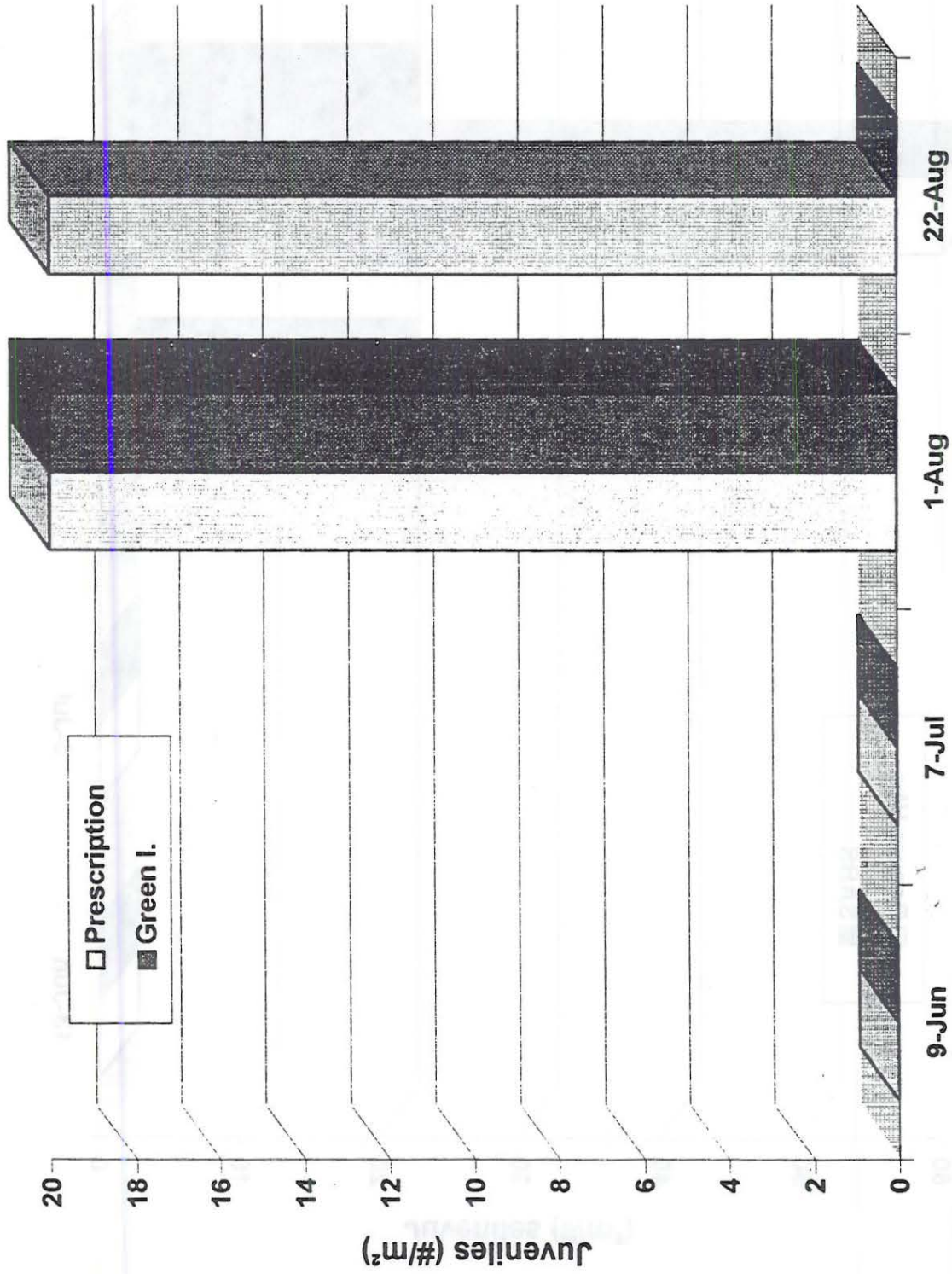
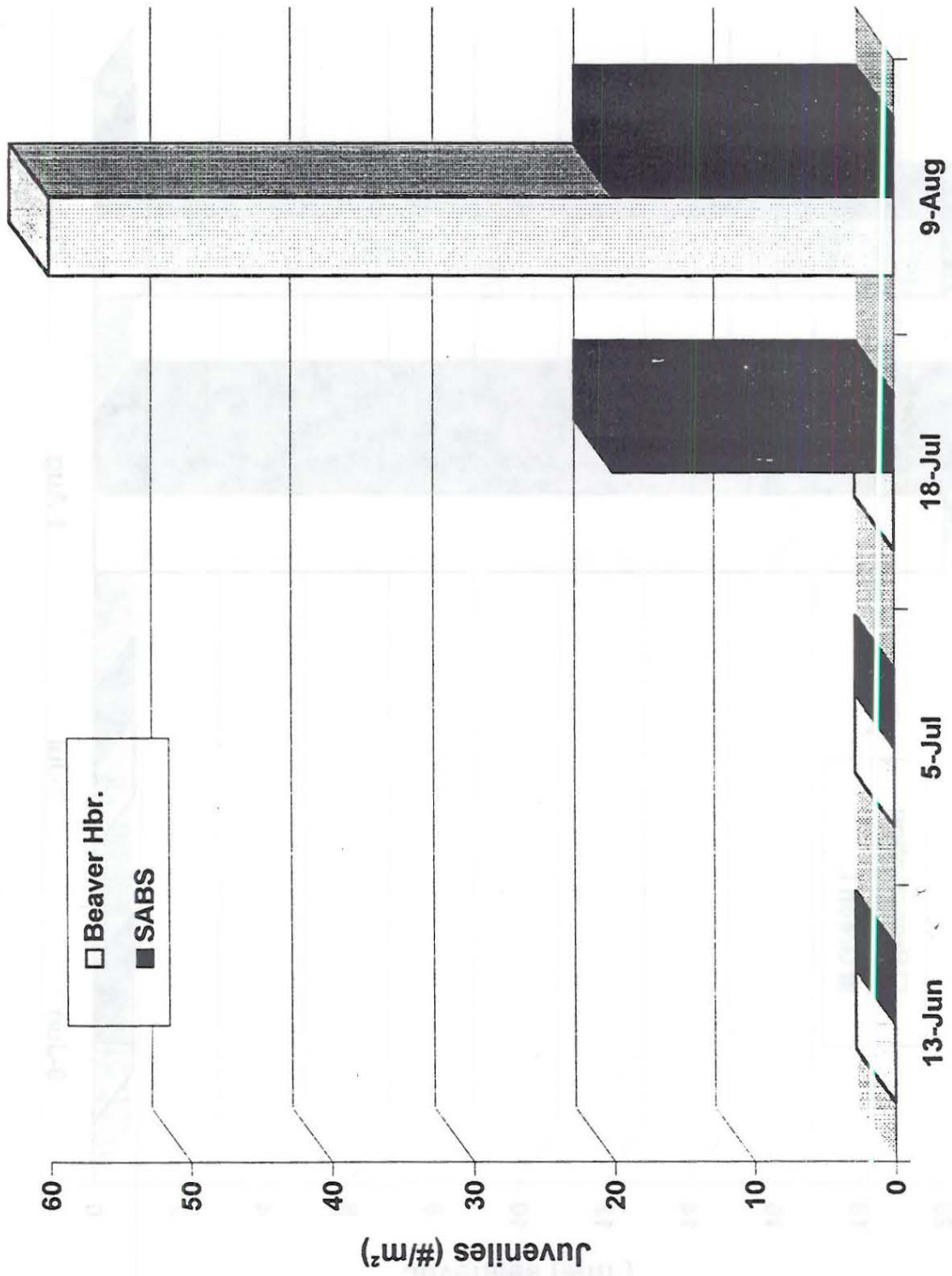


Fig. 10



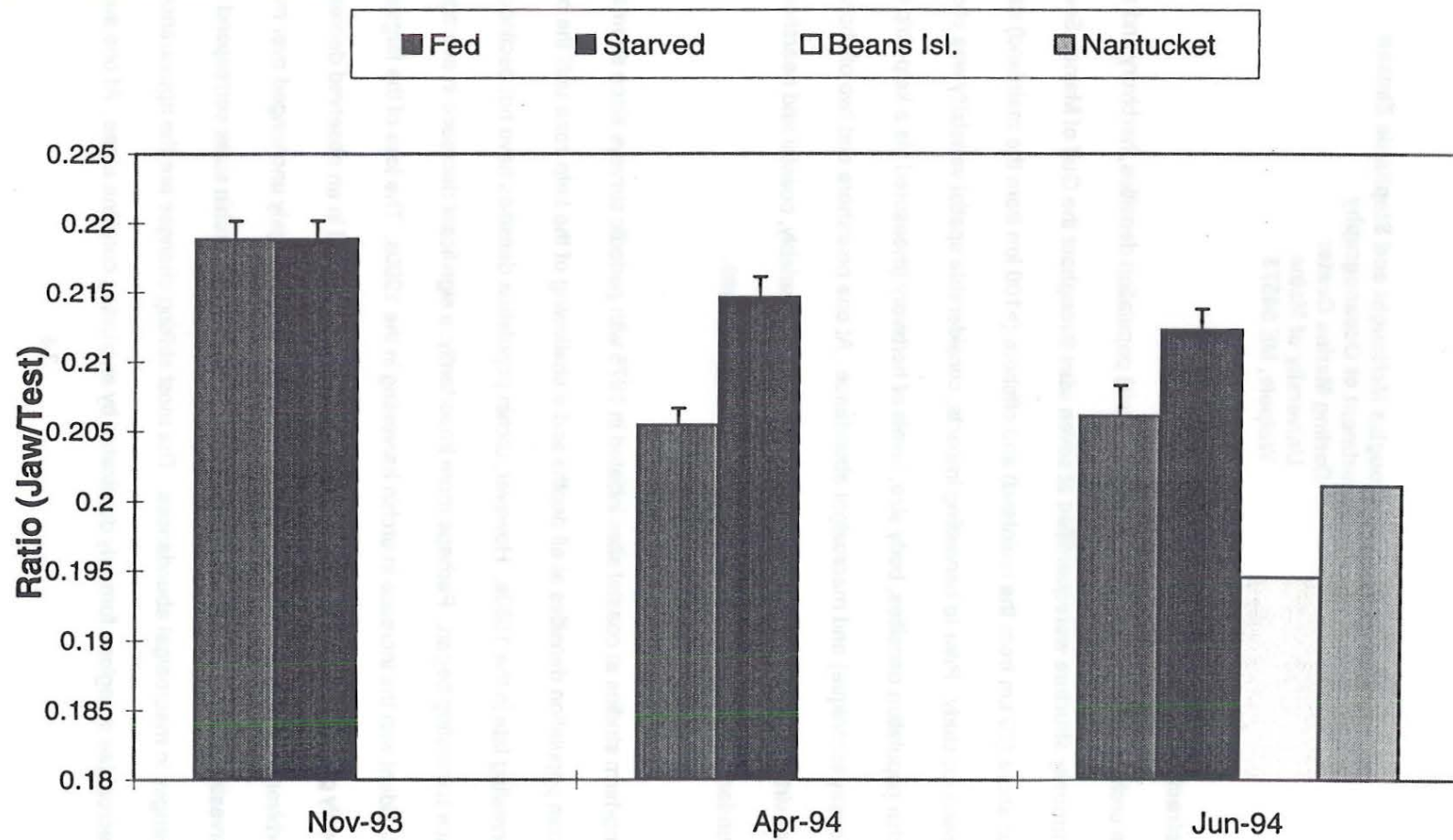


Fig. 11

**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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Abstract

Sea urchin (*Strongylocentrotus droebachiensis*) population densities, herbivory and algal community structure were quantified 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 since 1983) 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 Cashe's 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, Pemacuid 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 / m² in 1975 and 1984, to 62 / m² in 1985 and to a high of 133 / m² 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 / m²), 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 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 (≥ 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 ± 6.6 g wet weight/m² dropped significantly ($P < 0.001$) to 47.1 ± 4.9 g wet weight/m² 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 exist 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 concomitant 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

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

Fig. 2. Regional patterns of population density of three benthic forams (from Witman and Sebens 1992).

Fig. 3. Regional patterns of percent cover of macroalgae (from Witman and Sebens 1992).

Fig. 4. Regional patterns of macroalgal abundance as a function of water depth (from Witman and Sebens 1992).

Fig. 5. Map of study area showing depth contours.

Fig. 6. Regional patterns in the density of benthic forams, 1980.

Fig. 7. Regional patterns of rate of foraminiferal (benthic forams) density as a function of water depth, 1980.

Fig. 8. The correlation between the density of benthic forams and percent cover of macroalgae, 1980. The correlation is significant ($p < 0.05$).

Fig. 9. Regional patterns in the density of benthic forams (from Witman and Sebens 1992). The density of benthic forams is significantly correlated with percent cover of macroalgae ($p < 0.05$).

Fig. 10. Regional patterns in the density of benthic forams (from Witman and Sebens 1992). The density of benthic forams is significantly correlated with percent cover of macroalgae ($p < 0.05$).

Fig. 11. Comparison of population density of benthic forams in 1980 and 1990.

Fig. 12. Temporal trends in macroalgal abundance (from Witman and Sebens 1992).

Fig. 13. Temporal trends in macroalgal abundance (from Witman and Sebens 1992). The density of macroalgae is significantly correlated with percent cover of macroalgae ($p < 0.05$).

Fig. 14. Temporal trends in macroalgal abundance (from Witman and Sebens 1992). The density of macroalgae is significantly correlated with percent cover of macroalgae ($p < 0.05$).

Fig. 15. Temporal trends in macroalgal abundance (from Witman and Sebens 1992). The density of macroalgae is significantly correlated with percent cover of macroalgae ($p < 0.05$).

Fig. 16. Temporal trends in macroalgal abundance (from Witman and Sebens 1992). The density of macroalgae is significantly correlated with percent cover of macroalgae ($p < 0.05$).

Fig. 17. Temporal trends in macroalgal abundance (from Witman and Sebens 1992). The density of macroalgae is significantly correlated with percent cover of macroalgae ($p < 0.05$).

Fig. 18. Temporal trends in macroalgal abundance (from Witman and Sebens 1992). The density of macroalgae is significantly correlated with percent cover of macroalgae ($p < 0.05$).

Fig. 19. Temporal trends in macroalgal abundance (from Witman and Sebens 1992). The density of macroalgae is significantly correlated with percent cover of macroalgae ($p < 0.05$).

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 percent 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 m³ 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

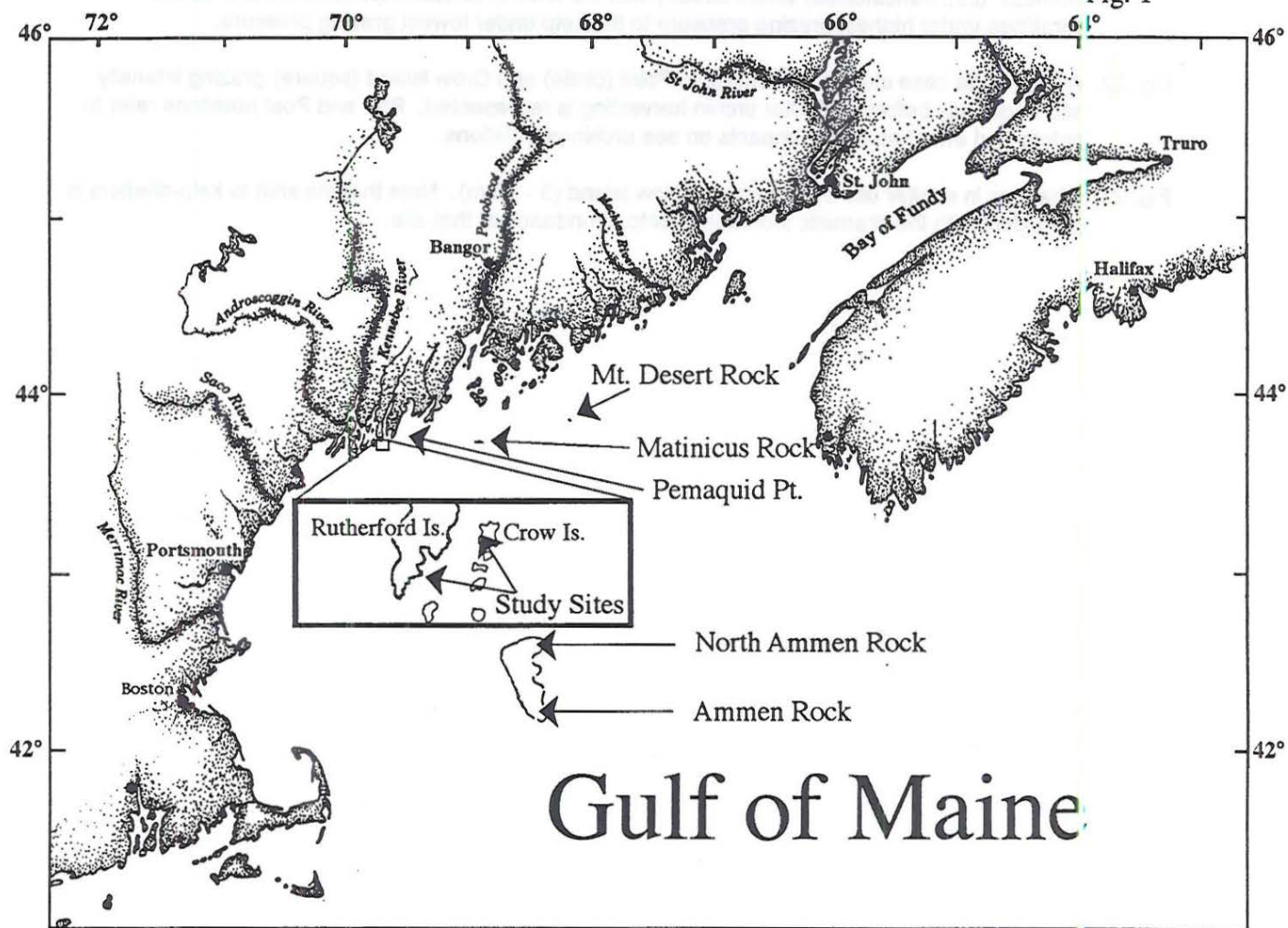


Fig. 2

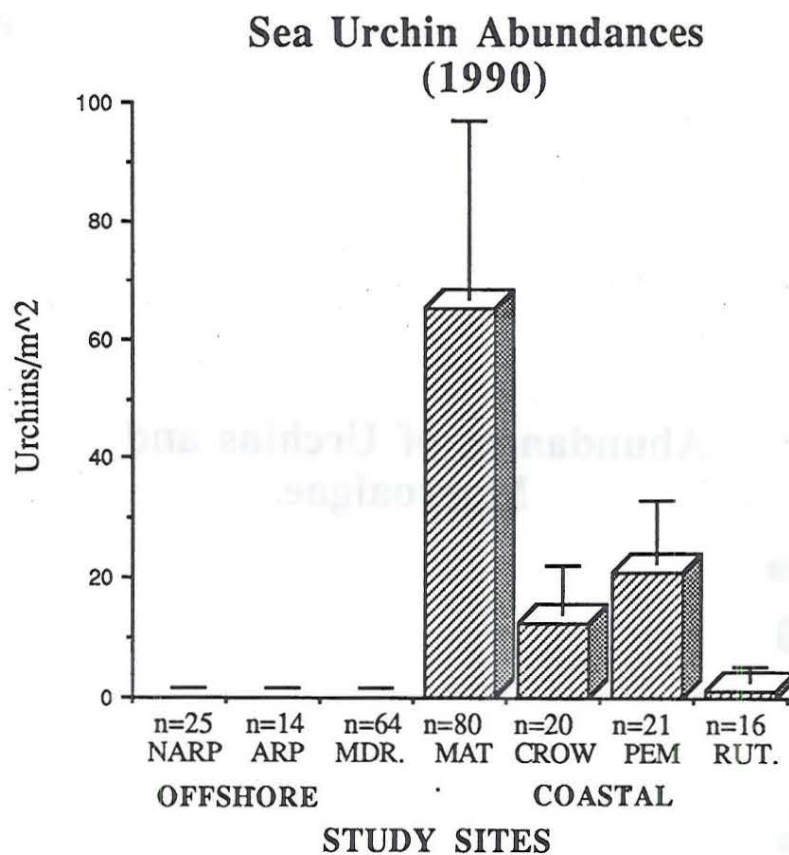


Fig. 3

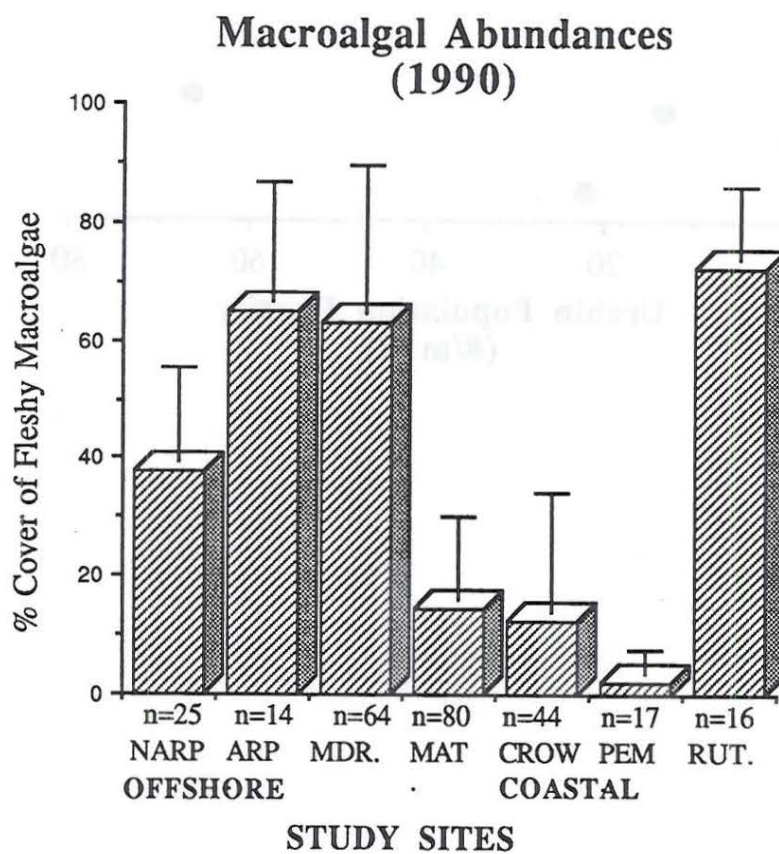


Fig. 4

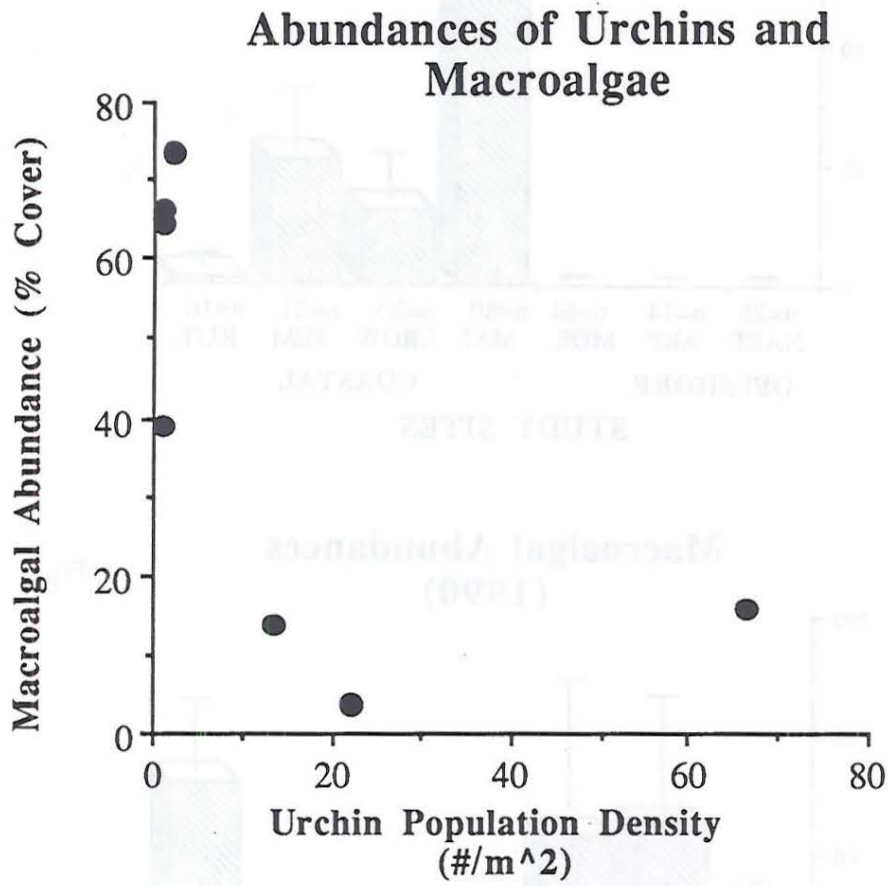


Fig. 5.

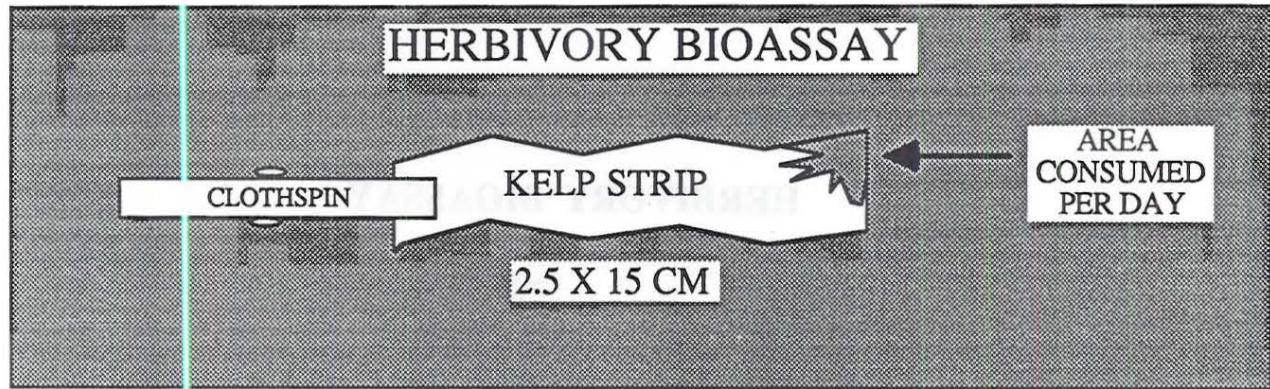


Fig. 6

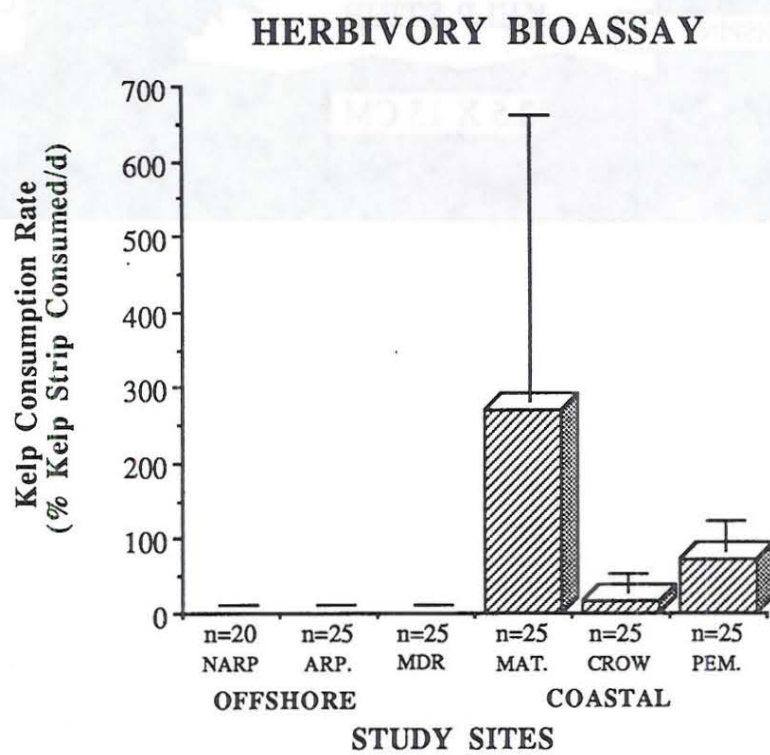


Fig. 7

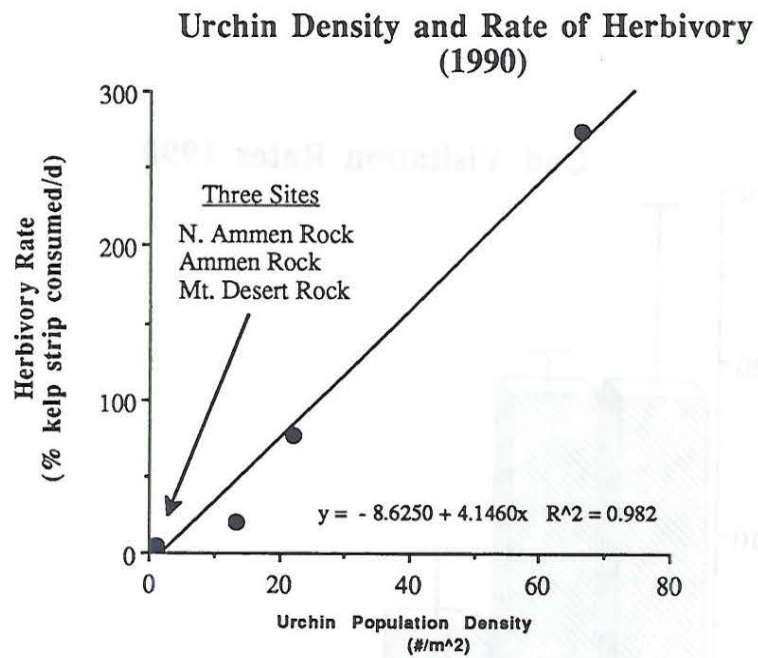


Fig. 8

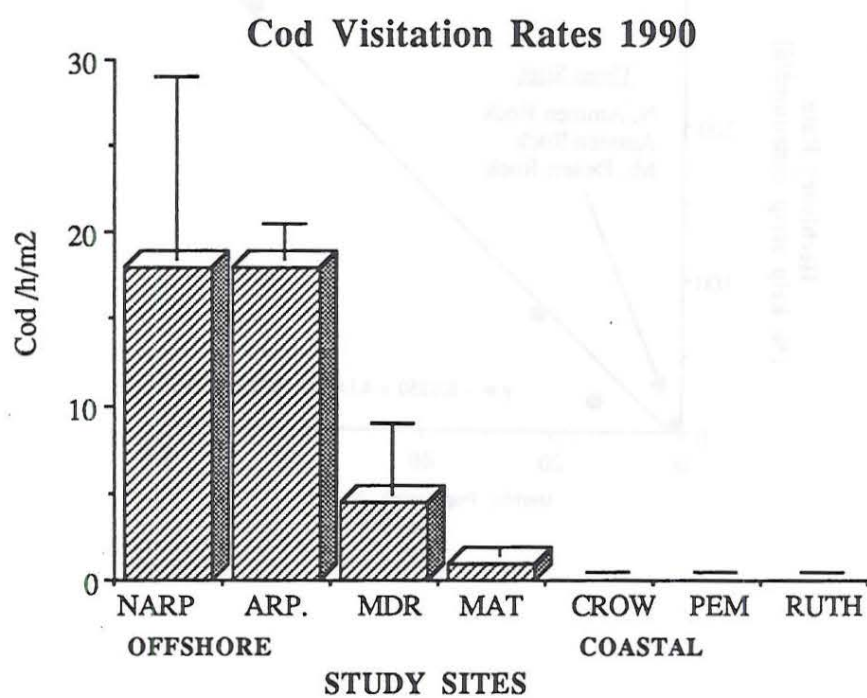
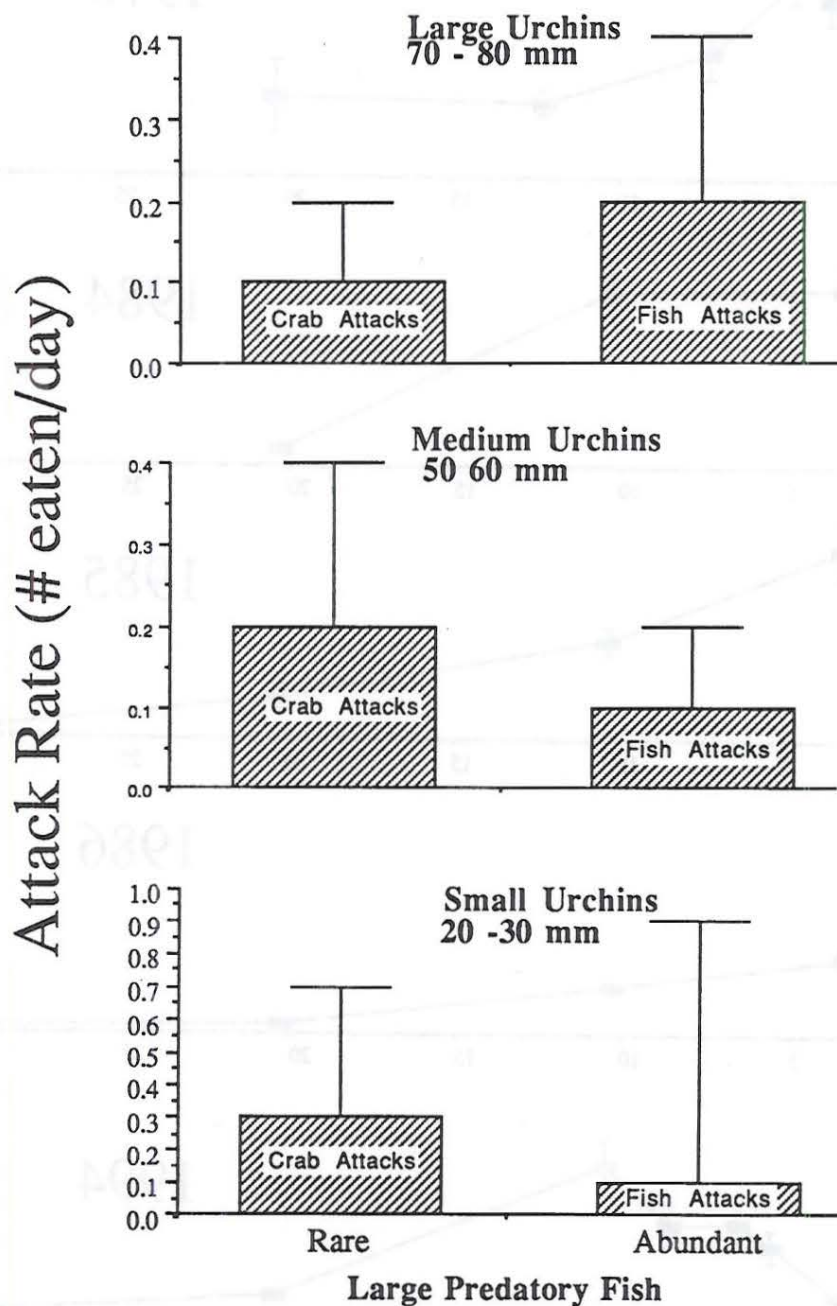


Fig. 9

Predation on Urchins



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

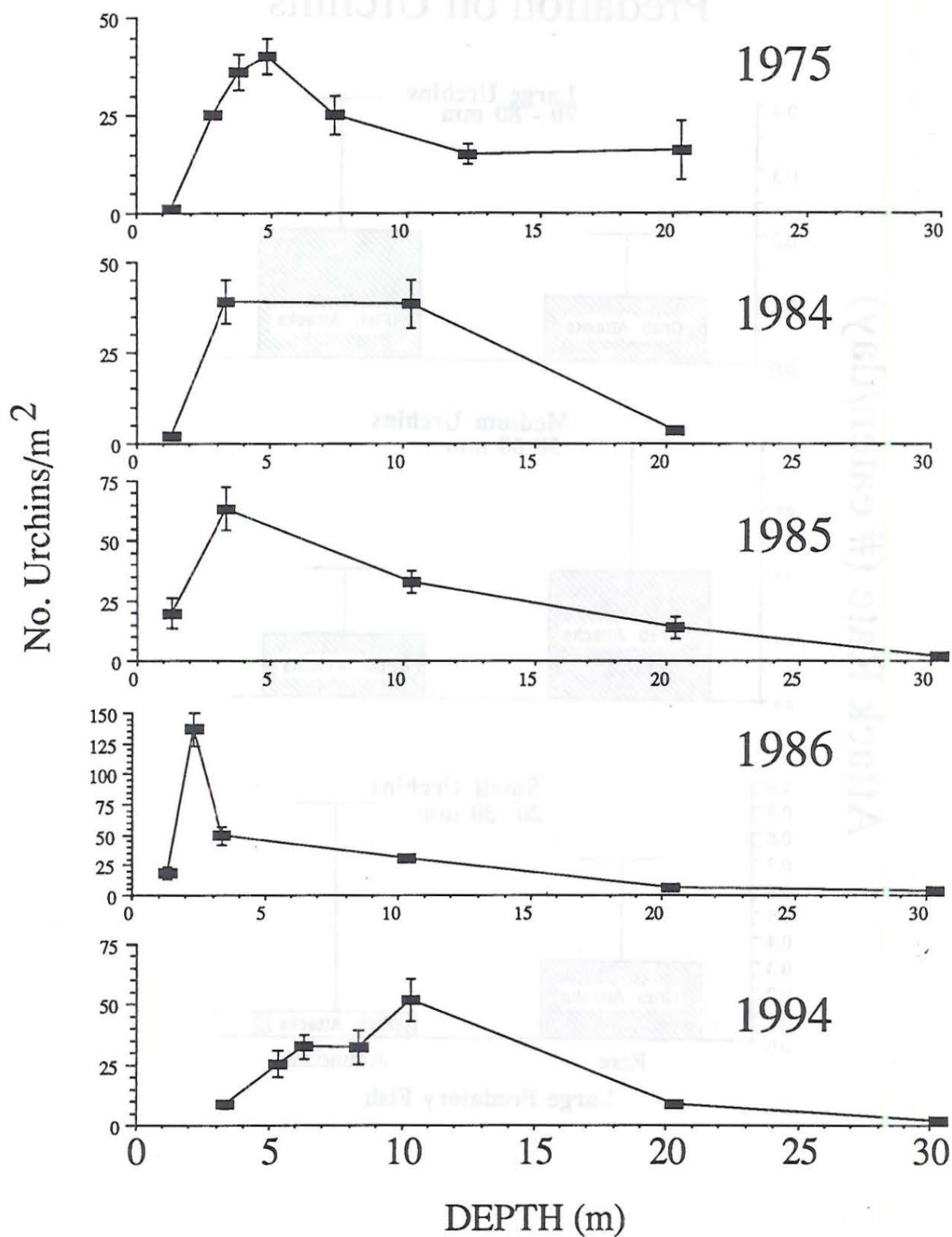
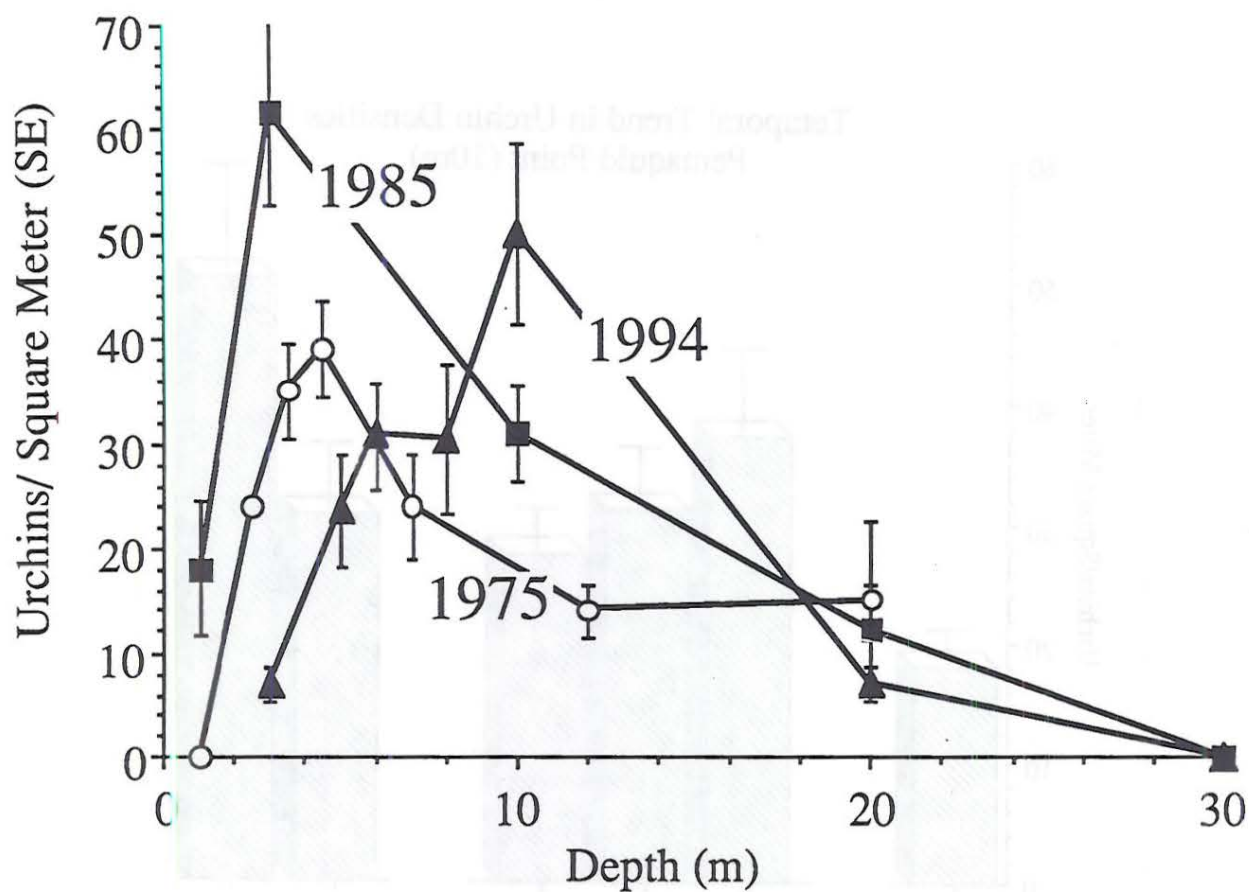


Fig. 11

Temporal and Depth Trends in Urchin Density at Pemaquid Point



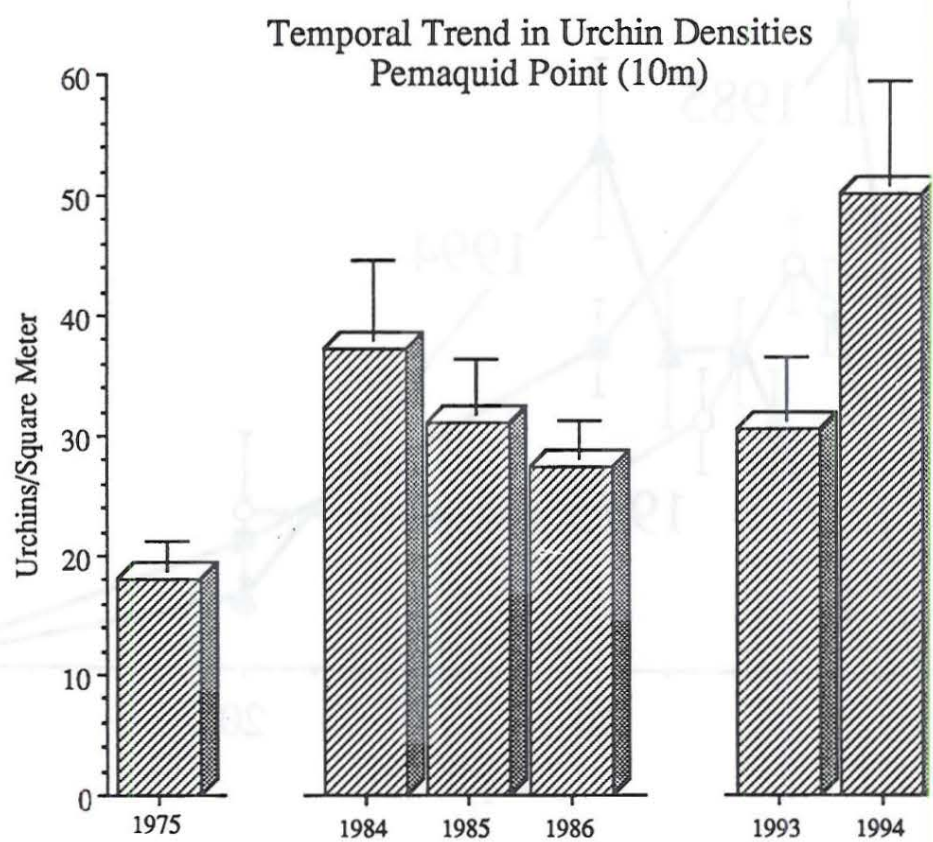


Fig. 13

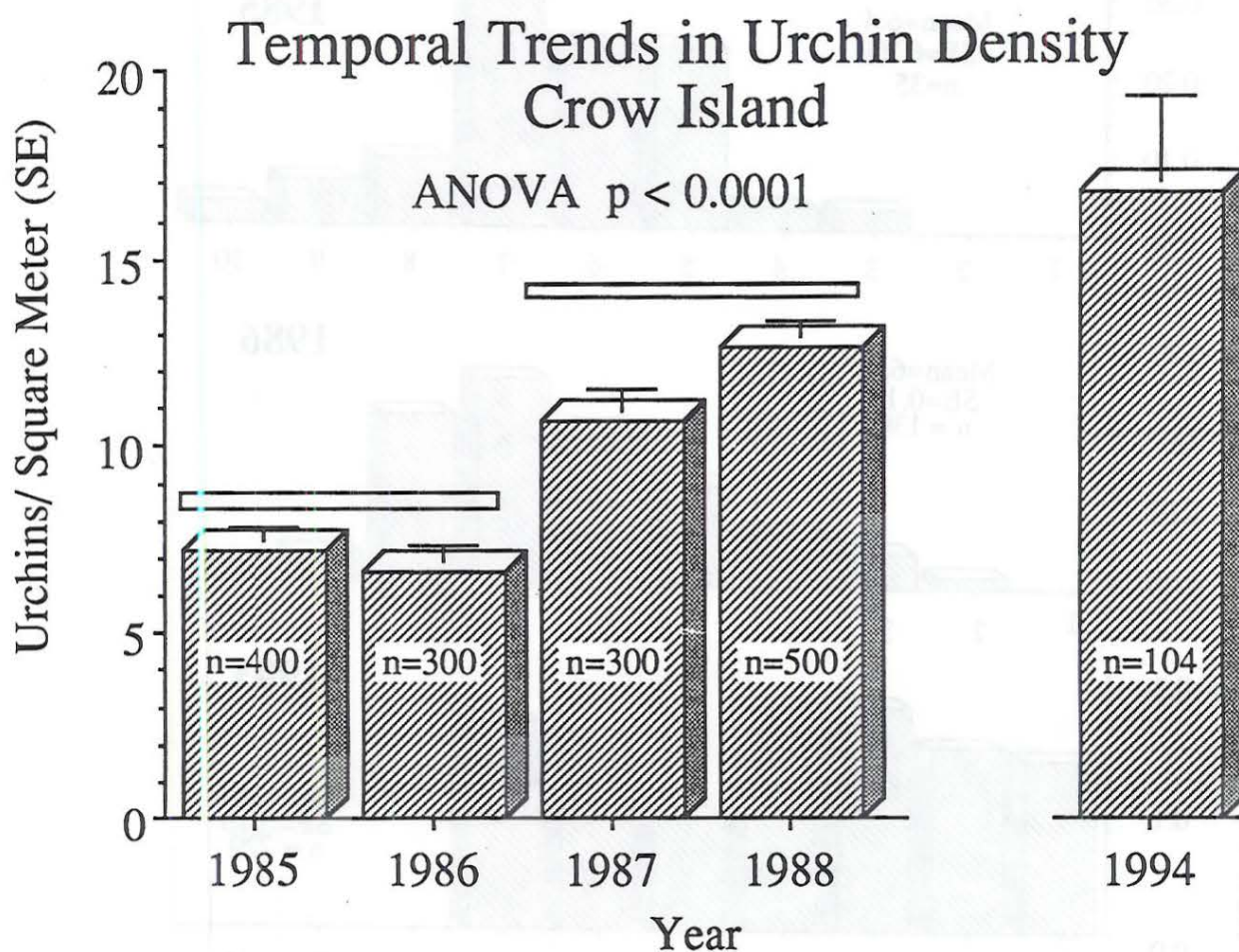


Fig. 14

Temporal Trends in Size-Frequency of Urchins at Pemaquid Point, Maine

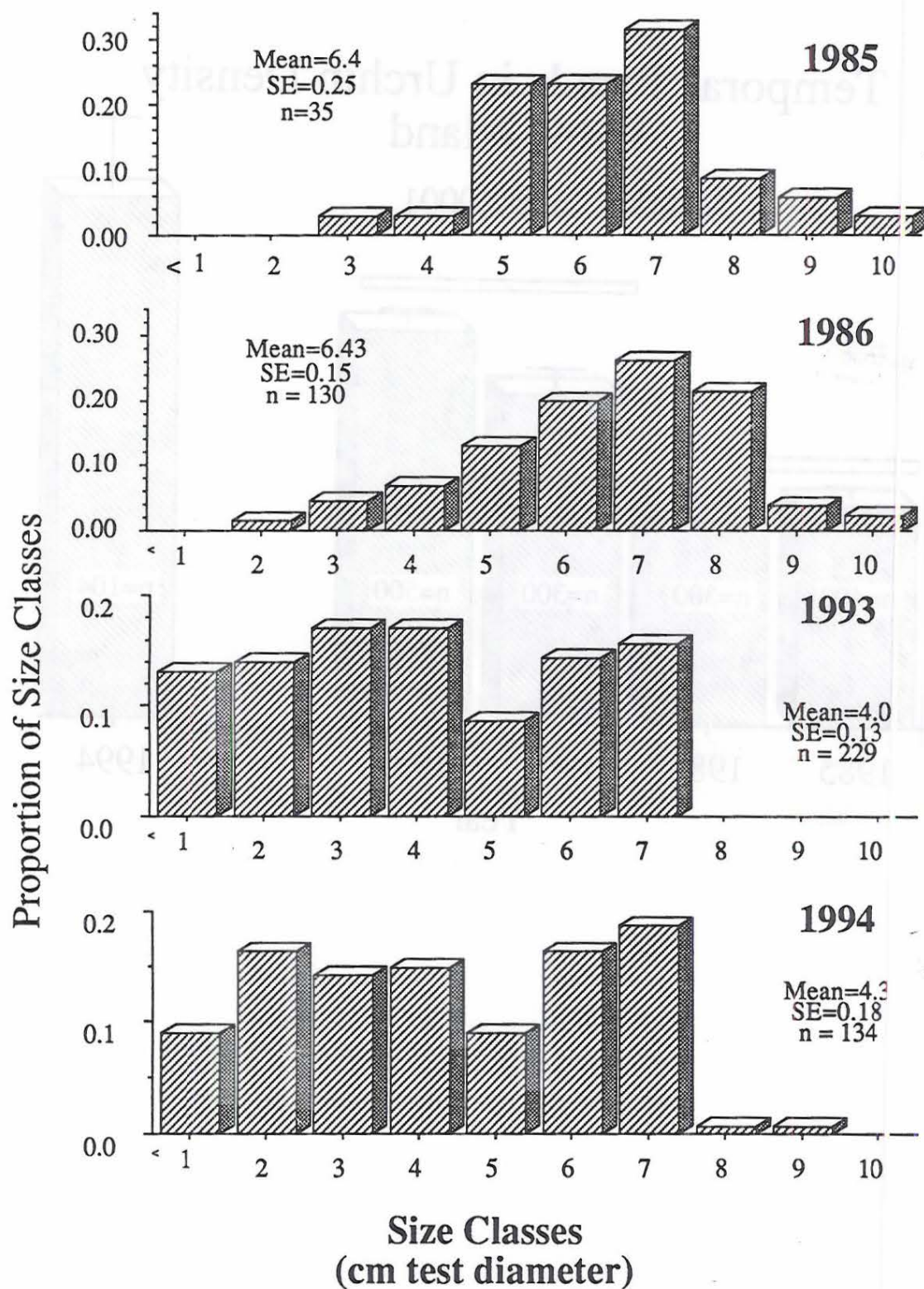


Fig. 15

Temporal Trends in Size-Frequency of Urchins Crow Island

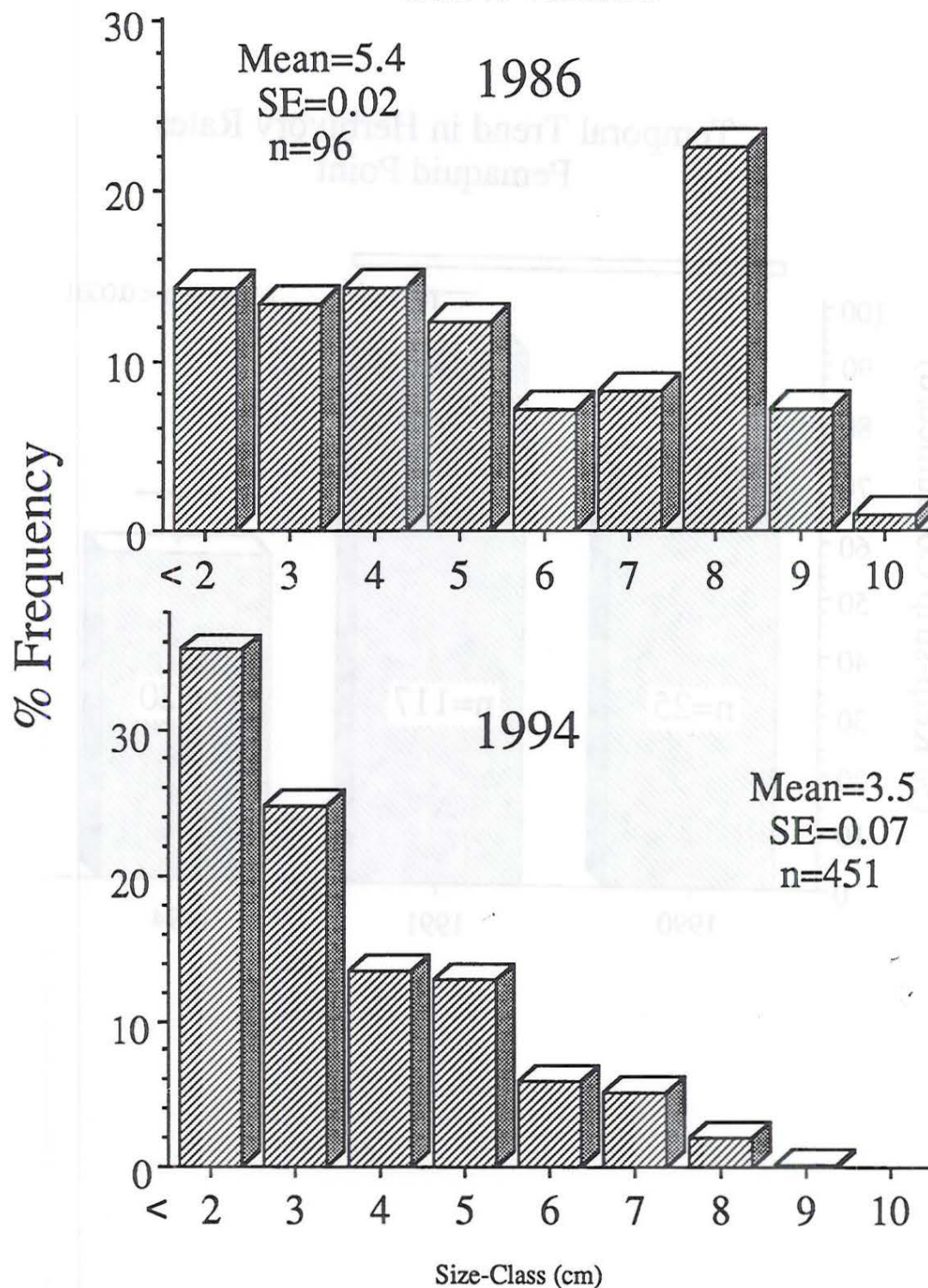
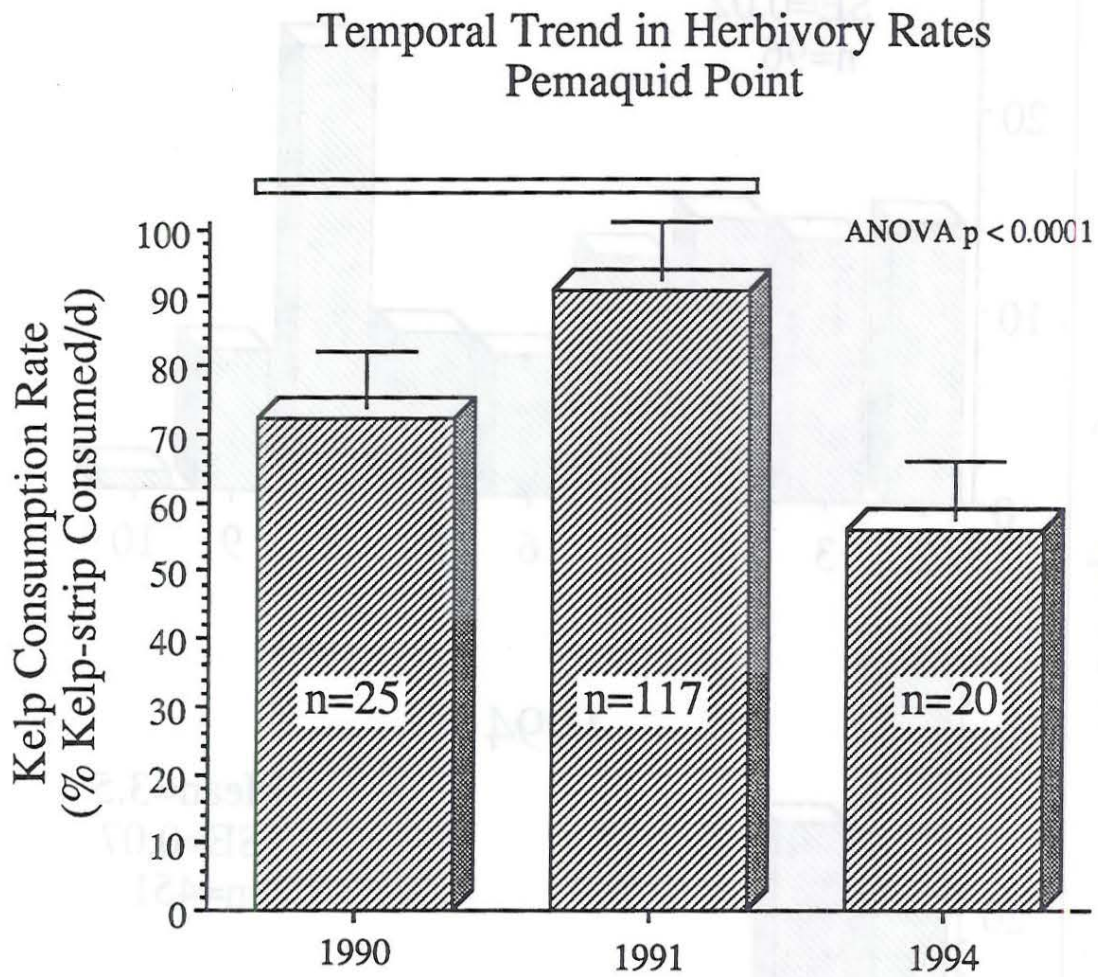
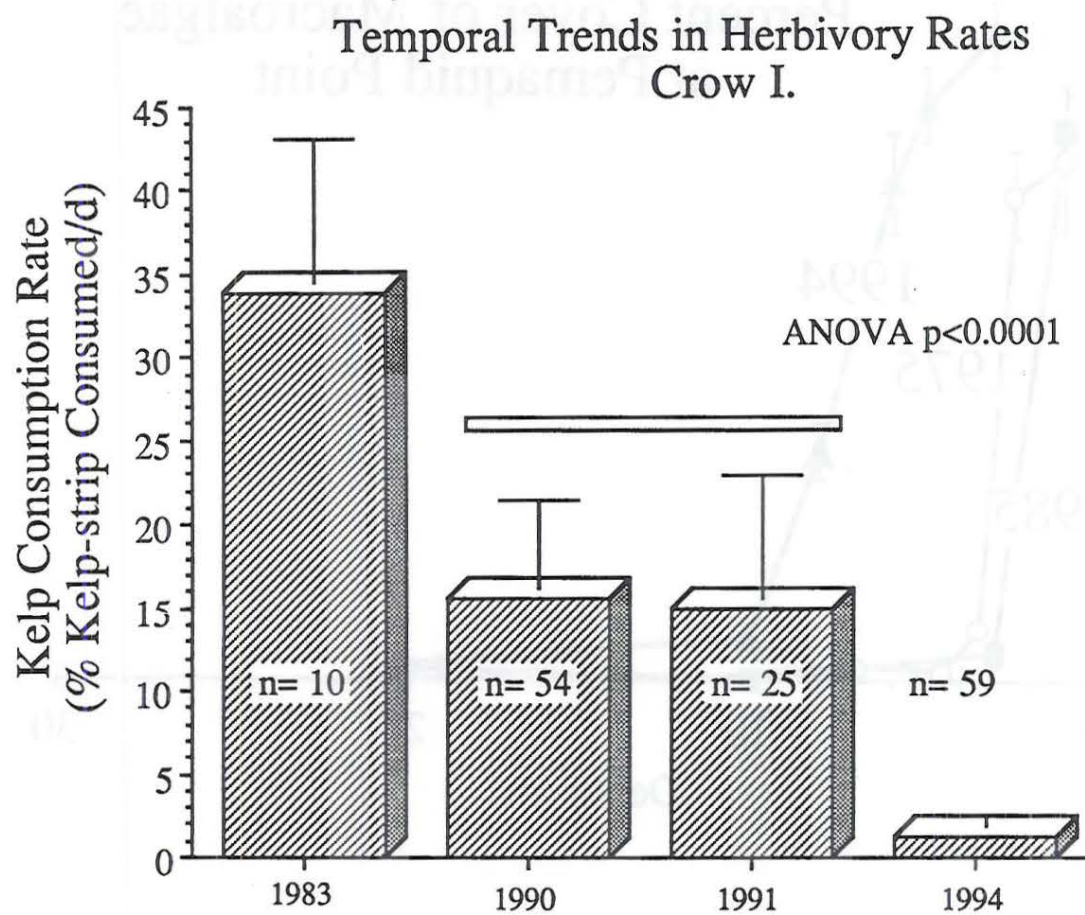


Fig. 16





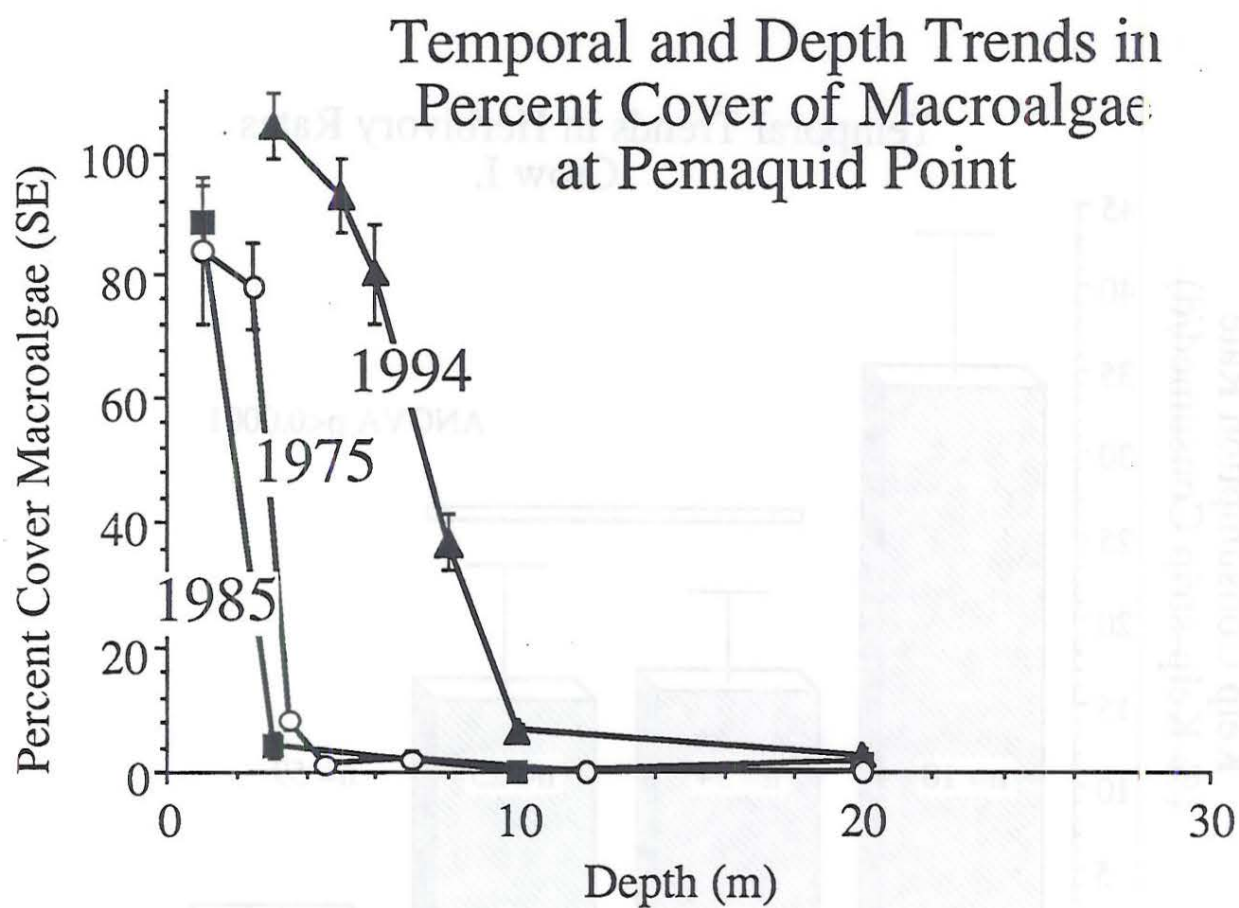


Fig. 19

Temporal Trend in Macroalgal Abundance Pemaquid (5-10 m)

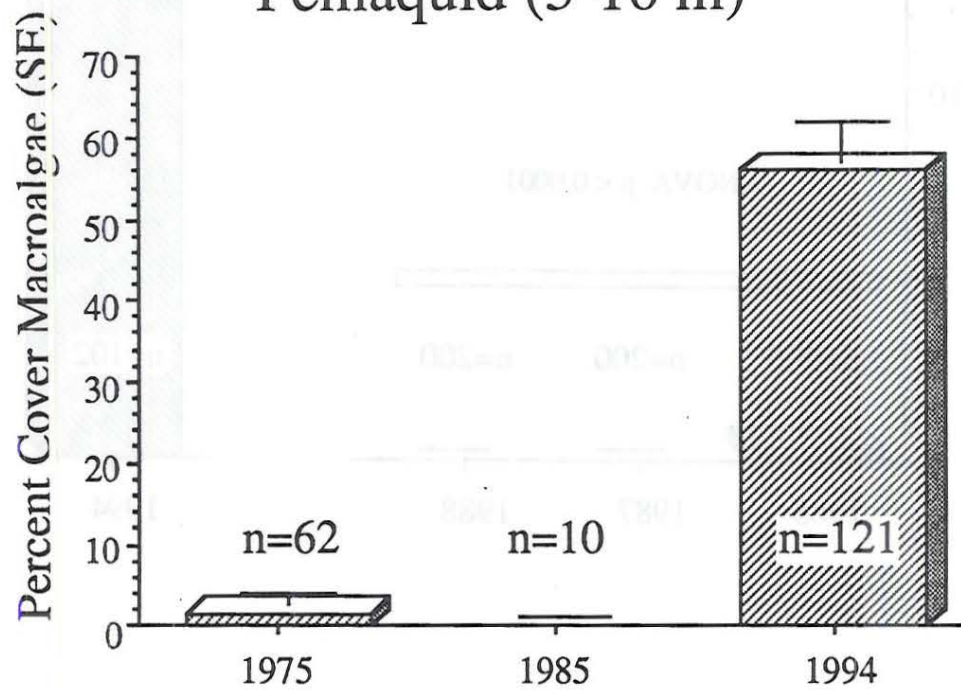


Fig. 2)

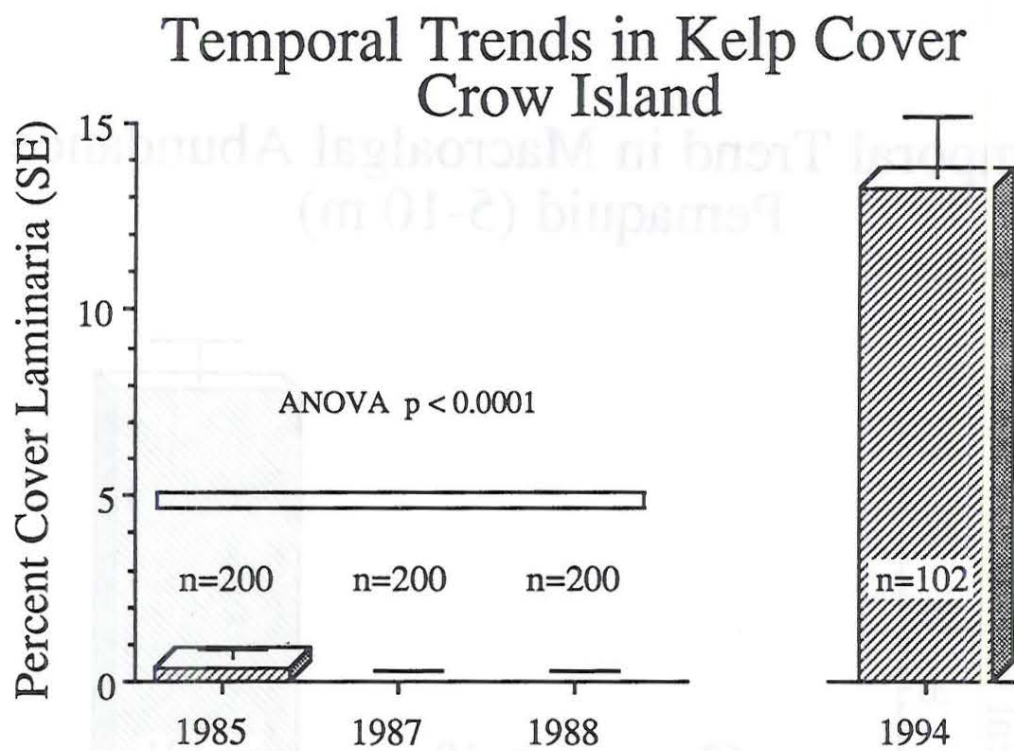
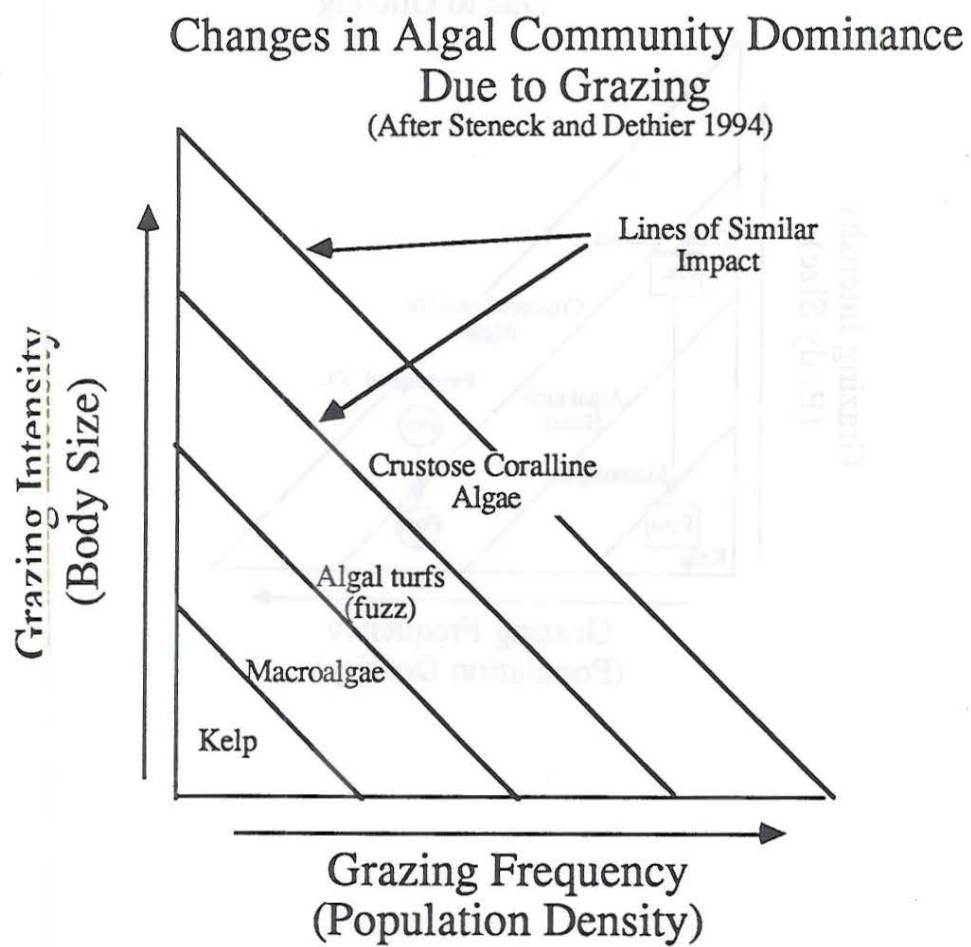


Fig. 21



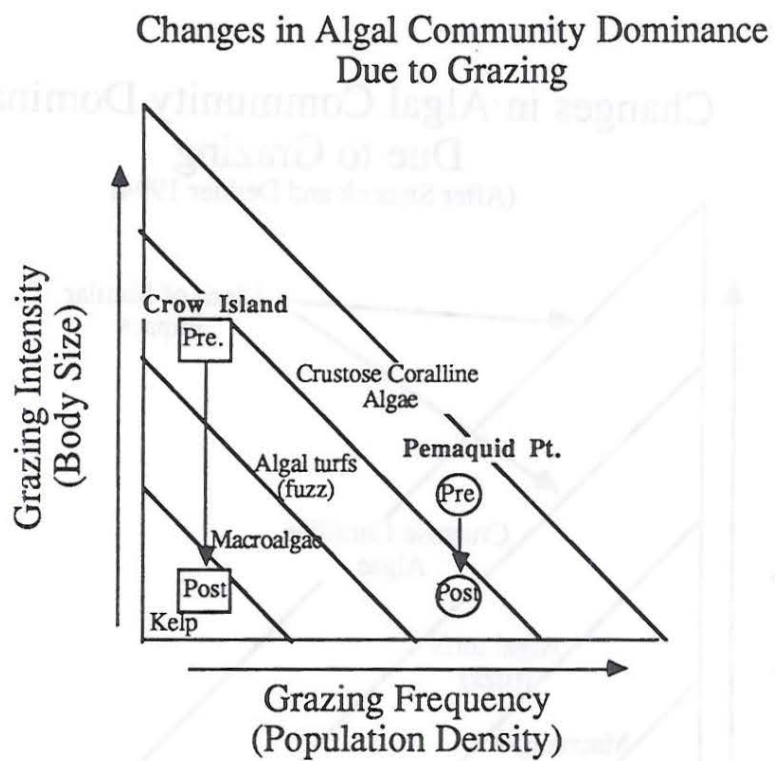
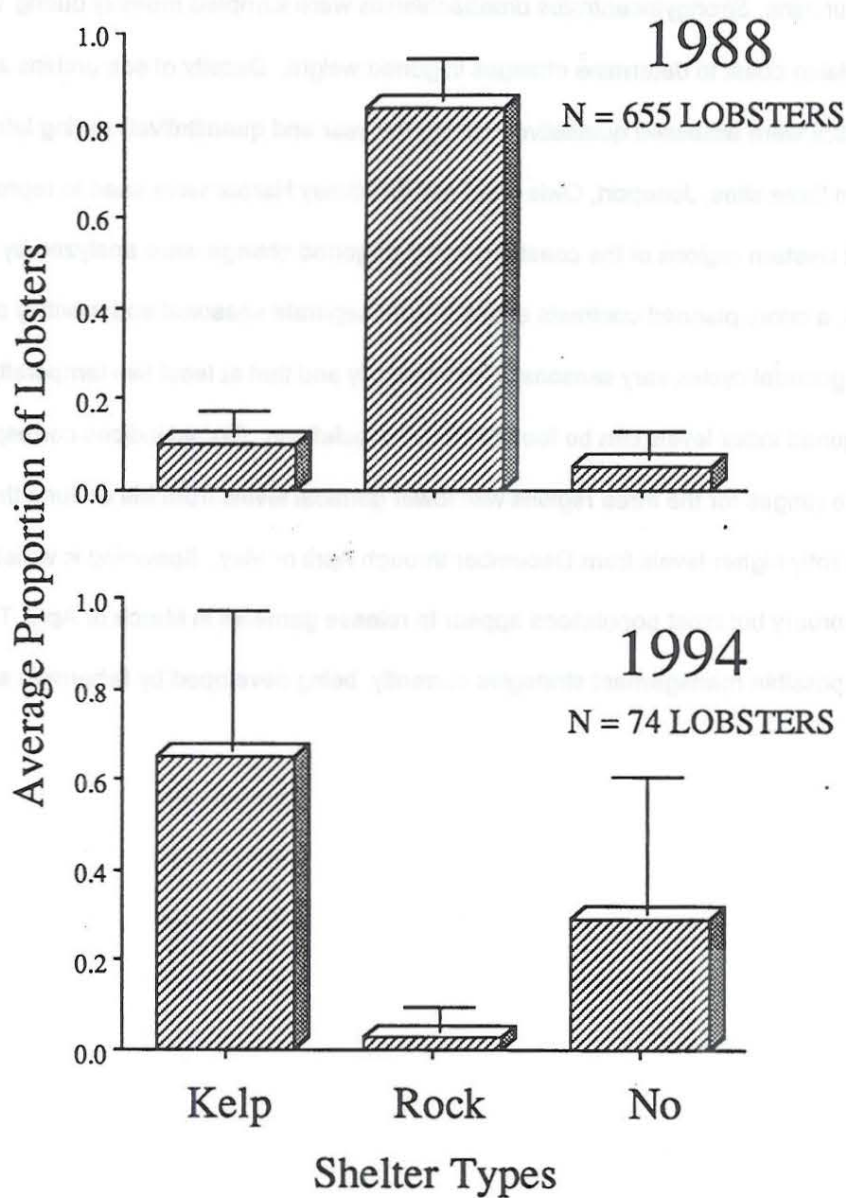


Fig. 23

LOBSTER SHELTER USE



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

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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 used 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 May 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 and diet on settlement, recruitment and growth of the green sea urchin *Strongylocentrotus 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 Gerham, 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 flocculent 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; Wilman, 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 newly 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

This report would not have been possible without the major effort of Charles Chester and numerous undergraduates. Jay Gingrich and Robert Bryant have been important collaborators and sources of information about the practical aspects of the fishery and urchin populations. Much of the

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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.

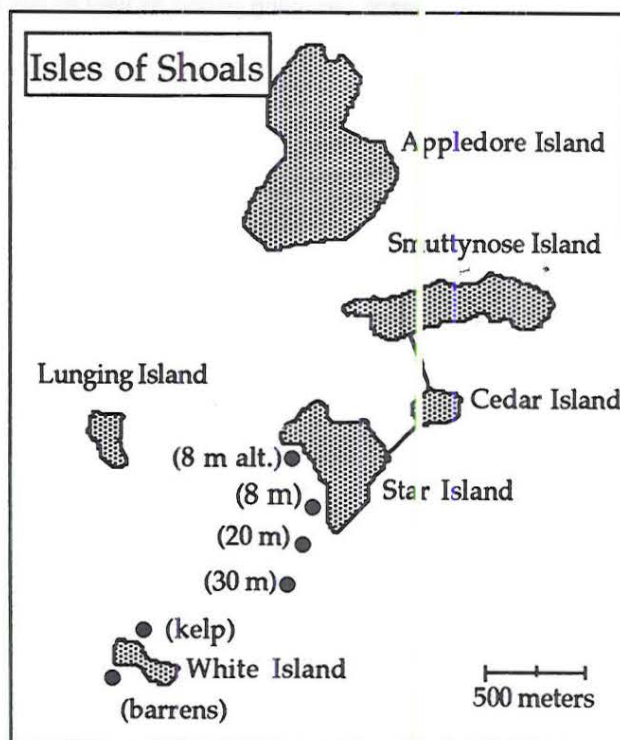
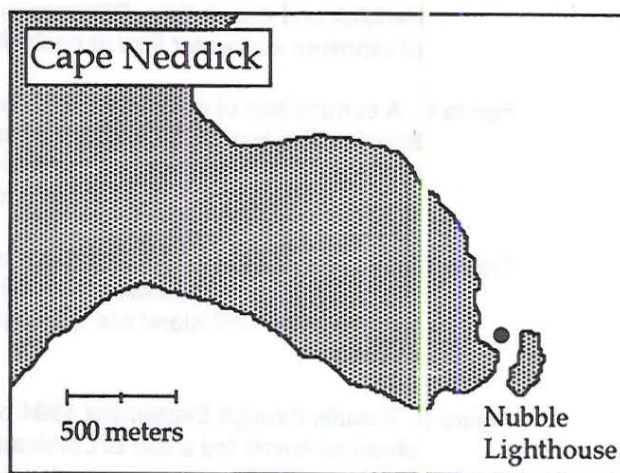
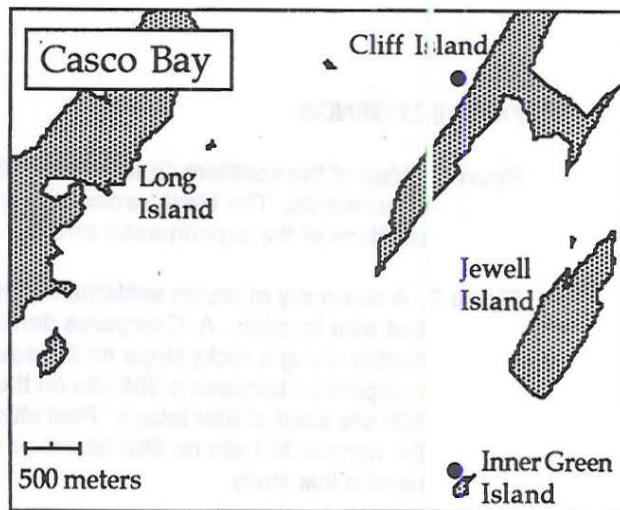
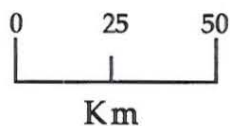
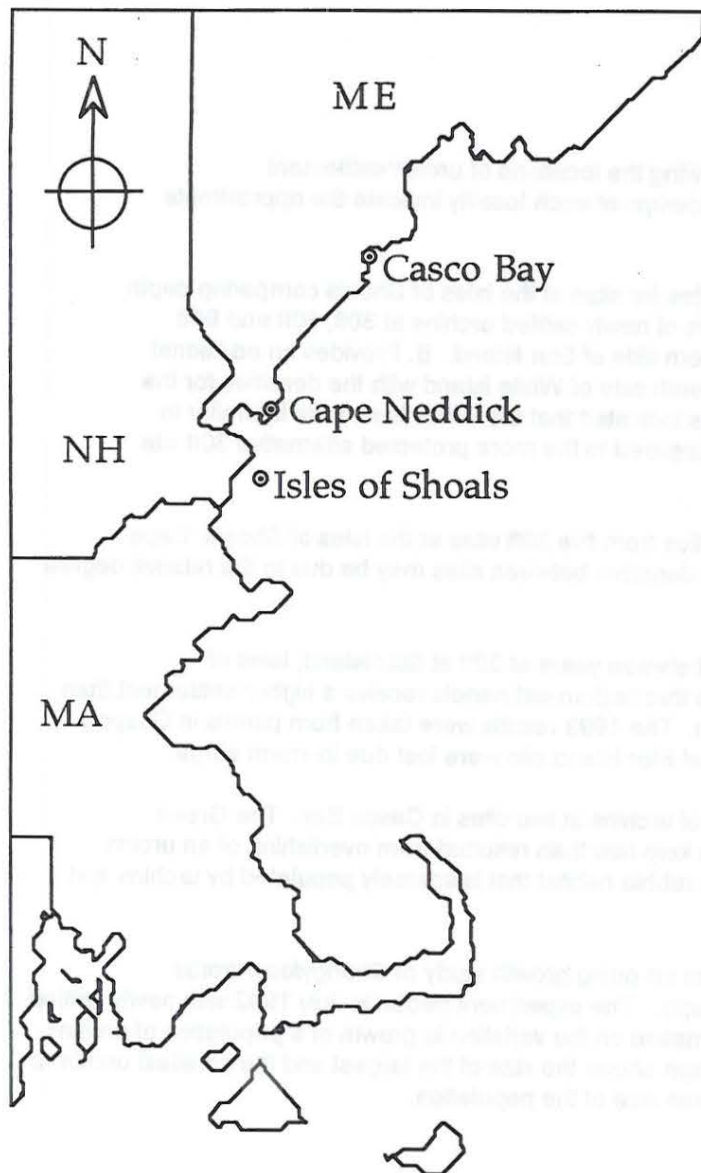
Figure 3. A summary of urchin settlement densities from five 30ft sites at the Isles of Shoals, Cape Neddick and Casco Bay. Differences in densities between sites may be due to the relative degree of exposure and water flow at each site

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.

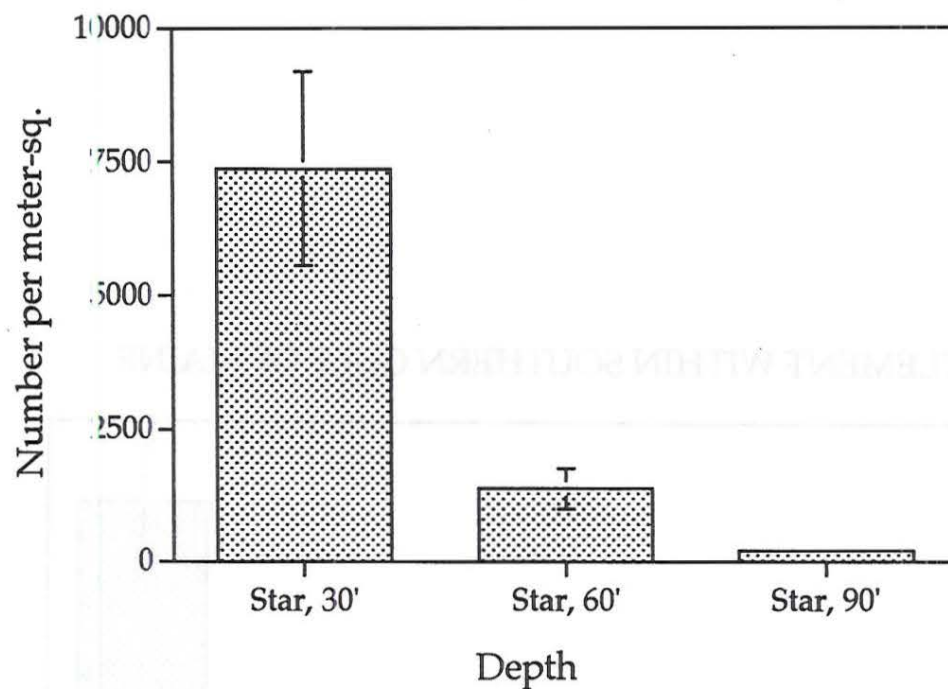
Figure 5. A comparison of settlement densities of urchins at two sites in Casco Bay. The Green Island site is more exposed and within a kelp bed than resulted from overfishing of an urchin barrens. The Cliff Island site is in a silty rubble habitat that is sparsely populated by urchins and algae.

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.

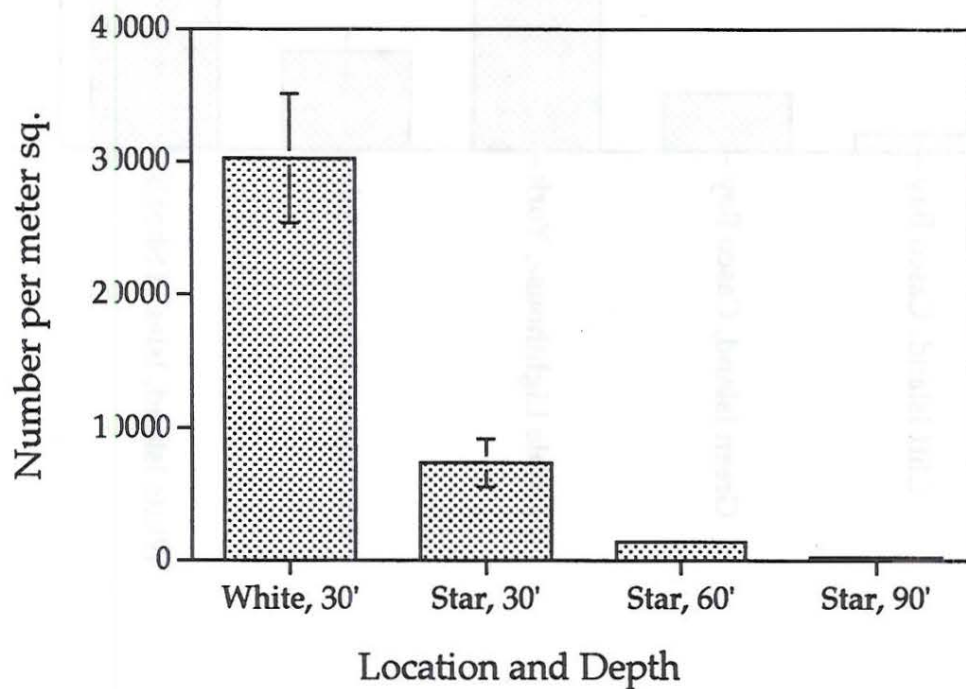
Fig 1



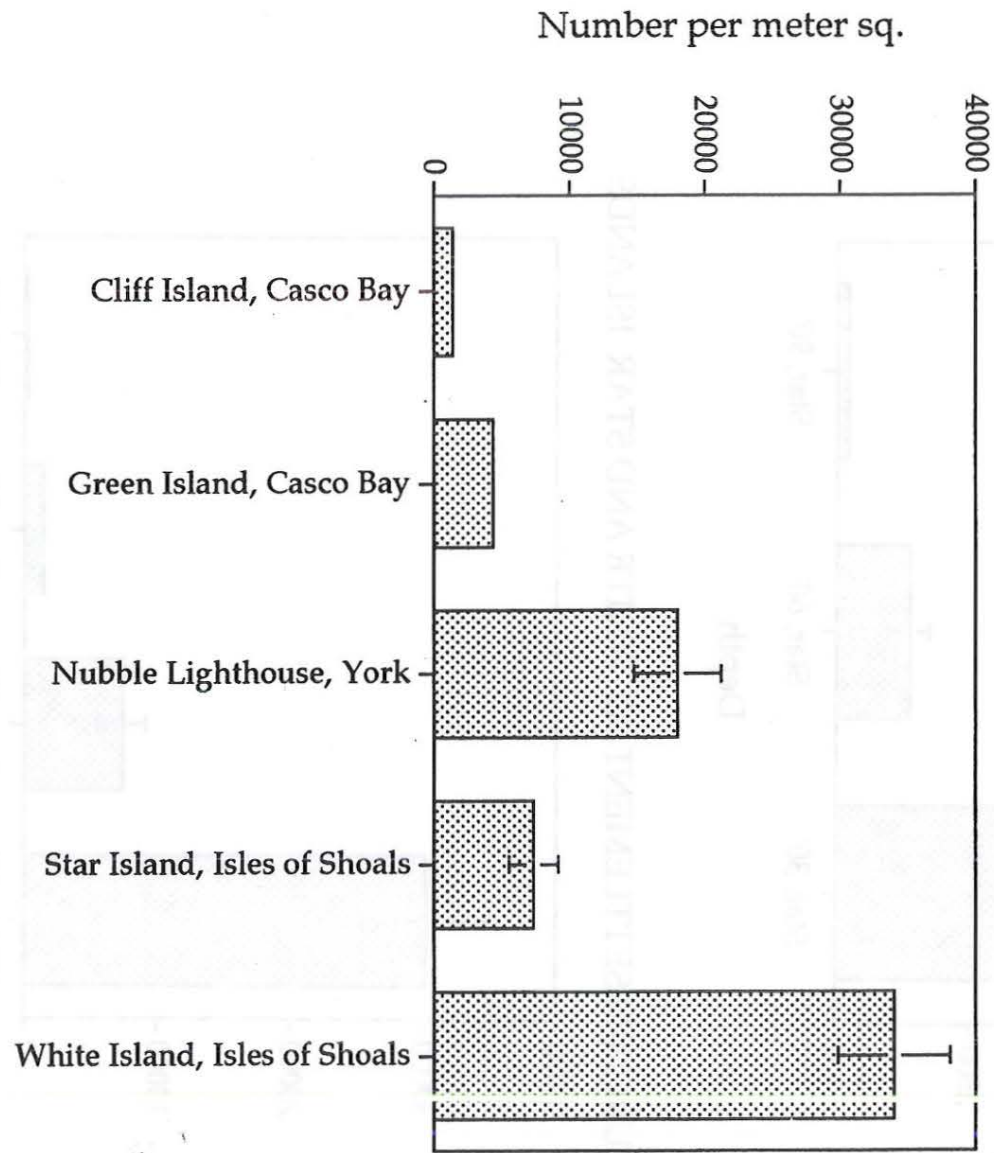
A. COMPARISON OF SETTLEMENT BY DEPTH



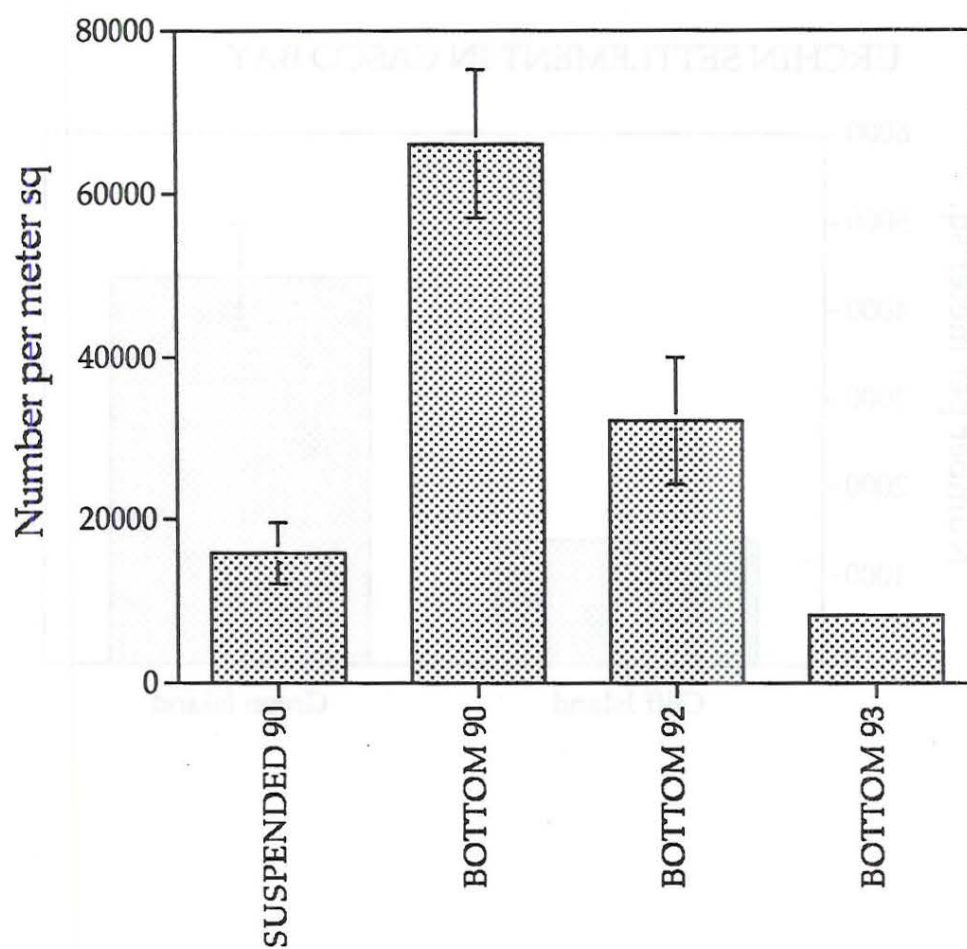
B. URCHIN SETTLEMENT AT WHITE AND STAR ISLANDS



URCHIN SETTLEMENT WITHIN SOUTHERN GULF OF MAINE

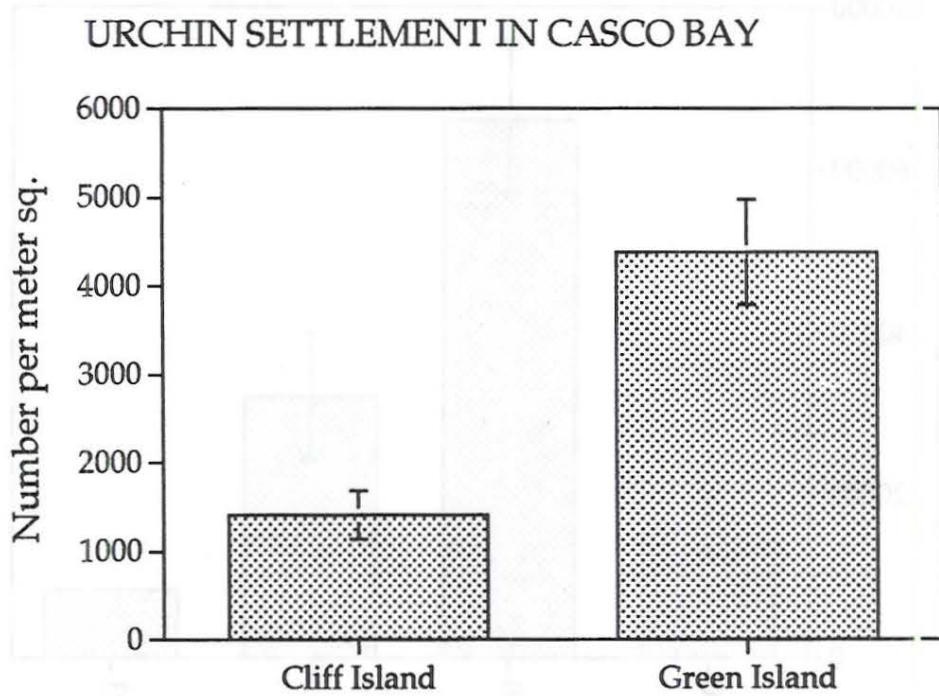


COMPARISON OF SETTLEMENT BY POSITION AND YEAR

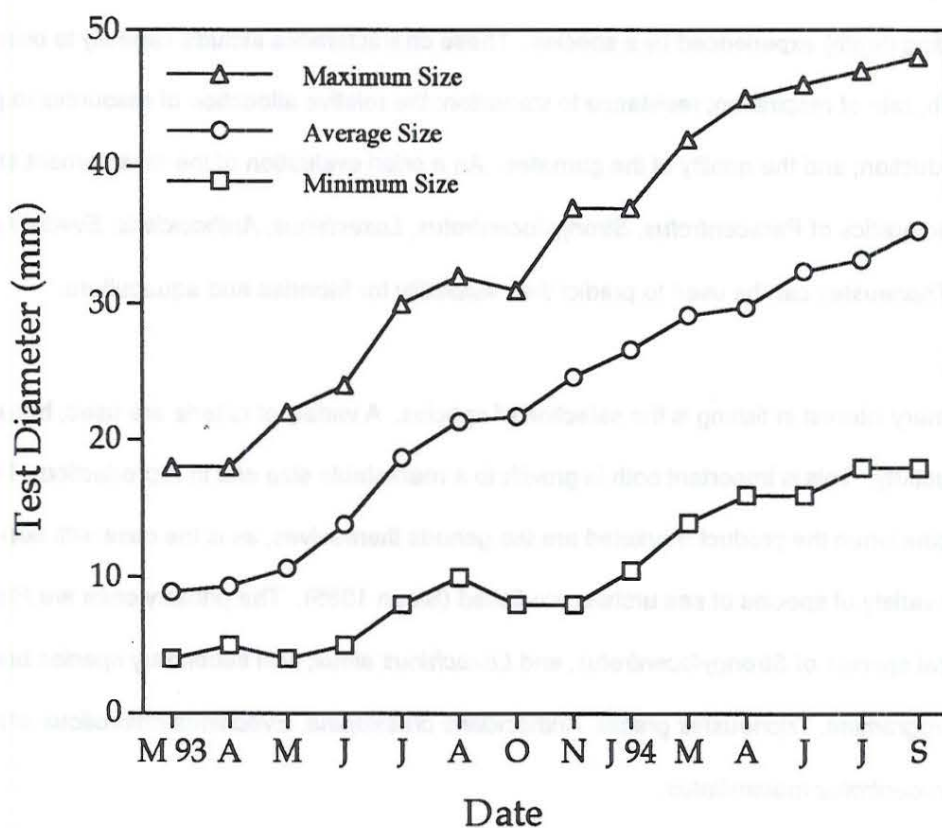


Position Relative to Bottom and Year

Fig 5



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*, *Anthocardis*, *Evechinus*, *Heliocardis*, 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 *Heliocardis erythrogramma*, *Tripneustes gratilla*, *Anthocardis 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 *Eucidaris 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, *Triptena 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)	
<i>Heterocentrotus trigonarius</i>	0.971
<i>Echinometra oblonga</i> *	0.649, 0.686, 0.868
<i>Heliocidaris erythrogramma</i> *	0.964, 0.964
<i>Tripneustes gratilla</i> *	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		
<i>Eucidaris tribuloides</i>	0.67	0.43
Toxopneustidae		
<i>Lytechinus variegatus</i>	0.95	
<i>Tripneustes ventricosus</i>	1.24	0.95
Strongylocentrotidae		
<i>Strongylocentrotus droebachiensis</i>	0.66	
<i>Strongylocentrotus franciscanus</i>	0.26	
<i>Strongylocentrotus intermedius</i>	0.33	
<i>Strongylocentrotus nudus</i>	0.36	
<i>Strongylocentrotus purpuratus</i>	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
<i>S. franciscanus</i>	125	Bernard & Miller 1973, Kramer & Nordin 1975 Tegner & Levin 1983
<i>S. intermedius</i>	35	Fuji 1967
<i>S. purpuratus</i>	40-50	Gonor 1972
<i>S. droebachiensis</i>	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 production	good	poor	good	poor	good
Feeding behavior	semi-passive foraging	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	reproduction, somatic growth
"Strategy type"	"C"	"S"	"R"	"S"	"SC"/"RC"
Population type	Flock of gluttons	Crowd of hungry 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 m² 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 complete 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 through 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

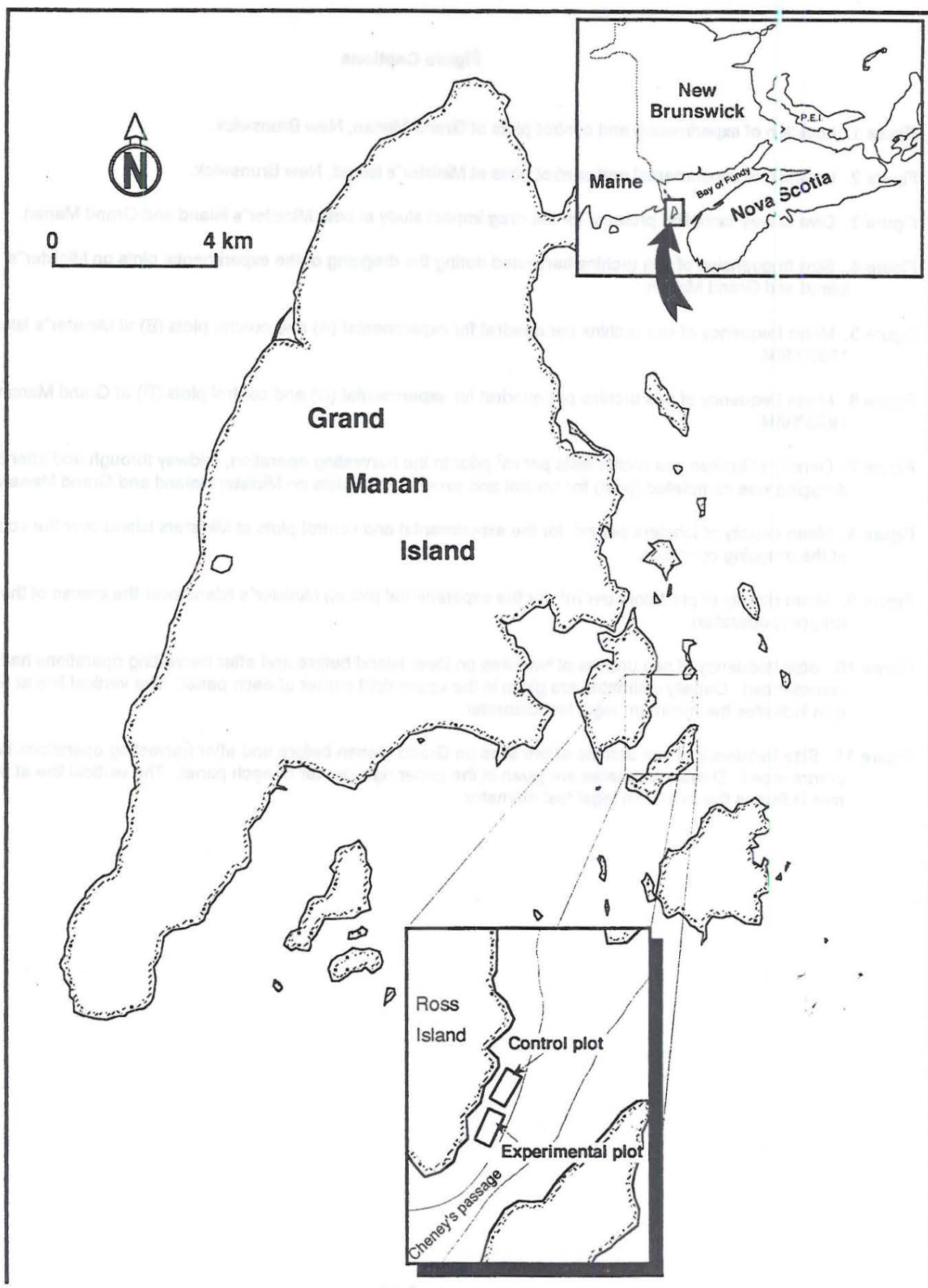
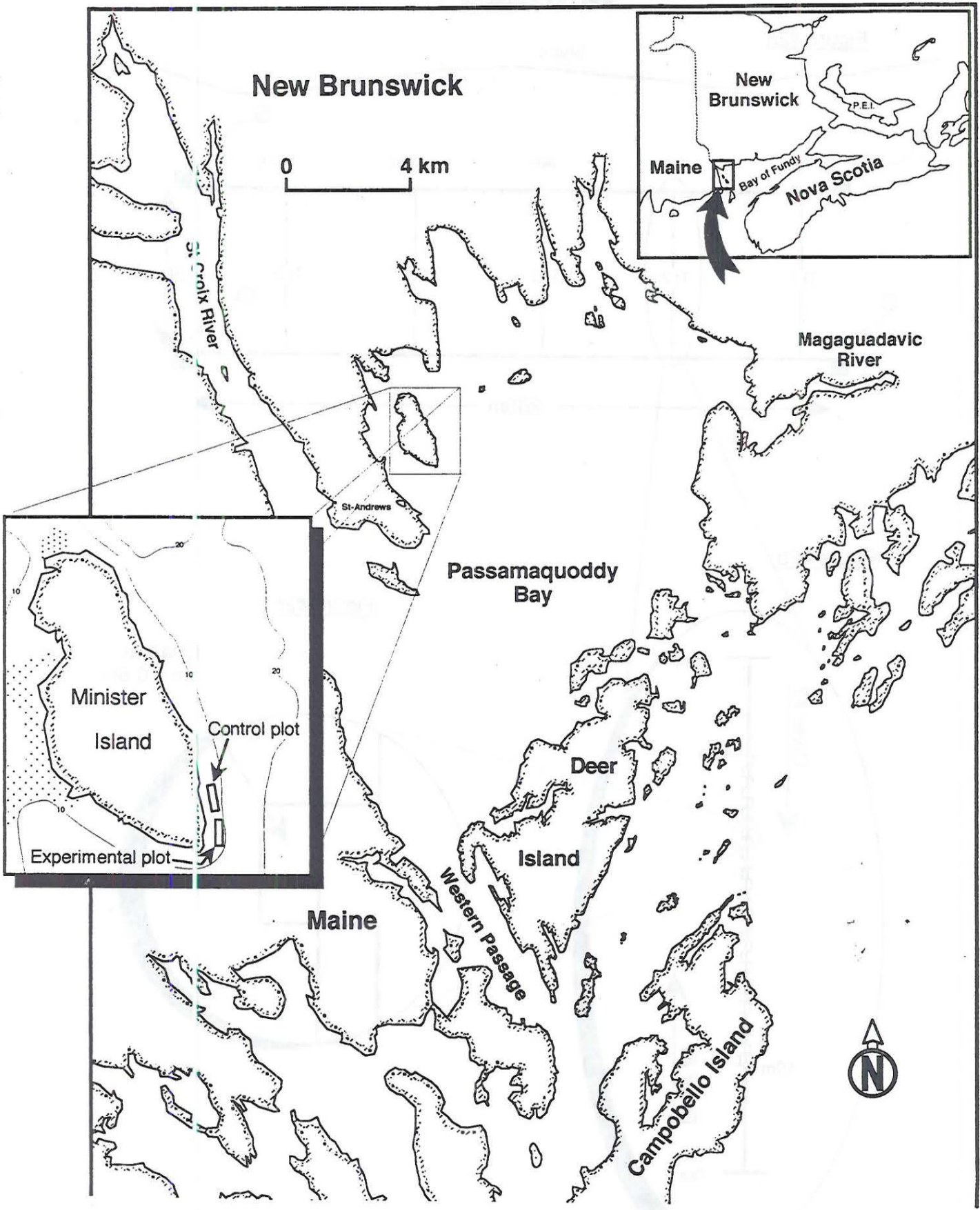


Fig-2



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

Figure #2a

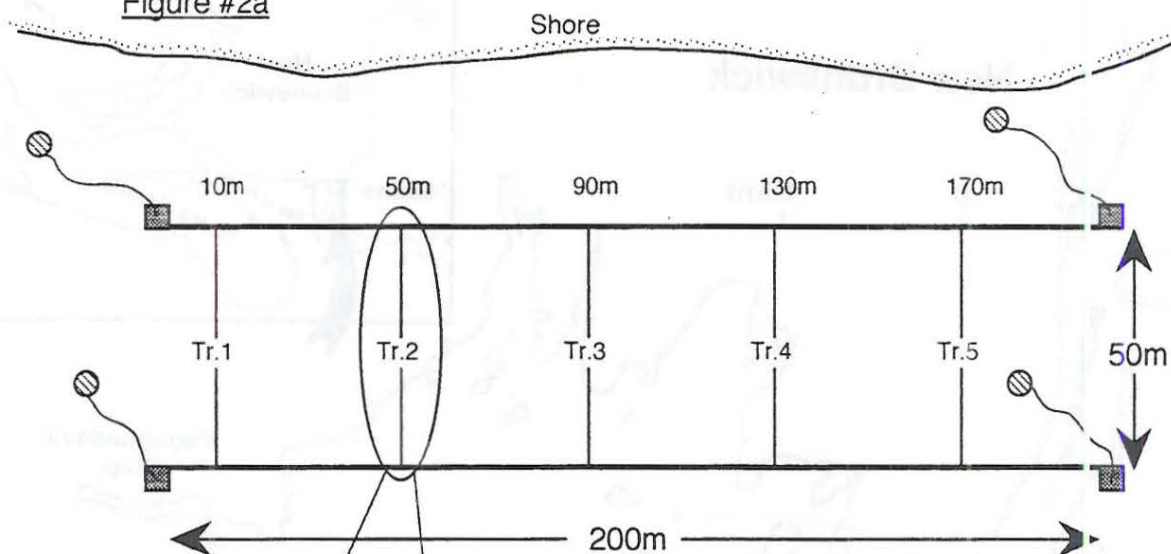


Figure #2b

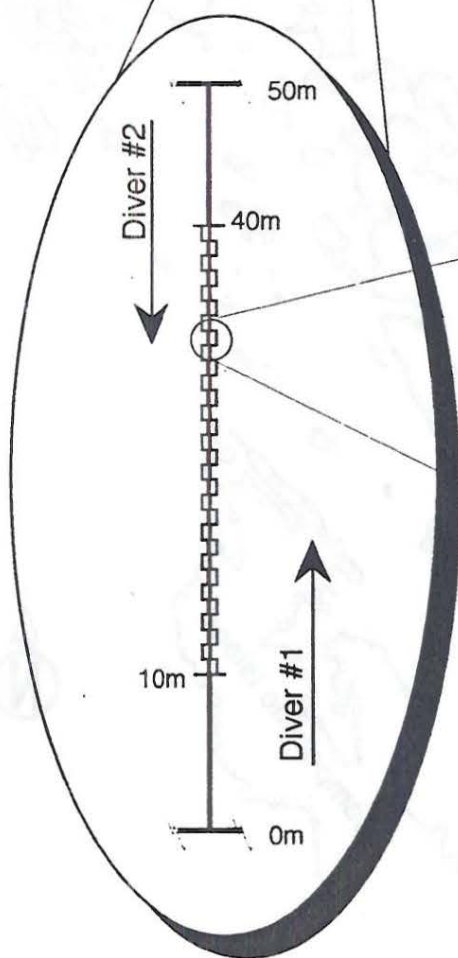
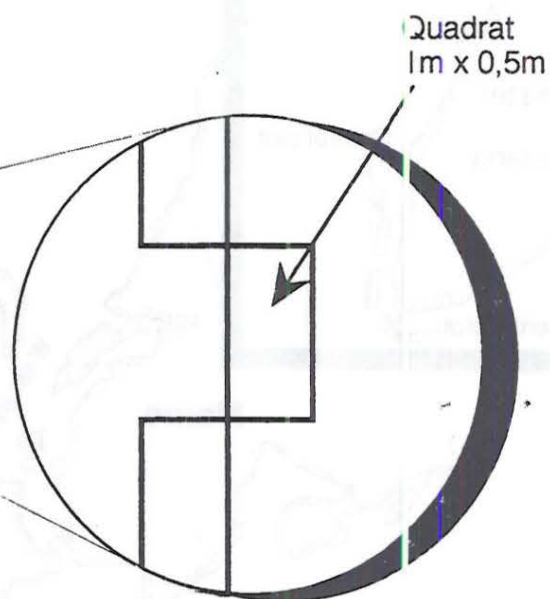
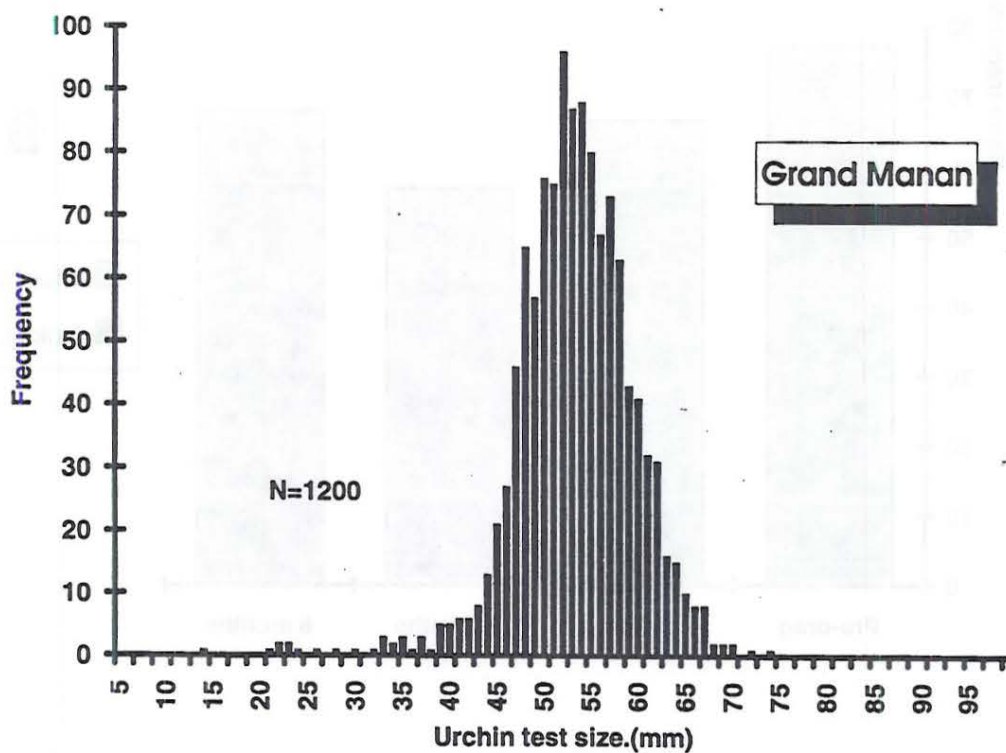
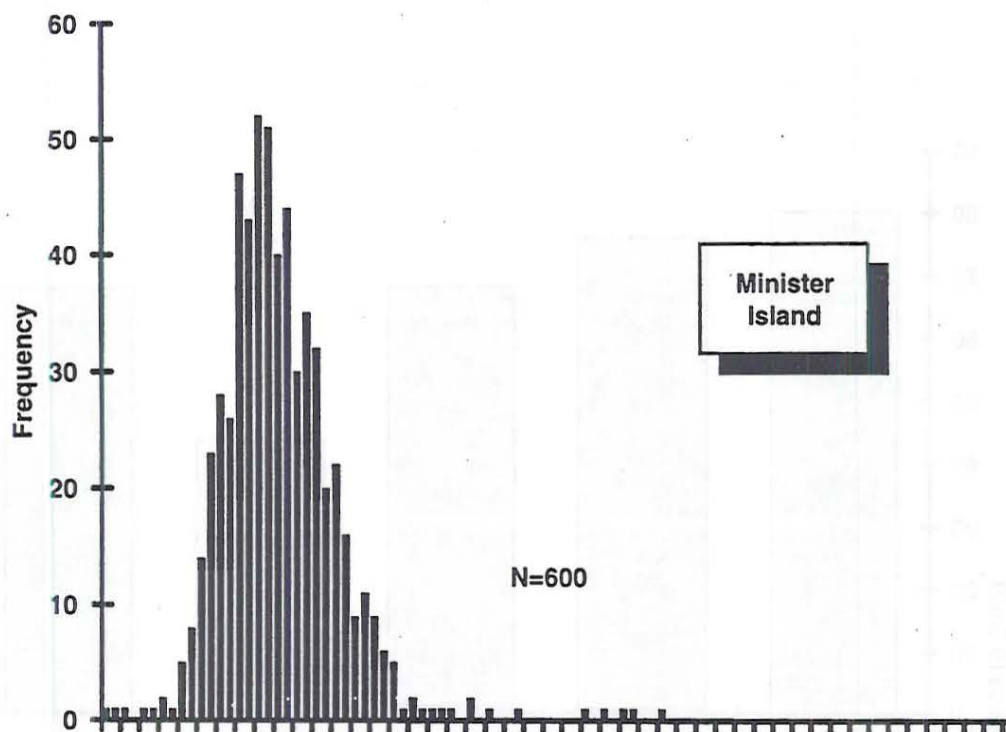


Figure #2c





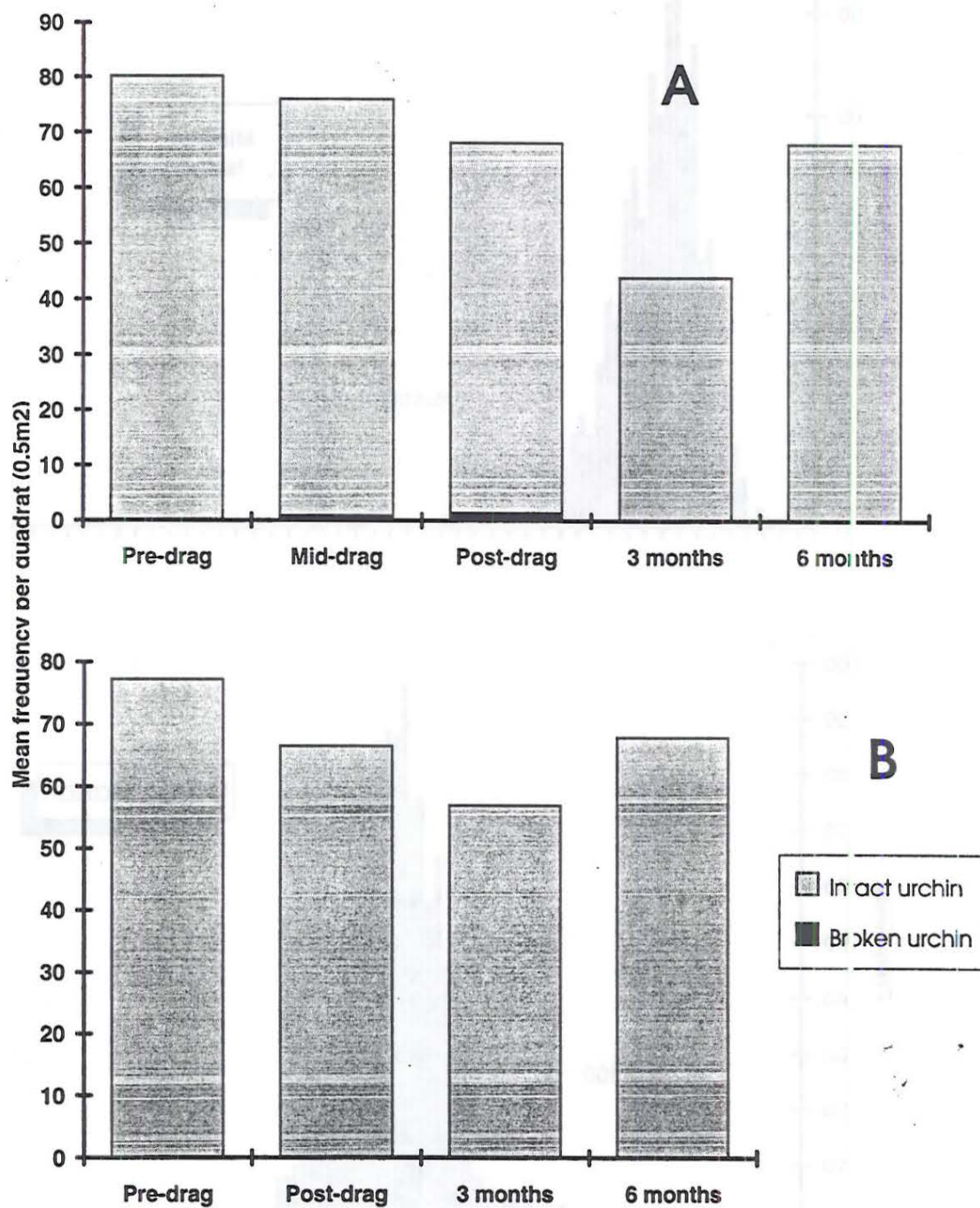
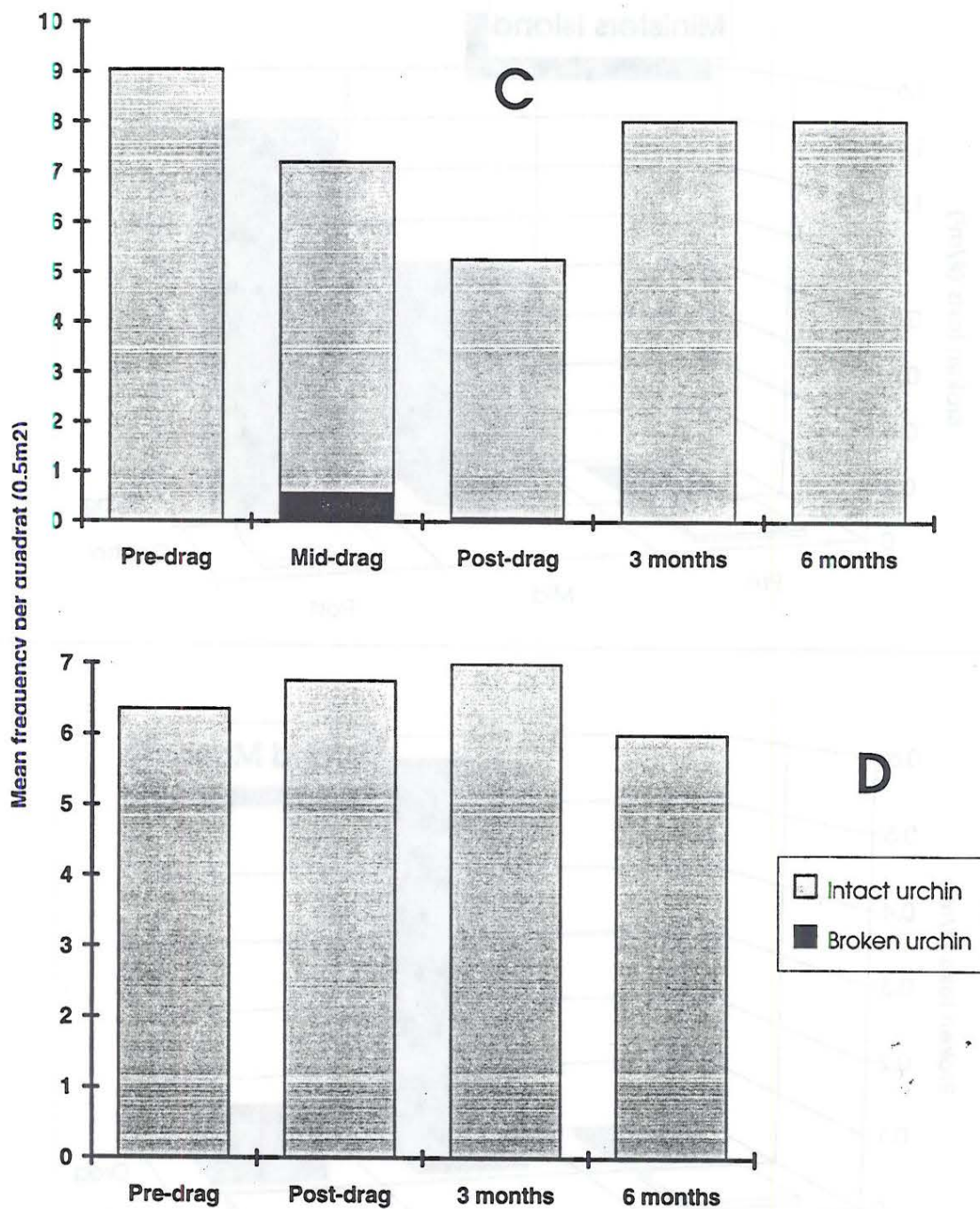


Fig. 6



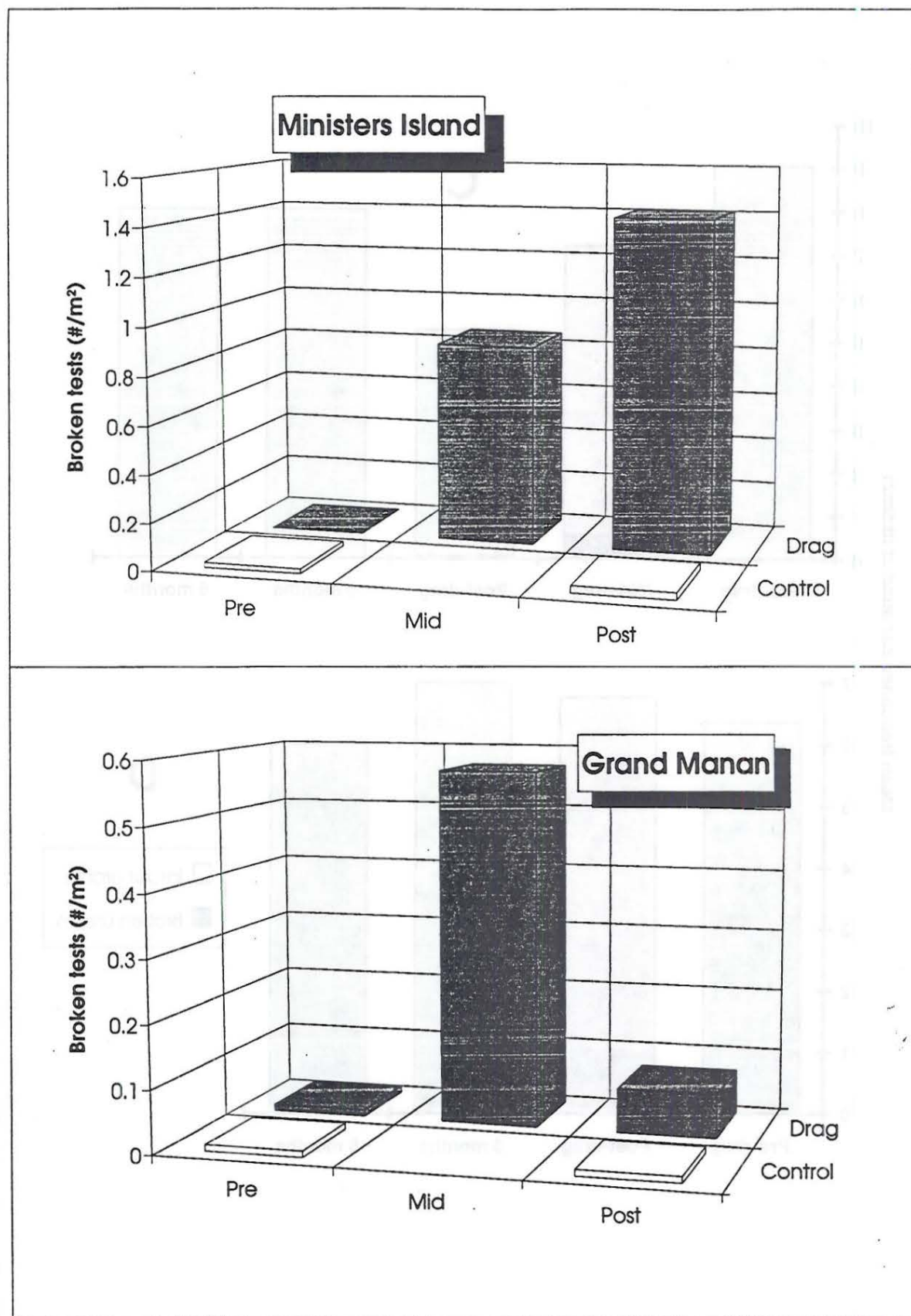


Fig-8

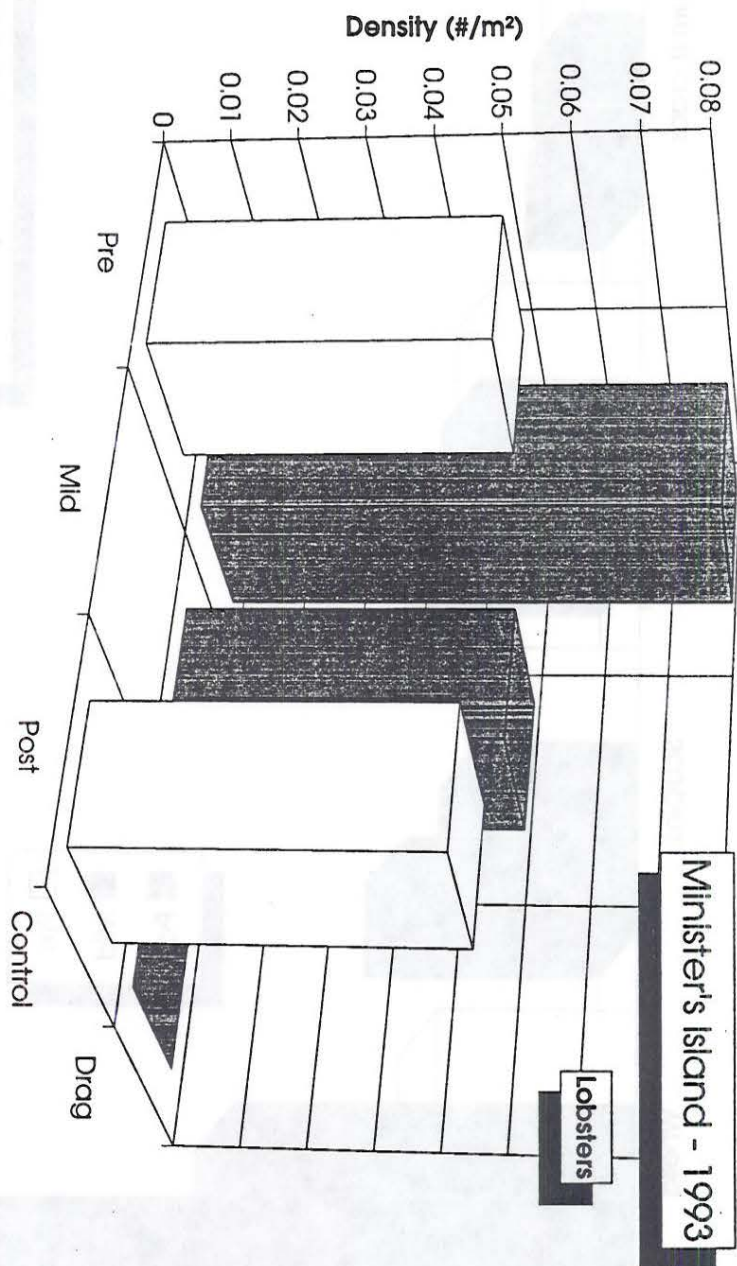
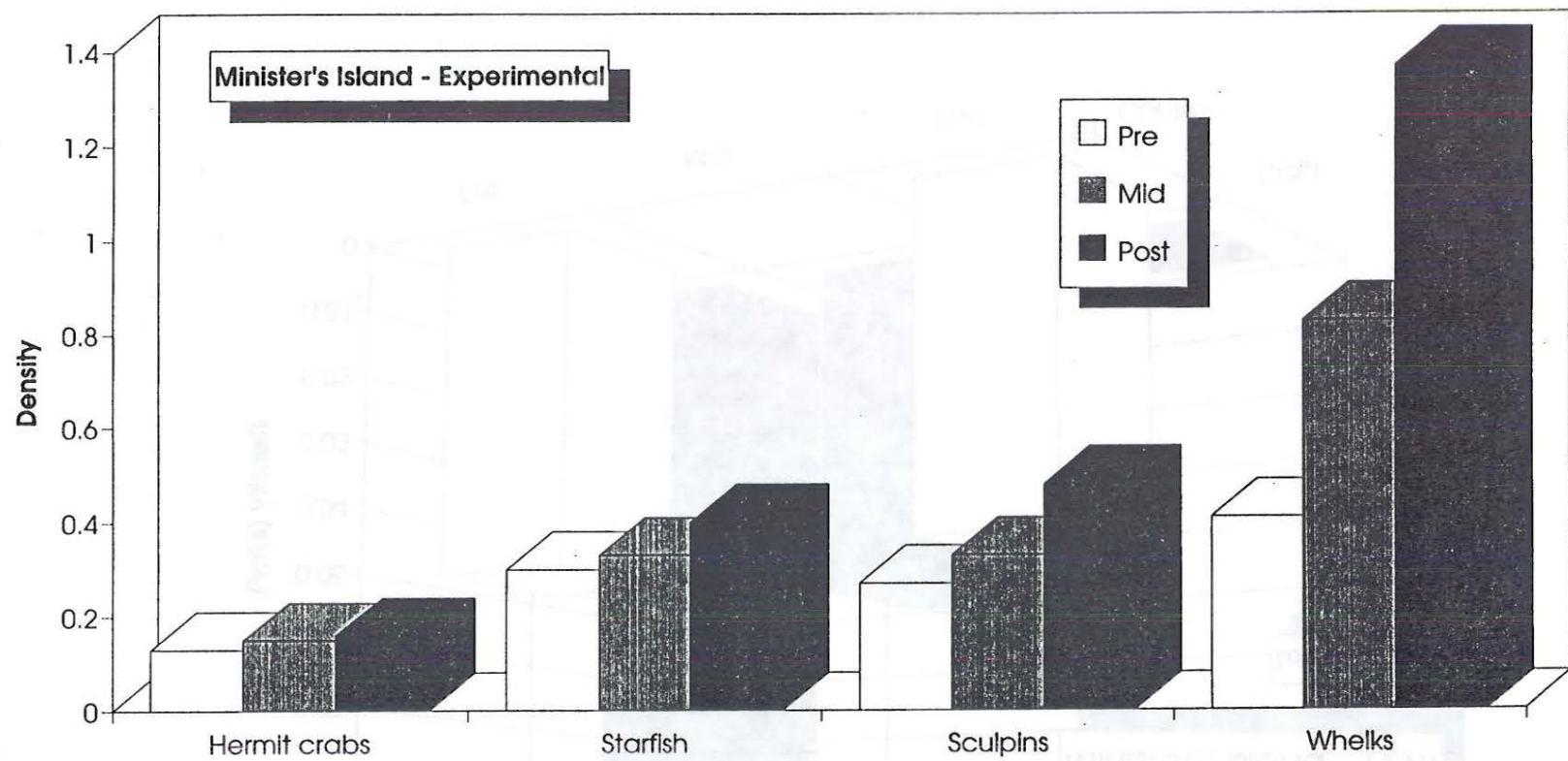
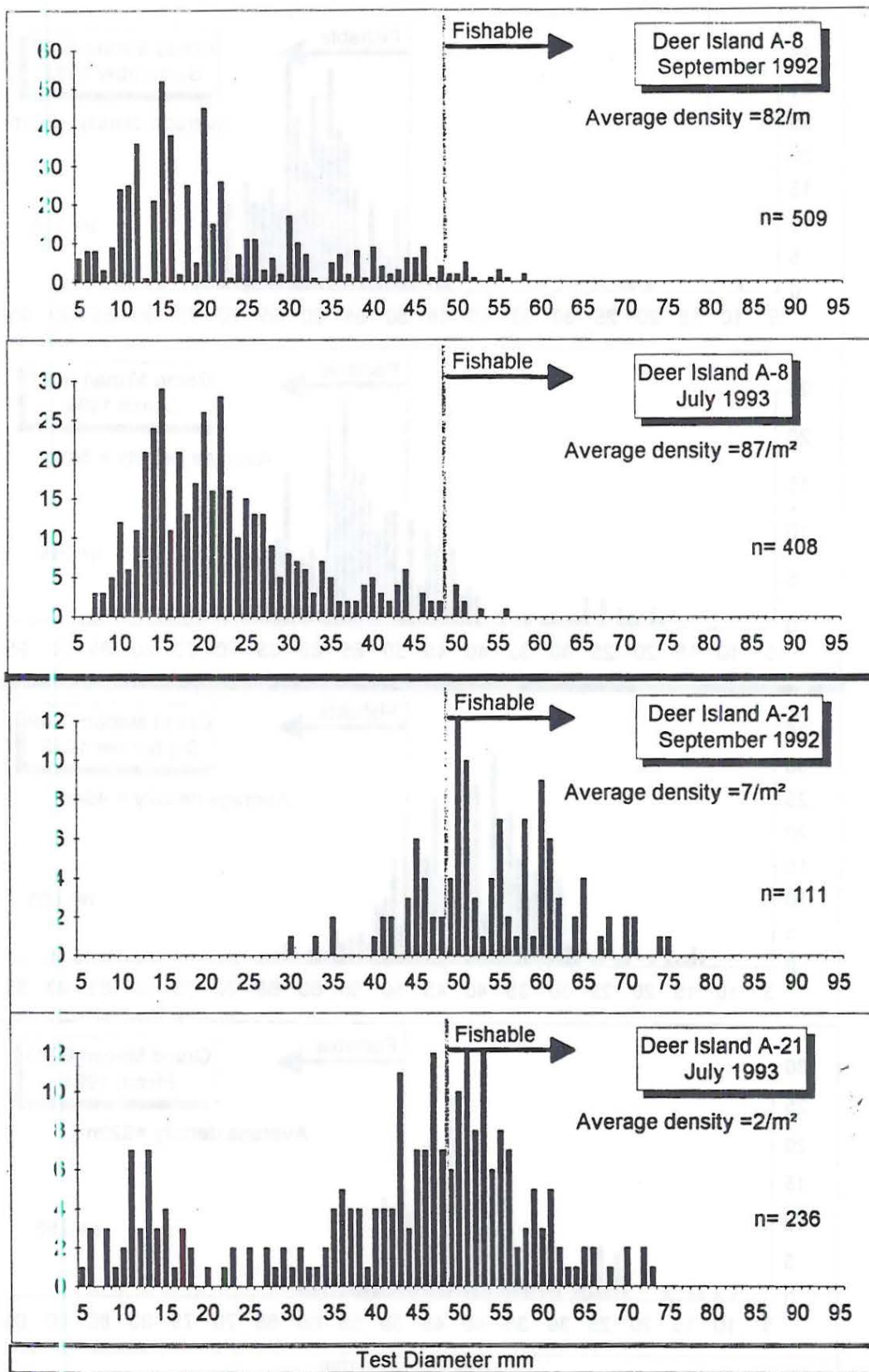
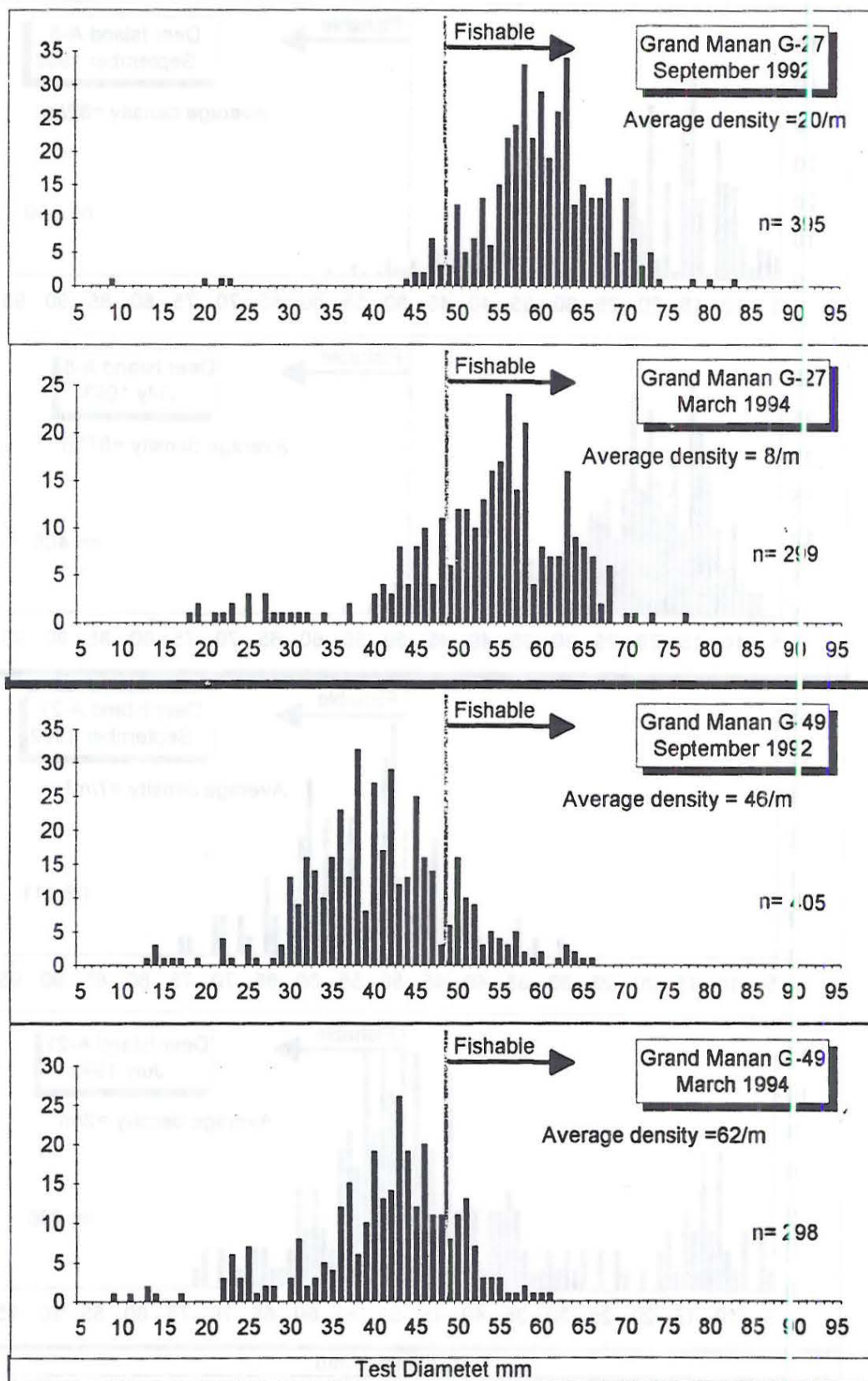


Fig. 17







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APPENDIX III

THE IMPORTANCE OF HABITAT IN FISHERIES MANAGEMENT.

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INTRODUCTION

Fisheries declines in the Western North Atlantic have reached crisis proportions. Canada has banned commercial fishing for several species along its maritime coast, and has challenged the internationally accepted 200 mile economic exclusive zone in order to protect its fishery resources. New England fisheries have come under strongly debated, restrictive fishery management regimes. There are many factors that have contributed to the failure of historical management strategies in these fisheries. These factors include over capitalization, inadequate effort control, and the politicization of management.

The science behind fisheries management has focused on the relationships between biomass, spawning stocks and the size of recruitment classes into a fishery on a species by species basis. This science has been well developed and executed, however, while the need to look at species complexes has been acknowledged, research examining the larger picture of the environment and habitat in which fish spawn, mature and reproduce has been overlooked by fisheries managers. In addition to controlling effort and determining spawning stock sizes, fisheries managers and scientists must gain a better understanding of the habitat and ecosystem influencing the groundfish populations so that we may be able to use the information to predict changes in population parameters and to protect critical times and areas in individual species' growth and development. This information must then be incorporated into fisheries management strategies in a proactive manner.

DISCUSSION

The bulk of the literature regarding the responses of marine fish to environmental parameters focused on one or two variables at a time. The investigators have searched for variables that have overriding influence on populations so that these variables could be used as predictors of stock recruitment. The investigations fall into two primary categories oceanographic and substrate variables. There is also a fair amount of literature regarding the interactions of

biological variables. These investigations have focused primarily on the existence of density dependent responses to fluctuations in stock size.

Oceanographic variables

Research into links between reproduction and recruitment and environmental variables such as salinity, temperature, depth, turbidity and substrate, during the juvenile stages of groundfish development has been conducted. Results have shown links between individual variables or a subset of environmental variables and parameters such as recruitment and geographic distribution (Colton 1972, Colvocoresses and Musick 1984, Myers et al. 1993, Rose and Leggett 1989, Scott 1982b, Swain 1993, Walsh 1992), however they have not always proved consistent (Horne and Campana 1989). This view of the system however, suffers from the same problems that individual species assessment does, namely, that the focus is too narrow. It is likely that the proportions of the variables included in the set of habitat, environmental and biological variables that determine recruitment success vary from year to year in importance. For instance, Myers et al. (1993) showed that salinity plays an important role in recruitment success for the Northern Atlantic cod stock off Newfoundland. The authors proposed several explanations for the underlying mechanism such as larval freezing, advection related processes or stability arguments, however, no conclusions regarding the underlying mechanism could be made. During years when the extent of ice cover is minimal other factors may determine recruitment strength, while the effects of all the abiotic variables are likely tempered by spawning stock biomass. Scott (1982a&b), Horne and Campana(1989), agree that it is absolutely necessary to look at the suite of biological and environmental variables in order to account for covariation among the variables.

Substrate

Preferences for specific substrate types have been described for several species of marine organisms. Associations of sediments and benthic invertebrates is well documents by Gray (1974), but have also been shown for finfish. The yellowtail flounder exhibits a strong preference for sandy bottoms, winter flounder are found on sand to sand-mud bottoms, cod and haddock prefer sand-gravel, silver hake prefer silts and clays etc. (Colton 1972, Scott 1982, Walsh 1992). Recently research into the underlying mechanisms and significance of these preferences has been conducted. Lough et al. (1989) overlaid distributions of juvenile cod and haddock over George's Bank in pre- and post-benthic stages. Pelagic juveniles were distributed fairly evenly within the gyre of the bank, however once these animals settled into their benthic stage they were located primarily over the gravel areas along the northeast peak of the bank, an area which corresponds approximately to statistical area 523 (Crecco and Overholtz 1990, Lough et al.1989) . The authors proposed that this may be due to differential survival of the juvenile fish on the different bottoms, with gravel offering more shelter against predators. This theory is supported by work conducted by Gotceitas and Brown (1993) in which they placed juvenile cod in a tank with three

substrates of varying rugosity and exposed them to a predator (larger cod). In the presence of a predator larger cod showed a preference for finer substrates while smaller cod showed preference for cobble which increased the probability of survival. When no cobble was present juvenile cod attempted to flee from the predator. This is also supported by work done Keats et al. (1986) who examined one and two year old cod associated with fleshy macroalgae in Newfoundland. The authors proposed that, based on stomach content and behavioral observations, shelter from predators is the primary reason for the one year old cods' association with the macro algae. Carr (1989) found increased recruitment of temperate reef fish to areas with giant kelp (*Macrocystus spp.*) and attributed the results to differential settlement or postsettlement mortality. Wahle and Steneck (1991 & 1992) proposed that habitat restrictions may exist for the American lobster (*Homarus americanus*) due to the vulnerability of early benthic phase lobster to predation in areas of insufficient shelter (cobble bottom) from predators. Shelter use has also been cited as the primary reason for the association of juvenile red hake (*Urophycis chuss*) with sea scallops (*Placopecten magellanicus*) (Steiner et al. 1982) and is an important factor in structuring some temperate and coral reef fish communities (Hixon and Beets 1993, Buchheim and Hixon 1992, Carr 1989&1991).

Density dependence

The studies described above provide evidence in support of the theory that demersal fish require specific types of habitat determined by benthic and oceanographic characteristics, for reproduction and juvenile development. Habitat that has specific benthic and oceanographic attributes can affect population sizes through density dependent mechanisms. Density dependent mechanisms have been identified in demersal species of fish. Ursin (1982) attributes the stability of recruitment of North Sea plaice to density dependent mortality in postmetamorphosis juveniles in the Wadden Sea. Myers and Cadigan (1993) showed that juvenile mortality is density dependent within cohorts during the juvenile stage for cod, plaice, sole and whiting and among adjacent cohorts for cod. The authors proposed four possible explanations for the underlying mechanism, competition for food, cannibalism, prey switching by predators (including human) to abundant year classes and competition for critical areas of appropriate juvenile habitat. A particularly interesting outcome is that density dependence is much stronger in cod than in haddock, with benthic recruitment variability at the youngest age observed also being greater for cod than haddock. However, cod is considered to have less variable recruitment to the fishery than haddock (Ursin 1982, Myers and Cadigan 1993). This implies that the natural mortality due to density dependence is high enough to mask the variability of recruitment in cod. Cod and haddock are found in very similar bottom types, with both preferring sand-gravel substrates (Scott 1982), but do have different diets. Haddock are primarily benthic feeders while cod is largely piscivorous, which would contribute to its higher density dependence due to cannibalism of older year classes

on younger ones (Bigelow and Schroeder 1953, Myers and Cadigan 1993). The effects of such a situation would be most noticeable during periods of high population densities. When populations increase they infiltrate areas of less favorable habitat in which natural mortality may be higher and reduce their ranges during episodes of low population size (Swain and Wade 1993; Rose and Leggett 1991; Crecco and Overholtz 1990). When a population is depleted and has retracted into the more favorable habitats within its range its vulnerability to fishing mortality increases (Crecco and Overholtz 1990, Rose and Leggett 1991, Winters and Wheeler 1985). Crecco and Overholtz (1990) predicted that under such conditions, unless fishing mortality could be restrained by a fishery closure or strict quota management, spawning stock biomass would be steadily fished down leading eventually to recruitment failure and collapse of the fishery.

Synthesis

Several states have implemented programs that attempt to address the problem of stewardship over environmentally sensitive or critical habitats. These programs and the research they support have focused on the shallow nearshore environments. These areas are more obvious to the general public and are much easier to sample. Off shore areas are significantly impacted by human endeavors, yet our knowledge of these areas pales in comparison to the nearshore environment.

The Commonwealth of Massachusetts created a program in 1975 called Areas of Critical Environmental Concern or ACEC's. Habitats in a broad range of categories including coastal, fishery, agricultural and inland wetlands can be designated as an ACEC. While no specific protection is afforded an ACEC, it does require any proposed development that might affect the area to withstand extra scrutiny. The program acknowledges the existence of areas that are critical to the survival of important species and the responsibility for stewardship of the state's resources. Massachusetts provides separate protection under the Division of Marine fisheries regulations for cases such as the winter flounder spawning closure that lasts from February 1 to May 31.

Maine has opted for a more systematic approach to addressing the stewardship of its marine resources. Brown (1993) catalogs habitats in a classification system developed for the state's marine and estuarine benthic habitats and identifies representative sites for these habitats. While this catalog does not include terrestrial ecosystems, it creates a fundamental data base from which managers and scientists will be able to identify areas in need of further research, areas in need of management and protection and from which assessments of human impacts can be made in the future. The habitats are divided into two large groups, marine and estuarine, defined by salinity (30ppt being marine). These are each subdivided into either intertidal and subtidal habitats, which are then differentiated primarily by depth and energy level. It is interesting, although not surprising, to note that the marine subtidal habitats are poorly documented and described in comparison to all

the others in the catalog.

As researchers establish the importance of the various environmental factors affecting the ecosystem supporting commercial and recreational fishes, managers, scientists and industry participants will have the much more difficult task of establishing how this information can be incorporated into fisheries management. At a recent workshop on habitat sponsored by the Regional Association for Research on the Gulf of Maine (RARGOM), a fisheries resources working group tackled this problem (Langton 1994). They defined critical or essential habitat as "geographically and/or physically discreet areas that a species must utilize at some phase in its life history.". The participants proposed a flow diagram which would allow fishery managers and scientists to work together to determine research needs, necessity of management action regarding the defined critical habitat and the direction of management strategies. These decisions would be based on a habitat-life history matrix that graphically represents the relationships of the variables which define a species' critical habitat. A multispecies model can be constructed by overlaying the life history matrices of species that co-occur.

The task at hand then, is to describe and map areas that previous work has shown are potentially critical habitats for valuable commercial and recreational fish. As habitat characteristics vary according to the unique biological, physical and chemical properties of an area, areas suspected of playing an important role in fish ecology should be assessed individually and then integrated to look at larger scale effects. The existence and recent advances in technologies such as Global Positioning systems, computer mapping database facilities, remote operated vehicles (ROV's), video imaging systems, high resolution sonar and acoustic technologies, will enable the description of these areas. Uses of these technologies have increased within the past ten to fifteen years and as a result sampling and analysis techniques have improved tremendously, especially in the use of ROV's for scientific sampling (Barry and Baxter 1993, Michalopoulos et al. 1993).

SUMMARY

Enough evidence exists in the literature to say that demersal fish require specific types of benthic and oceanographic conditions at some stage in their reproduction and/or early development. The proportion of the numerous variables vary in importance by species and location, and by the interactions of the variables themselves. In order to better study and manage our living marine resources, we need to describe and identify those areas of the marine ecosystem that are critical to commercially and recreationally important fish species. This is a goal that is becoming technologically achievable as well as biologically and economically important.

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