An evaluation of the Maine sea cucumber resources

and impacts of exploitation

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by

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1. Abstract

The sea cucumber is a relatively new, but rapidly expanding fishery in Maine. Like other new fisheries rapidly developed as a result of newly found markets, we have little knowledge about the status of the Maine sea cucumber resources and impacts of the fishery on the resources. Using the approaches developed with the support of the NEC Program development fund, we conducted this cooperative research to (1) survey the sea cucumber resources in major sea cucumber fishing grounds along the coast of Maine; (2) collect biological information of the Maine sea cucumber population; (3) evaluate the impacts of exploitation on the sea cucumber population by conducting a before- and after-fishing comparative study.

This study suggests that the major spawning event of sea cucumber occurs from January to March, but minor spawning events may also occur in other months. Differences in water temperature among different depths and seasons may account for differences in gonad development at different depths.

Through cooperative research, both fishermen and scientists participated in a large-scale survey of the population from 2005 to 2007 in Frenchman and Narraguagus Bays, which yielded more than 90% sea cucumber landings in Maine. The survey suggests that rock bottom appeared to be the most favorable habitat for the sea cucumber in the survey area and that exploitable stock biomass varied with depth, with sea cucumber more abundant in the shallow waters (< 20 meters). Stock biomass decreased substantially from 2005 to 2006, but was stable from 2006 to 2007.

No clear pattern was observed between the experimental plot and control plot for the soft substrates. For the hard substrates, the number of sea cucumber in the experimental plot tended to increase with the time after the dredging depletion in the BACI experiment, suggesting the recovery of sea cucumber density after dredging.

This project is the first one in this area that systematically studies the sea cucumber biology and fishery. The end users who will benefit from the results of this cooperative research will include the Maine Department of Marine Resources (developing management plan for the fishery) and fishing industry (sea cucumber resource availability and their distributions along the coast of Maine). This project has already had real and significant impacts and will have significant long-term impacts on the management of the sea cucumber fishery in Maine.

2. Introduction

Managing benthic fisheries is a difficult undertaking. Pertinent data are frequently not available and are difficult and expensive to obtain. This is particularly true for new/developing fisheries because funds for fishery research and management tend to be in extremely short supply. Paradoxically, this is also a time when a rational management plan is needed to prevent the over-exploitation that is often detected in benthic fisheries only after it is too late to prevent a collapse (e.g. Maine sea urchin fishery). This could be the case for the sea cucumber fishery in Maine if actions are not soon taken.

The Maine sea cucumber fishery began in 1988, but started expanding in 1994 when Asian markets opened up (Chenoweth and McGowan 1997). Scallop chain sweeps or light urchin drags are used as fishing gear. Fishing activity has centered in Washington and Hancock Counties with catch landed in Winter Harbor, Jonesport, Beals Island, and in Eastport. The fishery has recently experienced great increases in landings, corresponding to expanding export markets and a decline in the supply of more traditional sea cucumber species. The fishery has recently experienced great increases in landings, corresponding to expanding export markets. Reported landings increased from 860 mt in 1995 to 4,309 mt in 2000 (Fig. 1) with landing values of over half a million dollars (Fig. 2). Although landings dropped in 2001 (see Fig. 1) after development of new regulations and a limited entry system, landings in 2002 rose to over 2,800 metric tons, rising to nearly 4,632 in 2004 and may be held back more by processor capacity rather than by fishing effort or demand from Asian markets.

Like other emerging/developing fisheries, we have little information about the biology and ecology of the Maine sea cucumber, limited data on the fishery, and little knowledge about the key life history processes that characterize the population dynamics of the sea cucumber. As a result, we have a limited understanding of the current status of the resource and impacts of the fishery on the stock. The fishery was regulated minimally prior to 1999. However, as interest in the industry increased, concern over rapid depletion of the resource and conflicts with fixed gear of lobstermen in certain areas led to the enactment of regulations under the 1999 Sustainable Development of Emerging Fisheries Act (12 M.R.S.B671-B) in March 2000. This act limits the fishing season, drag size, and number of endorsements (to pursue the fishery) issued. Currently, the season is closed from July 1 to September 30 inclusive, with no nighttime harvesting. Drag width must be under 5'6" and the length under 22". Endorsements were granted to individuals who had landed and sold at least 250,000 lbs of sea cucumber between October 1, 1998 and September 30 1999 and are renewable on request. The weekly submission of harvester logbooks is also required. These data serve as a record of harvest locations and catch, effort, and economic data. However there is a significant discrepancy between reported landings from harvester logbooks compared to voluntary dealer reports suggesting that the logbook program alone is not adequate for monitoring the status of the fishery (Heidi Ryder, landings coordinator DMR, personal communication). Analysis of the logbooks to date does not show a decrease in landings per unit of effort (LPUE) but there are anecdotal reports of increased search time for boats involved. For species that aggregate, LPUE is often a poor indicator of resource status.

Because information on the resources and sea cucumber biology is sparse, impacts of the fishery on the resource and effectiveness of the current regulations remain unknown. Studies of sea cucumbers in other parts of the world, however, suggest that they grow slowly. Without an appropriate management plan, there is a real danger of over-exploitation. The evaluation of current status of the Maine sea cucumber resources and possible impacts of the fishery are thus urgently needed. Such a study will enable us to assess the resources, evaluate the impacts of the fishery on the stock, and develop a sound management plan for the fishery and place longer term monitoring of the stock on a more scientific footing.

There is reported interest in additional processing plants beginning operation which could increase landings and harvest demand further. FAO statistics document the rapid rise in sea cucumber landings from the Northwest Atlantic (primarily Maine landings) over the last ten years and concurrent decrease in total global landings. Despite high landings – in monetary terms Maine is still a small player in global beche-de-mer production and *C. frondosa* is a lower valued product. The peak value of the Maine fishery (ca. $1,870,000 in 2006; Fig. 2) was less than 4% of the 60 million dollar global trade. Entry into the fishery is currently limited but this measure is due to sunset in 2006 at which point a more permanent management plan must be put in place.

Studies of sea cucumber populations in other parts of the world suggest that they grow slowly (Woodby et al. 1993, Richmond 1994, Gudimova and Denisenko 1995, Gudimova 1999, 2000). Without an appropriate management plan, there is a real danger of overexploitation. Most research done so far is for the red sea cucumber (*Parastichopus californicus*) in the Northwestern USA and British Columbia (Bradbury 1990, Zhou and Shirley 1996, Boutillier et al. 1998, Philips and Boutillier 1998, Campagna and Hand 1999, Perry et al.1999, Cripps and Campbell 2000). On the eastern side of North America, however, limited work has been done, although recent studies have added to knowledge on *C. frondosa*. A study of the ecology and behavior of the common sea cucumber, *Cucumaria frondosa*, was done at Lamoine State Park beach by Jordan (1972) for his PhD thesis at the University of Maine (Orono). More recent studies have focused on fertilization success and feeding behavior as it relates to aquaculture (Medeiros-Bergen and Miles 1997, Hamel and Mercier 1997, Singh et al. 1998). These studies have improved our knowledge on *C. frondosa*, but still do not provide enough information on life history processes, such as growth and maturation, which are key for understanding the population dynamics of sea cucumbers in Maine. Some initial work done by the DMR has included small scale descriptive surveys to document relative abundance, associated bycatch, size range and sex ratio of sea cucumbers at several locations near fished areas – but lack of funding and staff has hampered the development of a longer-term monitoring program.

Poor understanding of *C. frondosa's* life history processes has limited our ability to develop a stock assessment framework, to evaluate the current status of the stock and the impacts of the fishery on the resource, and to identify and develop appropriate management strategies. Because of the sea cucumber's expected low growth rate (Gudimova and Gudimov 1997, 2001, Gudimova 1999), overexploitation may occur at landings well below the demand driven by oversea markets. This may lead to the depletion of cucumber stocks, resulting in the collapse of the fishery. Initial surveys and literature reports also show that at some locations (areas with fishable densities) sea cucumbers may constitute 50% or more of the biomass of benthic organisms. The live catch weight of a single tow (ca. 15 minutes) is often 1000 lbs - with daily catches averaging around 25-30,000 pounds per boat. It is unclear if and how long it may take to re-establish these areas after harvest has occurred or the ecological effects that removal of these organisms may have on the local benthic community. The collection of both fishery-dependent and fishery-independent data and quantification of important biological and ecological parameters will enable us to assess the resource, evaluate the impacts of the fishery on the stock, and lay the groundwork to discuss alternative and, perhaps, more effective management measures (overall or area quotas, closed or rotational harvest areas, gear restrictions/ mesh size etc.).

3. Project Objectives and Scientific Hypothesis:

The objectives of the project were to conduct a cooperative research to (1) survey the sea cucumber resources in Maine; (2) collect biological information of the Maine sea cucumber population (e.g. size structure, size-specific maturation, size-specific fecundity, etc.); (3) collect ecological information of the Maine sea cucumber population (e.g. spatial and temporal variations in abundance and its associated key biotic and abiotic environmental variables characterizing the habitat; (4) evaluate the impacts of exploitation on the sea cucumber population by conducting a before- and after-fishing comparative study; (5) estimate current status of the resources; (6) evaluate the effectiveness of the current management plan; and (7) deliver the results to the shareholders of the Maine sea cucumber fishery and public.

The null hypotheses tested in the study are (1) there are no correlations between morphological variables and fecundity of sea cucumber; and (2) there are no significant impacts of fishing on the sea cucumber population.

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5. Methods

The project objectives are addressed through an extensive industry-based sampling program in the major sea cucumber fishing grounds along the coast of Maine and lab measurement of various key sea cucumber biological parameters.

5.1. Biological studies

Sea cucumbers are unique in morphology, behavior and biology relative to other commercially harvested species and a standardized procedure is therefore needed for collecting data and measuring biological characteristics. With the support of a NEC Program Development fund, we developed a standardized procedure for biological sampling of the Maine sea cucumber (after dissecting and studying individuals sampled from the Maine sea cucumber fishery). The detailed description on the procedure can be found in our report to the NEC (Grant # 03-686).

Samples have been collected from different locations, habitats, and depth throughout the year to measure the changes in gonad weights, size compositions, and relationships among various morphological variables. The sampling is coordinated among the DMR scientists, fishermen, and UMaine scientists. Field sampling was done by the DMR scientists and industry members, while UMaine scientists were responsible for lab measuring and dissecting.

Limited biological research has been done on sea cucumber along the coast of Maine. Jordan (1972) conducted a study of the ecology and behavior of *C. frondosa*, at Lamoine State Park beach. More recent studies have focused on fertilization success and feeding behavior in aquaculture (Medeiros-Bergen and Miles, 1997; Hamel and Mercier, 1997; Singh *et al*., 1998). *Cucumaria frondosa* is thought to grow slowly and subject to high mortality before settlement. Factors such as slow growth, aggregate distribution, and the potential for an Allee effect at low population densities make *C. frondosa* a potential candidate for overexploitation and recruitment failure.

In this study using the samples collected over 12 months along the coast of Maine, we evaluated relationships between morphological variables and gonad weight. We evaluated the seasonal variation in gonadosomatic index (GSI) to determine the spawning time for sea cucumber along the coast of Maine. We also evaluated if gonad development was influenced by water depth. The information derived in this study can provide biological information essential for the assessment and management of sea cucumber stock along the coast of Maine.

Sea cucumbers were sampled from February 2004 through March 2005. We were not able to collect data from July – October 2004 due to the summer seasonal fishery closure. An industry fisherman randomly sampled sea cucumbers from Frenchman Bay, which is where more than 50% of catch is harvested in the state of Maine (Fig. 3). One fisherman collected all the samples using the same sampling protocol for this study. These samples were gathered every 2-4 weeks with an increased frequency around expected spawn dates March-April based on the previous study (Feindel, 2002).

We collected samples from three different depth strata, including shallow (3.7-12.7 m), mid-depth (12.8 – 45.5m), and deep (45.6 – 91.4), to test impacts of depth on spawning. Fifty to sixty animals were collected at each depth stratum per sampling time, for a total of 150-180 animals measured during every sampling time. Twice we were unable to acquire samples from every depth stratum due to weather conditions. A total of 1,777 animals were sampled and measured from 12 sampling dates in this study. Sea cucumbers were transported to the Darling Marine Center of The University of Maine in coolers and put into flow-through 400-liter polyethylene tanks without filtration.

Lab work was carried out within three days of collection so loss of muscle mass or visceration (the expulsion of the animal's internal organs as a defense mechanism) would be unlikely. It was necessary to develop a standardized sampling procedure because *C. frondosa* is variable in shape. Each animal was agitated by hand until it became long and rigid. This was easily accomplished by a gentle massage until the tentacles were completely withdrawn and the sea cucumber stiffened. Measurements of length, width, and circumference were then obtained with a flexible tape measure ribbon to the nearest cm. The live weight was also recorded for the agitated condition to the nearest mg.

Using a scalpel, each sea cucumber was dissected by slicing lengthwise along the dorsal side of the animal. The dorsal side may be identified because it is often lighter in color and may be softer to the touch. Muscle bands were cut immediately to prevent internal contraction. The tentacles, intestine, respiratory tree, and gonad were removed. Each organ was weighed individually and the development of the gonad tubes was observed and noted when inflated (pre-spawn). The weight of the empty body cavity was measured. Finally, we calculated GSI by dividing the gonad weight by the total live weight for each sampled sea cucumber,

$$GSI = \frac{weight\ of\ the\ gonad}{total\ live\ weight\ of\ the\ animal} 100\% .$$

An analysis of variance was conducted to determine whether GSI might differ among depth strata. We also tested if a significant difference existed in GSI between every two neighboring sampling times.

Correlations between the gonad weight versus length, width, body cavity weight, and live weight were evaluated for each depth by sex. The morphological variable with the highest correlation coefficient (r) value was selected for deriving the gonad-morphological-variable relationship, which allows for the prediction of gonad weight from the morphological variable.

5.2. Industry based survey

The Maine Department of Marine Resources (DMR) has collected voluntary dealer reports (i.e., total landings) since the state's commercial fishery began. Fishery-dependent information was additionally required starting in 2000. This includes information on landings and harvest locations. The fishery is currently managed through limited entry, a seasonal closure, license requirements, restriction of night harvest, reporting of catch, and limits on drag width. In 2005, new legislation (Public Law 2005, chapter 27: statutory authority 12 M.R.S.A. §§6171, 6801), established a sea cucumber management fund setting aside a small percentage of revenue from harvest for continued research on *C. frondosa* and enforcement of regulations.

Fishing activity has been centered in Washington and Hancock Counties with catch landed in Winter Harbor, Jonesport, Beals Island, and in Eastport and 90% of harvest occurs in Frenchman and Narraguagus Bay. Currently, there are 12 endorsements to harvest, however, only 4-8 boats are active in any one season (Feindel, personal communication).

In order to estimate stock biomass, spatial statistics, also known as geostatistics, are commonly used, which encompass a diverse group of techniques that can be used to model the spatial variability of a process, such as sea cucumber density, to estimate the value at unobserved locations (Bailey and Gatrell, 1995; Petitgas, 2001). Spatial variability is usually divided into two categories: first- and second-order effects, or large- and small-scale variability. Large-scale variability is the variation in the mean value of the process over the study area, while small-scale variability is the spatial dependence of the process, or the similarity between neighboring sites (Bailey and Gatrell, 1995). Intrinsic second-order methods such as kriging are now commonly used to estimate exploited fish stock biomass (Simard et. al., 1992; Petigas, 1993; Pelletier and Parma, 1994; Maravelias et. al., 1996; Lembo et. al., 1998; Maynou et. al., 1998; Rivoirard et. al., 2000; Petigas, 2001; Grabowski et. al., 2005).

As is common in fisheries surveys, financial resources impacted the degree of total sampling intensity possible. Dependence on industry members for sampling trips also influenced the choice of survey techniques that would be most practical for this investigation. Because of these financial and temporal constraints, it was not possible to use these “traditional” geostatistical stock assessment methods for this survey.

Instead, a classical random stratified sampling survey approach was undertaken to assess sea cucumber stock biovolume. Random stratified sampling (Cochran, 1977) is one of the most widely used methods to estimate the abundance of different fish species (Doubleday, 1981). This type of analysis is cost-effective, generally applicable, and produces estimates of variance of abundance. Effectiveness of this method depends on how well the survey strata are selected in reflecting the variability of organism spatial distributions. In this method of analysis, the study area is subdivided into different strata, and station locations are selected at random within each stratum. At each location, sampling gear is then deployed. The average size of the catch of a species within a certain stratum is multiplied by the total area of the stratum to estimate the total number of individuals, weight or volume (relative population abundance or biomass) of the species in the stratum. The sum of estimates per stratum provides an estimate of abundance of the species over the entire study area.

Habitat diversity, size of entire area, variability among sample estimates within different strata, and financial considerations affect decisions on strata boundaries, the total number of stations sampled and methods to apportion these among the different strata. Stratified sampling increases the precision over simple random sampling by reducing the variance of estimates due to increased homogeneity in catches within a stratum versus between strata (Nielsen and Johnson, 1983). For this type of analysis, strata need not have an equal number of samples, but weighted estimates are needed for some unequal sample allocations (Cochran, 1977). Sample size within each stratum is often used as stratum weights in estimating mean estimates and variances.

The survey considers depth to be a key factor in the selection of strata boundaries as depth influences community structure and abundance (Smith et al., 1994). It is important to note that stratification based on water depth also accounts for differences in water temperature and salinity. These abiotic factors have the potential to influence the distribution of fish species (Smith et al. 1994).

According to Smith and Gavaris (1993), an appropriate allocation of possible samples to the various strata can play a large role in improving the precision of abundance estimates. For the purposes of this investigation, information of sea cucumber locations from harvester logbooks and scallop survey data on *C. frondosa* helped in determining how to subdivide the number of possible samples among the different strata.

The objective of this study was to estimate sea cucumber stock biovolume by conducting a stratified random survey. By comparing biovolume estimates from this survey to fisheries data collected by DMR on total landings, it is possible to estimate exploitation rate for sea cucumbers.

Initial data in the form of harvester logbooks and preliminary surveys combined with input from the industry focus group, which was held November 2003, serve as the basis for survey design.

5.2.1. Testing and comparing survey approaches (Camera/ Dive/ Drag)

Working with industry, Maine DMR tested the feasibility of using a camera approach for the survey. The camera approach is found to be inappropriate for the sea cucumber survey because of the following reasons (1) sea cucumbers are extremely patchy at the scale of several square meters and we have to perform a good number of drops at the station to have any confidence in the data and (2) sea cucumbers tend to congregate on rocky out-croppings or areas with 3-D structure when on a flat (e.g. mud) bottom – precisely the areas where a camera frame is likely to be difficult to land (without tipping) – or where it will be difficult to count animals (e.g. – the back-side of rock).

A dive survey is a good methodology (because a direct counting method with no efficiency involved) although slower and more work. The survey design was stratified according to 'dive-able' depths (< 60 ft) and deeper depths. This will enable any future surveys to consider using divers for this stratum. However, a dive survey cannot be applied to deeper strata.

The advantages to the drag survey are: it makes best use of the cucumber boats and captains; it is a good 'averager' over distances; it is logistically quicker than alternative methods; it allows for direct measurements on retrieved animals and analysis of representative bycatch from the fishery. Some disadvantages are the need to estimate drag efficiency and environmental disturbance (though it occurs in areas already frequently dragged), as well as interference from lobster gear.

After evaluating and testing all the three methods, we decided to use the dragging for the large scale of surveys.

5.2.2. Industry-based surveys

An industry-based survey was conducted in the survey area to collect biological and ecological information for the sea cucumber stock. Seasonal shifts in their distribution occur and these may be a function of prey availability, water temperature, and spawning migrations.

The survey took place in Frenchman Bay and Narraguagus Bay where 90% of industry sea cucumber harvest takes place. Frenchman Bay was divided into 2 depth strata: greater than 20 meters (FMGT) and less than 20 meters (FMLT). This provided a means to compare shallow and deeper depths to determine whether depth may play a significant role in the abundance of *C. frondosa*. Depth strata were decided by considering that if dive surveys were used in the future, dives would have to occur at less than 60 meters. By designating this depth in this drag survey, it was possible to remain consistent with strata in future surveys if dive sampling methodology were undertaken. Additionally, there is the potential that these two depths may have a biological difference because depths of greater and less than 20 m vary in temperature and salinity which may impact abundance.

To determine sampling sites, commercial harvest locations were plotted along the coast of Maine based on harvester logbook data (Fig. 4). Additionally, sea cucumber data obtained in scallop surveys were included. Sites with greater than 100 cucumbers per standard tow were then selected and the map was plotted over a 500 m coast grid (Fig. 5). Grids within 1000 m of plotted points were then considered because the survey was intended to focus on areas consisting of fishable densities of sea cucumbers. Next, the Frenchman Bay grid was divided into two strata: (1) Frenchman Shallow and (2) Frenchman Deep (Fig. 6). Based on this grid, stations were randomly selected within each stratum and sampling stations were selected without replacement. The survey stations selected based on this approach for the 2005 survey season were shown in Fig. 7 (for other two years, see result figures shown later). Additionally, the third area to be considered was Narraguagus Bay. This was not designated into shallow and deep strata because nearly 100% of the mapped area is less than 20 m.

Because of possible shifts in distribution of *C. frondosa*, shallow and deep strata in each area were surveyed during only one reproductive season in each year. The 2005 survey season was from November 17, 2004 through April 15, 2005, a total of eight trips were made with field observers recording data from the Maine Department of Marine Resources. Two observers were present on each trip to record data and only three individuals acted as observers throughout the investigation. Survey time varied between six and ten hours at sea. Poor weather conditions did not play a role by limiting collection of samples. Four trips were made out of Southwest Harbor, three out of Winter Harbor, and one out of Milbridge, Maine during the 2005 survey season.

The 2006 survey season was from November 15, 2006 to December 15, 2006. A total of eight trips were made with field observers recording data from the Maine Department of Marine Resources. Two observers were present on each trip to record data and only three individuals acted as observers throughout the investigation. Survey time varied between six and ten hours at sea. One hundred eight sampling sites were towed, and 18 sites were not surveyed because of unfishable grounds (e.g., mud bottom, presence of cables, untowable bottom) or gear issues (e.g., presence of lobster traps).

The 2007 survey season was from March 30, 2007 to May 9, 2007. A total of seven trips were made with field observers recording data from the Maine Department of Marine Resources. Two observers were present on each trip to record data and only three individuals acted as observers throughout the investigation. Survey time varied between six and ten hours at sea. Ninety-nine sampling sites were towed, and nine sites were not surveyed because of unfishable grounds and gear issues.

Onboard the boats, research technicians recorded density, location, habitat type, depth, and average size/location. Site-specific ecological data and sea cucumber biological data were analyzed to identify key ecological variables that influence the biology and abundance of the sea cucumber in the main fishing ground for sea cucumber in Maine. These included bottom-type, depth, and associated fauna when applicable. The relationships between *C. frondosa* and these additional variables have not been further analyzed to date.

Biovolume was determined by multiplying the mean standard catch volume (L) of each site by the total area (m^2). Total biovolume and the associated variance of *C. frondosa* were calculated within each stratum and then summed for all strata. This provided an estimate of total abundance of the study area. Catches were standardized to volume per meter squared at each sample site.

Detailed procedures for estimating sea cucumber stock sizes are described in Appendix I.

5-3. BACI experiment

A sentinel site was selected for the before- and after-fishing comparative study. The site was divided into two settings, one for the control area and the other for the fishing area. For both areas, a detailed survey was done to collect information on ecological variables and sea cucumber biological data. This survey was followed by fishing with a standard sea cucumber drag within a designated area at the site - leaving a control area unfished.

Two different bottom habitat sites (soft and hard) will be identified in the vicinity of Bean Island in Sullivan Harbor. Two plots each (i.e., experimental site and control site) of two different habitats (soft mud with underlying clay-tye sediment and rock/cobble/gravel with dese kelp), ranging from 3.7 to 8.2 meters MLW, were set up. Due to the density of fixed gear (lobster traps) replicate dredge sites could not be established. During the sea cucumber removal phase the 100-meter by 3.4-meter experimental plots were repeatedly dredged using commercial gears.

Each plot was marked at each end by GPS and poly-buoyed concrete anchors to facilitate re-visits. A 100 meter transect line was set randomly in each plot. A diver counted all cuke cucumbers within a meter either side of the transect line and collect all sea cucumbers within a meter squared area every 10 meters. We originally planned to dredge two to three plots (1 or 2 experimental and 1 replicate) of 100 meters by 5 meters (about 2-3 dredge widths). However, because of the fixed gear (i.e., lobster traps) issues in the experimental areas, we could only dredge one plot. The diver counted any remaining sea cucumber along the transect line set within each dredge path.

Total count, volume (L) and weight (Kg) were recorded for the dredge. Total count, size, and/or weight of a subsample were recorded for each dive transect, from which a total volume/weight was extrapolated.

The dredging was done on August 23, 2006. The diver survey of the control site which is next to the area dredged was done on August 24, 2006. Diver surveys were done for both dredging and control plots on the following dates: (1) August 31, 2006 (i.e., after one week); (2) September 21, 2006 (i.e., after one month); (3) November 21, 2006 (i.e., after 3 months); and (4) April 24, 2007 (i.e., after eight months).

6. Data

The data collected in this study include various morphological measurements and fecundity information collected in the biological study and density, location, habitat type, depth, and average size/location collected in the industry survey. In the survey we also collected the site-specific ecological data and sea cucumber biological data (e.g., morphological measurements). All the data were inputted and saved in Excel files which are submitted to the NEC.

7. Results and conclusions

7-1. Biological studies

C. frondosa along the coast of Maine had large temporal variations in GSI and such variations were similar among the three depth strata (Fig. 8). Significant changes in the mean GSI between months occurred repeatedly throughout the investigation (Tables 1, 2, and 3). Shallow sites exhibited three significant changes in the average GSI between the sampling times during our study (Table 1). For the mid-depth stratum, we were unable to test for the significance between months for gonad weight until May 2004 because, occasionally, samples brought in to represent our mid-depth stratum fell into the shallow or deep stratum. Two significant changes in the average GSI between May 2004 and March 2005 were observed (Table 2). Similarly, missing information from the deep water stratum did not allow GSI to be calculated between May of 2004 and February 2005 (Table 3). The average GSI for deep depth stratum tended to be lower than those of the other two depth strata (Tables 1, 2, and 3). The highest mean GSI occurred during January through March (Fig. 8) with the average GSI being greater than 10% of total body weight, which was significantly higher than at other times during the year.

The average length of sampled sea cucumbers over the sampling period for each depth was found to be independent of time and did not change significantly ($P>0.05$; Fig. 9). The morphological variables including live weight, length, width, and body cavity weight tended to be correlated with each other. Log live weight appeared to show the strongest correlation to log gonad weight for both females (Fig. 10) and males (Fig. 11). Correlation coefficient r values for log live weight and log gonad weight were highest for both females and males in all depths (Table 4). This suggests that the live weight might be the best indicator of gonad weight.

Regression analyses of data pooled over the three depth strata suggest that for females log body cavity weight (Fig. 12) had a higher coefficient of determinant (Table 5) than log length (Fig. 13) with log gonad weight. For males, log body cavity weight (Fig. 14) also showed a stronger coefficient of determinant (Table 5) than log length (Fig. 15) with log gonad weight. All regression models were found to be significant ($P < 0.05$).

The result shows that sea cucumbers along the coast of Maine had the highest GSI during January through March. This suggests that gonads are at peak development stage during January to March for both sexes. The dramatic decrease in GSI following March likely corresponded to the release of sperm and eggs and subsequent deflating of internal gonad structures. It was not possible to weigh and measure individual eggs and sperm during the course of this study. However the dramatic decrease in the average GSI at each depth observed post-March implies that a major spawning event took place during both consecutive seasons around this time. This result differs from that in a previous study which suggested that *C. frondosa* in Maine spawned later in the spring (Feindel, 2002). It is interesting to note that there were significant changes in mean GSI between months that occurred several times throughout the study. This suggests that animals may be producing eggs and sperm with the potential to spawn throughout the year, but it is more likely that differences in average GSI are reflective of developmental changes rather than actual spawning events.

We only used the GSI as a metric of temporal change in gonad development in this study. Although the GSI is simple and straightforward, histological characters tend to describe more accurately the reproductive state of ovaries than GSI alone. Future studies should employ both approaches for testing the consistency of the two methods in describing the reproductive state of ovaries of sea cucumber along the coast of Maine.

With the exception of females in February to March 2004, high correlations were observed between morphological variables and log gonad weight. This may be because gonad weights usually show the greatest variation as animals are preparing to spawn. Earlier gonadosomatic studies of fisheries have reported that gonad development is highly dynamic (Guy *et al.*, 2002) and triggered by warmer temperatures for other species of holothurians (Chao *et al.*, 1995).

In both sexes, live body weight and body cavity weight can be useful in predicting gonad weight. The r^2 of the relationship between these two variables and gonad weight is relatively low compared with other fish species (Ricker 1975), and may be reflective of variations due to combining all individuals of different maturation stages over different time period. This low r^2 values may also result from large measurement errors associated with measuring morphological variables of sea cucumber because of its unique biology.

Percentage gonad weight was significantly greater between January and March than during later months at every depth. It is interesting to note that animals collected in shallow water appeared to lag in gonad development and spat release when compared to samples collected in deep waters as evidenced by the greater percentage gonad weight lingering on in later months for shallow sites.

Feindel (2002) suggested that sea cucumbers spawned later than we observed in 2004-2005. According to data from the Maine Department of Marine Resources, the years of our investigation were characterized by cooler air temperatures than Feindel experienced during his field season (Figs. 16). Although sea surface temperatures did not appear to show much variation among all years (Fig. 17), water bottom temperatures were also reported as cooler in 2004-2005 (Fig 18). It is possible that the lag displayed in spawning for shallow animals may reflect that sea surface temperatures in 2004-2005 were most similar to climate conditions of 2002.

Our study supports the hypothesis that gonad development can be significantly influenced by depth. It appears animals harvested from shallower depths increase and subsequently decrease with regard to overall mean GSI later than deeper and mid areas. This may occur because shallower waters are warmer later in the season. Hamel and Mercier (1996) supported this hypothesis in their earlier work on *C. frondosa* in Canada. They suggested that the delay at shallower depths might be due to differences in pressure differences, interaction with other species, or possibly a combination of the collective influence of more than one variable (Hamel and Mercier, 1996).

It is important to consider that many species of echinoderms have been observed to aggregate before spawning or to spawn synchronously, increasing potential fertilization success even when individuals are not close to conspecifics (Pearse *et al*. 1988; Minchin 1992; Byrne 1999). We do not know how far eggs and sperm are able to travel and it is possible that *C. frondosa* may be density dependent for successful reproduction to take place.

During certain sampling dates, there were no data available for some depths. This may have been due to an instance where one depth classification collected actually fell into a different category due to assigned depth classifications for the purpose of this study. It is important to note that even though the entire sample size was quite large, differences between depths and sex may have reduced numbers to be too small to adequately observe trends. Sample size may have been inadequate if animals aggregated in similar size cohorts. This is unlikely in this study, however, because sea cucumbers exhibited a range in size from 5.2-32.1 cm and each group of individuals appeared varied in size, although the mean size of sea cucumbers sampled in different time is similar.

It is noteworthy to point out that the dataset from sampled animals may not necessarily represent the entire population structure. However, information collected from these animals suggested that average sea cucumber length was independent of sampling time and did not appear to change dramatically during the course of this investigation. Although overall sex ratio did not appear to display any bias, some samples were mainly composed of one sex or the other. There is not enough data to hypothesize why this may have occurred, but future investigation of sex ratio over a long period of time and large sample sizes would be interesting.

In summary, we concluded that the GSI peaked in January – March for both years covered in this study. The morphological variables live weight and body cavity weight were determined to be good predictors of gonad weight. All depths appeared to show similar patterns in gonad development, but animals collected in shallow regions were observed to lag in the development compared to those from mid and deep depths. Management practices based on these findings may include rotational harvest from shallow to deeper waters following the predicted spawning season so that animals have the opportunity to reproduce at different depths. If size limits were to be implemented on this species, live weight would be the best indicator of individual fecundity.

7-2. Industry survey

The maps of sea cucumber spatial distribution were created using GIS software. These spatial distribution maps display the standard catch in volume L/m^2 in Frenchman Bay for the two depth strata in the three survey years (Figs. 19, 20, 21, and 22), and the standard catch in Narraguagus Bay (Fig. 23). Bottom type was quantified into four categories including 1) gravel, 2) mud, 3) rock, and 4) sand.

In Frenchman Bay, the survey abundance indices ranged from 0-1.087, 0-1.037, and 0 – 0.224 L per standardized swept m^2 for the 2005, 2006, and 2007 survey years, respectively. If we measured the survey index as the gram per standardized swept m^2, the survey abundance indices ranged from 0 – 916.9, 0 - 758.3, and 0 – 170.4 grams per standardized swept m^2, respectively, for the 2005, 2006, and 2007 survey years. If we measured the survey index in the number of sea cucumber per standardized swept m^2, the survey abundance indices ranged from 0 – 3.645, 0 – 4.148, and 0 – 0.856 sea cucumbers per standardized swept m^2, respectively, for the 2005, 2006, and 2007 survey years. Patterns were not observed to be dependent upon depth strata. In the 2005 survey of Narraguagus Bay, the survey abundance index ranged from 0-0.340L/m^2, 0 – 321.5 g/m^2, and 1.352 cucumbers/m^2, respectively. Mean standard survey catch in Frenchman Bay was greater overall than that of Narraguagus Bay. As expected, *C. frondosa* appeared to show patchy distributions. This is consistent with prior research that had suggested the species tended to aggregate. The survey abundance index showed a decreasing trend from 2005 to 2007 in the surveys.

The estimation of total biovolume, biomass, and abundance is described in Table 6 for the < 20 m depth stratum and in Table 7 for the > 20 m depth stratum in the 2005 survey of Frenchman Bay. The results are presented in Tables 8 and 9 for the two depth strata in the 2006 survey and in Tables 10 and 11 for the two depth strata in the 2007 survey in the Frenchman Bay. The estimation results based on the 2005 survey of the Narraguagus Bay is described in Table 12.

The overall biomass decreased substantially from 15347 mt in 2005 to 5777 in 2006 in the Frenchman Bay, and this was the case for both deep and shallow water depth strata covered in this survey (Table 13). The biomass in both the shallow and deep depth strata in 2007 was similar to that in 2006, suggesting the biomass was might be stable in the last two years. The substantial decrease from 2005 to 2006 and 2007 might reflect the impacts of fishing activity on the stock.

The reported landings for the Gulf of Maine were 3886.1 mt in 2005, which is 22.8% of the total biomass (17,069 mt) of Frenchman Bay and Narraguagus Bay in 2005. The total sea cucumber landing was 3978.2 mt in 2006. However, we did not survey the Narraguagus Bay in

2006. If we use the ratio of stock biomasses of Frenchman Bay and Narraguagus Bay in 2005, the exploitation rate of sea cucumber in 2006 was 62.6%, much higher than that in 2005. However, it should be noted that the stock biomass estimation described here was derived with 100% dredge efficiency. The drag was not likely to be more than 50% efficient (Feindel, personal communication). Thus, less than 11.4% and 31.3% of the total biomass was harvested in 2005 and 2006, respectively. We don't know, however, what is the sustainable level of exploitation. Given its slow growth and complicated life history process, of which we do not have a good understanding, we would suspect that the sustainable level for exploitation could not be too high. We also don't know the survival rates of these individuals that were impacted by dredging but not landed. The large decrease in the estimated stock biomass and substantial increase in the exploitation rate in 2006 suggest that this level of exploitation (in 2006) might not be sustainable. More studies, however, need to be done to evaluate the impacts of survey timing on the estimation of stock biomass. Because surveys were done in different months among three years (due to gear conflicts and industry partners' schedules), the possible seasonal movement might affect the accuracy of the survey, which should be considered when we compared temporal trends in stock biomass.

The number of sea cucumbers found on each sediment type was plotted to determine whether *C. frondosa* might show a preference (Fig. 24). Rock bottom appeared to be the most favorable habitat for the sea cucumber in the survey area. For example, a total of almost 1,400 sea cucumbers were harvested in the 2005 survey. In Frenchman Bay for depths greater than 20 meters, 27% were collected on gravel bottom, 1% on mud, 72% on rocky substrate, and 0% on sand. In Frenchman Bay for depths less than 20 meters, 6% were collected on gravel bottom, 20% on mud, 69% on rocky substrate, and 5% on sand. In Narraguagus Bay, 18% were collected on gravel bottom, 6% on mud, 65% on rocky substrate, and 11% on sand.

The objective of this study was to estimate the stock size of sea cucumbers in the major fishing grounds of Maine. It is important to note that several factors limited the choice of survey approaches. Monetary and logistical resources defined sampling intensity possible and affected the scale of this investigation. The survey frame was limited to the primary fishing grounds, and participating fishermen and weather conditions determined sample dates and times. Physical structure of the study areas may additionally have influenced survey information. Finally, the estimation results assume there are not relationships between sea cucumbers and their environment that influences the spatial variability of animals. These might include migratory behavior, spatial aggregations, and seasonal variations may have also had an affect on the results. Because the survey took place over one reproductive season and sampled areas were randomly selected based on fisheries data, this assumption was likely not to be seriously violated.

There were some sites that were selected as part of the survey but could not be towed due to bottom types and/or lobster gears. Since loss of sampling grids resulted in smaller than expected survey areas, actual areas sampled were calculated by subtracting the lost grids from the original number planned. Therefore, only the actual area sampled was included.
Although the survey did not encompass the Gulf of Maine, it did allow for a comparison of the survey based estimation of stock biomass in Frenchman Bay and Narraguagus Bay and the total annual landings data provided by DMR.

Future surveys incorporating standard catch data encompassing the entire Gulf of Maine would aid in providing a better understanding of how the stock is distributed throughout region, both within and outside of fisheries targeted areas. Collecting additional data on biotic and abiotic factors such as bottom sediment, salinity, and water temperature would also provide critical information on habitat and distribution for *C. frondosa*. These variables could be layered into GIS maps to show how spatial distribution for this species may be influenced by them. Additionally, repeated random stratified surveys would both aid in creating a more complete spatial database for sea cucumbers in the Gulf of Maine, as well as provide a means by which to ascertain whether the stock is changing due to harvesting pressure over time.

C. frondosa was most frequently harvested on rock substrate. It is possible animals prefer this type of bottom sediment and/or harvest efficiency is greater in these areas. For the purposes of this investigation, habitat impact was not considered in this survey and there is no estimate of total area for each bottom type classification. It would be interesting for future studies to stratify surveys based on bottom type and calculate biomass for each. This would provide a more accurate stock estimation.

Additionally, it is important to include that management decisions based on the results of this random stratified survey may also need to consider that sea cucumbers may have some critical density that is needed for successful fertilization and thus reproduction. Managers may need to take into account that numbers alone do not necessarily reflect the status of the stock. Therefore, governance should target a level of biomass large enough able to maintain numbers above what may be a critical threshold value for the population so that consequences such as an Allee effect do not cause the population do not occur.

The life history of relatively sedentary species such as *C. frondosa* suggests that individuals do not migrate far from source populations to replenish exploited areas. Therefore local extinctions may occur, which has serious management implications for this fishery. Also, and more significantly, replenishment during planktonic larval stages is likely to be extremely important to stock population dynamics and recovery. The patchy distribution of the sea cucumbers and differences in their abundance over small spatial scale must also be taken into account in the management decisions for this species. Local scale management is likely necessary and important to effectively maintain viable biomass. For *C. frondosa*, understanding and incorporating the needs of the community into management strategies may stabilize stocks. The number of users, timing of harvesting, limits on catch, and seasonal closures should be regulated at the local level as long as enforcement and sanctions are well established.

While the random stratified survey estimated that 10% or less of the total biovolume of *C. frondosa* was harvested in 2004, it is interesting to consider that the model-based stock assessment suggests fishing mortality may be as high as 0.7 (Kirshenbaum 2005). Although it was not possible to be certain of the actual level of harvesting pressure, there are several possible reasons for the different results.

First, the biovolume estimate assumes at least 50% collection efficiency by dragging. However, four types of sediment were recorded for the sites of sea cucumber collection and each may have different values of efficiency. Therefore, assuming 50% over the entire area considered may be insufficient as a generalization.

Secondly, sea cucumbers have a patchy distribution and sampling sites were based on fishery dependent data. Sites considered for sampling were chosen because they were known through logbook and scallop survey data to have served as harvesting locations in the past. Therefore, this may have resulted in an overestimation of sea cucumber volume throughout the region because areas targeted had greater than average numbers due to aggregations.

Additionally, the survey did not consider habitat impact. It would be extremely interesting in future investigations to determine the percentage of bottom sediment in the study area quantified as gravel, mud, rocky, and sand. If the mean number of sea cucumbers and standard deviation for each habitat type could be estimated, it would then be possible to calculate a more accurate estimate of total biovolume based on potential habitat preference.

It is possible that the random stratified survey underestimated the percentage of *C. frondosa* that harvested in 2004, however, differences in level of estimated fishing mortality may additionally be due to errors in estimating F from size composition data in the stock assessment. The estimate was based on 933 samples collected by the Maine Department of Marine Resources. Some animals were harvested by dragging and others by SCUBA divers. This sample set may not be representative of the actual size distribution of the *C. frondosa* population in the Gulf of Maine. It is possible the smallest individuals were neglected in collection due to gear selectivity and/or difficulty in observing by divers. Also, the length-based method assumes constant recruitment and it is possible that sea cucumbers recruit in distinct cohorts separated in time. Finally, the sample size may also have been too small to reflect differences in population structure throughout the region.

Most likely differences in the estimated level of harvest are the result of both survey design and errors in stock assessment. Although it is not yet possible to be certain how close the values proposed as target and threshold biological reference points are to the precise levels of fishing pressure that will sustain the sea cucumber fishery in Maine, it is clear there is the need to be cautious making management decisions until more information is known on the biology and fishery for this species.

7-3. BACI experiment

The number of sea cucumbers counted for the plots for five different post-removal diver sampling intervals was summarized in Table 14. No clear pattern was observed between the experimental plot and control plot for the soft substrates. For the hard substrates, the number of sea cucumber in the experimental plot tended to increase with the time after the dredging depletion in the BACI experiment, suggesting the recovery of sea cucumber density after dredging. This suggests that for the hard substrate habitats sea cucumber abundance can recover within three months. The interpretation of this result should be cautious because of lack of repetitions in the BACI experiment.

Lack of pattern in changes of sea cucumber abundance in the BACI experiment for soft substrates may result from that fact that dredging may be less efficient on soft substrates, which may result in large proportion of sea cucumber being not removed from the BACI experimental area. The dredging efficiency may be much higher for the hard substrates, leading to efficient removal of a large number of sea cucumbers in hard substrate habitats. Thus, impacts of dredging on the sea cucumber abundance are likely to be less significant for soft substrates.

8. Partnerships

The majority of fishermen in this fishery are involved in this project one way or another. Five fishermen attended the first focus group meeting together with one concerned citizen (Peter Collin from Stonington, ME), two scientists from the Maine DMR and two scientists from UMaine. Mr. Dan Conley, one of the fishermen in the sea cucumber fishery has helped in collecting monthly samples for the biological data measurement. He has been very good to work with, responsive with sample collection needs and suggestions for survey approach and timing. DMR identified Lawrence Ray (Co-PI) and his crew for boat time and industry-based survey. In addition, DMR hired two fishermen as project assistants in the survey and BACI experiment as proposed in the original proposal.

After we derived the 2005 survey results, PIs (L. Ray, D. Ray, Feindel, and Chen), Conley (fisherman) and DMR scientists (Dr. Linda Mercer and Dan Shick) met in Dec. 2005 in Ray's Milbridge home to discuss the management implications and the project's next step. After that, we also had a few more meetings at the DMR West Boothbay Harbor to discuss issues related to the project, survey and management implications.

The questions addressed in this project are critical for the sustainable use of sea cucumber resources along the coast of Maine, and thus are the common interests of stakeholders. This common interest is the key for a good partnership among fishermen, scientists, and managers formed in this project. We have used fishermen's knowledge and data obtained from the fishery to help design the survey and the results derived from the survey are consistent with what fishermen have observed in the fishery. This is also helpful for forming good working relationships among fishermen, scientists, and managers in the future.

9. Impacts and applications

The PIs of this project consist of currently active sea cucumber fishermen and scientists of the Maine Department of Marine Resources and University of Maine. This combination allowed us to consider, and subsequently address concerns/questions of fishing industry, scientific community and management agency on the Maine sea cucumber fishery. The results derived in this project can be used in developing management plan for the Maine sea cucumber fishery.

The end users who will benefit from the results of this cooperative research will include the Maine Department of Marine Resources (developing management plan for the fishery) and fishing industry (sea cucumber resource availability and their distributions along the coast of Maine).

This project has addressed the following NEC priorities: (1) to develop partnership between commercial fishermen and researchers, educators, and coastal managers; (2) to enable commercial fishermen and commercial fishing vessels to participate in cooperative research and development; (3) to help bring fishermen's information, experience, and expertise into the scientific framework needed for fisheries management; and (4) to equip and utilize commercial fishing vessels as research and monitoring platform.

This project is a natural extension of the project entitled as "A preliminary study of the Maine Sea Cucumber (*Cucumaria frondosa*) Fishery" funded by the Northeast Consortium Program Development (Grant # 03-686). The approaches developed in the program development project and in a previous NEC program development project entitled as "A simulation framework for developing optimal sampling strategies for the Maine sea urchin stock" (Gant #: 02-628) will be used in this project for biological sampling, survey design, and data analyses.

Because of this project, over the last year, we have received numerous calls and emails from general public and fishermen inquiring about this project from USA, Canada, Iceland, Russia and China. The questions range from general questions about the biology of this species, potential fishery, to potential health problems that may cause to workers (in particular those migratory workers) in processing the sea cucumber. Most of the people who made an inquiry found this project from the NEC website.

The information collected and results analyzed in this project have played a critical role in formulating new management plan for the sea cucumber fishery in the state of Maine in 2005. We have provided the information to the Maine Legislature and Sheril Kirshenbaum (graduate student) was invited to testify about the Maine sea cucumber fishery before the Marine Resources Committee of Maine Legislature.

This project is the first one in the area that systematically studies the sea cucumber biology and fishery. We were invited by the Canadian Department of Fisheries and Oceans (DFO) to present at the Atlantic Canada emerging fisheries workshop Dec. 2005. Sheril Kirshenbaum made the presentation, and I was told by the workshop organizer that the information she presented at the meeting is very informative, valuable and helpful.

The end users who will benefit from the results of this cooperative research will include the Maine Department of Marine Resources (developing management plan for the fishery) and fishing industry (sea cucumber resource availability and their distributions along the coast of Maine).

This project has already had real and significant impacts and will have significant long-term impacts on the management of the sea cucumber fishery in Maine.

10. Related projects

"A preliminary study of the Maine Sea Cucumber (*Cucumaria frondosa*) Fishery" funded by the Northeast Consortium Program Development (Grant # 03-686)

11. Presentations

- Maine sea cucumber fishery presented at the School of Marine Sciences Graduate Symposium, Darling Marine Center, May, 2003.
- Assessing the Maine sea cucumber fishery. Northeast Consortium Annual meeting, Portsmouth, NH. Dec. 9, 2003.
- Biology and management policy of sea cucumber fishery in Maine, School of marine Sciences Graduate Symposium, Darling Marine Center, May 2004.
- Kirshenbaum, S. and Y. Chen. 2004. A fecundity study of the Maine sea cucumber population. 134th American Fisheries Society Annual meeting, Madison, WI, Aug. 23-27. 2004.
- Testified before the Marine Resources Committee of Maine Legislature, March, 2005.
- Sea cucumber fishery in Maine, School of marine Sciences Graduate Symposium, Darling Marine Center, May 2005.
- The Maine sea cucumber fishery research presented at the Canadian DFO Invertebrate Emerging Fisheries workshop in Halifax, NS. Dec. 2005.

12. Student participation

One of key participants of this project, Sheril kirshenbaum, was a graduate student who graduated from the dual Master degrees program in Marine Biology and Marine Policy in Dec. 2005. She has been responsible for the lab work, presented the work at various meetings and conferences, and answered the public enquires which we have received over the last years. Several undergraduate students of the University of Maine (Orono) also helped with the lab work.

Part of this report is from Kirshenbaum's thesis for the dual Master degrees in Marine Biology and Marine Policy.

13. Published reports and papers

- Kirshenbaum, S. 2005. Assessment and management of the Maine sea cucumber (*cucumaria frondosa*). Thesis for MS in Marine Biology and MS in Marine Policy, School of Marine Sciences, University of Maine, Orono, Maine.
- Chen, Y. ,S. Feindel, and S. Kirshenbaum. 2005. A preliminary study of Maine sea cucumber fishery. Report submitted to the Northeast Consortium.
- Kirshenbaum, S., Y. Chen, and S. Feindel. 2007. Reproductive biology of sea cucumber, *Cucumaria frondosa*, off the coast of Maine in USA (in revision).
- Feindel, Chen, Kirshenbaum, etc. Develop an industry-based survey program for a sea cucumber population with a patchy distribution (in preparation).

14. Images

See figures 3-7 and figures 19-23.

15. Future research

Biological study

Future research should be focused on the study of the following areas:

(1) growth;
(2) recruitment;
(3) natural mortality;
(4) spatial dynamics (i.e., seasonal movement) and role of spatial scales in studying the population dynamics of sea cucumber and in developing management policy for this stock;
(5) factors that may influence the life history process; We also need to have a better understanding of role of spatial scales; and
(6) distribution of sea cucumber outside the current fishing grounds.

Only with a better understanding of these two processes will we have a better understanding of the sea cucumber population dynamics, which is critical to the management of the fishery.

Developing possible rotational closure preceding spawning event

Management decisions are often based on current data available. Annual, seasonal, and daily changes in conditions should be incorporated into a policy of adaptive governance. We need to study the possibility to institute a rotational closure to allow previously harvest regions to recover and animals reestablish themselves over time.

As found in this study, the timing of spawning appears to vary by year depending on climactic conditions so that a regular seasonal closure around this time would be difficult to plan. Rotational closures throughout the season would both allow dispersal and settlement of larvae when animals are spawning in some areas and also offer adults that have a just spawned the chance to recover later.

When an area is dragged, we estimated that gear efficiency is less than 50%. Therefore, dragged regions will not be completely depleted if a rotational closure provides the opportunity for animals to reestablish, grow, and reproduce within the area. This conservative measure would provide necessary stock protection should the fishery be open to more boats. More research should be undertaken to identify critical habitat for cucumbers and select areas where a rotational closure would best be instituted. This study suggests that sea cucumbers are most highly concentrated in areas with a rocky substrate so the most animals would be protected under a rotational closure if areas selected are categorized as rocky.

One possible source of contention with industry members is that there is already a seasonal closure during the summer to avoid conflicts with lobster gear. However, it is likely that a rotational closure would readily accepted among the small number of current license holders that actively harvest because they already abide by a de facto rotational closure system by waiting to revisit a recently harvested region. Therefore, industry members should not be adversely affected by rotational closure and it would be expected that they would mutually agree upon adherence to this policy. Under such circumstances, enforcement would not present high additional transaction costs. More studies are needed in identifying a management framework to incorporate the proposed rotational closure and how the industry may respond to this management measure.

Monitoring with industry involvement

In fisheries, the effective capacity to regulate what goes on in isolated and widely scattered fishing grounds is limited. National governments often underestimate the strengths of experience and knowledge based informal management systems while over-estimating their ability to manage a resource (Pomeroy 1996). Management decisions based solely on the traditional calculation for MSY are not adequate in a multi-species environment and more importantly, ignore the critical aspect of industry participation in creating new institutions. Pomeroy suggests that fisheries management at the local level may be more effective than management by distant national government fisheries agencies which are typically under-staffed and under-funded.

Fisheries cannot be managed effectively without the cooperation of members to make laws and regulations work (Kuperan, K. & Mustapha 1994; Yamamoto, T., 1994). Studies from around the world have shown that industry members can effectively regulate access and enforce rules through their own institutions and social practices under certain conditions (Hviding and Jul-Larsen, 1993; Ruddle 1994; Dyer and McGoodwin 1994). Involvement at the local level provides a great deal of shared knowledge on which to base scientific future scientific research. Given the small size and close associations of members in the Maine sea cucumber industry, I recommend establishing an industry-monitoring program. Fishermen can take part in collecting information on *C. frondosa* to estimate biological information on which to base management decisions. Harvesters can be trained in dive survey methodology and encouraged to participate in sea cucumber monitoring programs during the spawning related closures. This will provide a constant supply of field data on temporal and spatial distribution and possibly growth if tagging studies continue. More importantly, it would encourage sea cucumber fishermen to be invested in the future of the industry and have an active role in conservation strategy. More studies need to be done to work out the detailed structure for such a monitoring program.

Limited Entry

The small number of harvesters makes the future sustainability and profitability of the Maine sea cucumber industry more likely. Acheson (2003), Ostrom (2000), and Wade (1994) suggest that small group and common norms among users with some degree of homogeneity make compliance more likely and promote sustainable harvest. These conditions allow for local level user monitoring. Restricted access also reduces competition and keeps members invested in the future of the fishery.

The addition of new boats will be likely to result in the opening of more processing plant along Maine's coast. If this were to take place, the sea cucumber population would become extremely difficult to monitor. In turn, transaction costs would increase dramatically and a competition to take as much as possible (i.e. tragedy of the commons scenario) will ensue. The long-term economic and social viability of the industry will be at risk if entry into the fishery is opened to more boats.

Finally, limiting licenses will further promote conservative measures. Stakeholders are more vested in the future of the industry because they feel a sense of ownership and responsibility for the species. For the Maine sea cucumber, harvesters share a kinship relationship and have a mutual understanding of what the fishery means to shared revenue. This mutual interest in the welfare of the fishery and shared respect for one other provide the unique opportunity to protect the species from overexploitation.

Given the importance of limited entry, any possible increase in fishing efforts should be subject to careful studies.

Maine sea cucumber forums

The forums promoting education on conservative practices and how they relate to the future of an industry are vital in creating incentives to become vested in the fishery. When users understand the ways in which their actions affect potential income and the continued accessibility of the resource, they will be more likely to want to protect it from overexploitation. Meetings can include educational sessions presented in a manner that is both interesting and inoffensive. Through an interactive learning environment, harvesters can be encouraged to participate in educating everyone about what they know. This arrangement promotes open dialogue and fishermen would feel they are on equal social footing with government members and scientists. In turn, this would create a sense of community among all stakeholders involved and build a bridge for honest information to be exchanged in a non-threatening setting.
The Maine fishing industry already meets annually at the Maine Fishermen's Forum in Rockland, ME. This conference is attended by government officials, industry members, university scientists and students, and many additional other interested groups. Most sea cucumber industry members already participate in these proceedings because they are involved in other industries. Therefore, it would be relatively easy to incorporate a type of sea cucumber session into the already established and highly regarded larger conference. The cost would be low and it would provide an easy means to encourage open dialogue among stakeholders in a friendly setting.

Biological reference points for management

Although biological reference points (BRPs) were estimated for the Maine sea cucumber fishery (Kirshenbaum 2005), the current estimation of the BRPs is affected greatly by growth parameters and natural mortality of which there is not yet a good understanding for *C. frondosa*. Future studies should reduce the uncertainty associated with the estimated BRPs.

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Appendix I. Procedures for estimating sea cucumber stock sizes in Maine.

(1) Got data set in Excel from the Maine Department of Marine Resources (Glen, personal communications);

(2) Calculated tow locations and tow time using in Excel from raw data;

(3) Copied out repeat tows to represent individual stations; e.g., when "replicate" survey tows extrapolated there is a total of 106 tows; 10 UF, 7 PS; Initially plotted was FMLT 76, FMGT 41, FMPS 10'

(4) Added "note" column to identify when a single tow was "extrapolated" then hid column;

(5) Added "SEQ" column to enumerate tow number as performed in chronological order (note: all tows are around 5 minutes);

(6) Calculated "size index" for catch size frequency composition. Size index = length x d1 x d2 x0.001 (Feindel 2000; note: a "tote" weighs about 140-150 lbs (creaser));

(7) Created pivot chart to calculate mean, standard deviation, count of size index for each tow

(8) Copied catch, mean size index, standard deviation, count data to "station" table and renamed "station&cat" (note: "COUNTSI" is also a measure of size – number of cukes in a 10L bucket – except when vol is less than 10);

(9) Replotted initial planned survey stations in GIS. Separate table for each stratum and "permanent stations";

(10) Created DBF file of STATION&CATGIS file for import into GIS and removed unfishable stations (*Note: Drop UF because of traps stations from analysis (treats as mean catch) and shrink fishable area by percent UF by too shallow, rocky or land etc);*

(11) Plotted tow start and haulback points; Created line theme to represent distances between tow start and haulback. Autolabeled points with station name, drew distance lines, hand entered station names in new theme table. Used Xtools to calculate distance of drawn line (Projection property set at Maine, East State Plane 1983. Projection: Transverse Mercator, Spheroid GRS 80, Central Merisian: -68.5, Reference Latitude: 43.666666666667, Scale Factor: 0.9999, False Easting: 300000l False Northing: 0;

(12) Incorporated tow distances into "Station&Cat" Data;

(13) Estimated weight of sampled cukes based on size index and conversion regression from Feindel 2000 (note: agrees extremely well with Jordan, 1972 regression). Pivot chart on cuke LF to compute mean/sd/ count size index; total sampled weight. Expanded sampled weight to equivalent catch weight. Standardized per meter towed (Estimated catch weight/ (distance towed x drag width in M)). Note drag width limited to 5'6" → 1.6764m (these

are outside dimensions so perhaps induces a small bias). Recalculated using 1.6002 m (5.25 feet) as INSIDE DRAG DIMENSION (assumes 1" bar stock);

(14) Calculated survey means for each stratum on grams/m^2 towed, liters/ m^2 towed, abundance/ m^2 towed. All estimates bootstrapped. (Distribution of catches skewed to the "left"- long right tail). 90 & 95% confidence intervals calculated (again bootstrapped – using 10,000 iterations). Used resampling program (http://www.uvm.edu/~dhowell/StatPages/Resampling/Resampling.html).

(15) Applied means to survey frame (accounting for unfishable areas). When area truly unfishable – shrunk the survey fram in proportion to number of unfishable random stations. When unfishable due to traps – simply dropped station (assumes that on average same as other stations);

(16) We believe that weight-based is more representative because often situation where volume of catch is determined by putting animals in 10L pail. This is not the same as throwing 200 cukes in a tote and letting them squash down (i.e. catch volume is overestimated usually). Looked up standard fish tote volume (NMFS) – use 75L instead of 70L;

(17) Calculated weighted mean count per volume * 75L (tote conversion) for conversion from stock abundance to totes (more accurate than using standard 220 cukes/tote mean).

Notes:

FMLT = 715 total possible squares (500m x 500m = 250000 m^2 = 25 hectares) = 17875 total hectares (original was 730 squares – revised 2006/7 down because taunton bay included) (sheril initially 18250 and 8850)

FMGT = 354 possible squares = 8850 hectares

TOTES = 145LBS = 65.8 kg
TOTES = 140 LBS=63.503 KG = MEAN OF 220 CUKES/TOTE

Table 1. Shallow depth (2-6 fathoms) mean GSI for each time period sampled. Different letters between the two neighboring sampling times correspond to a significant change in average GSI between the sampling times.

SHALLOW

Time	Female	Mean GSI	N	Male	Mean GSI	N
Feb-Mar	a	0.1057	77	a	0.1398	79
Mar-Apr	a	0.0905	62	a	0.1031	83
Apr-Apr	b	0.0709	70	a	0.0909	69
Apr-May	c	0.0687	78	a	0.074	58
May-Jun	c	0.0781	44	a	0.0609	49
Jun-Nov	c	0.0791	51	a	0.0597	46
Nov-Dec	c	0.0846	49	b	0.0876	51
Dec-Jan	d	0.117	46	c	0.1514	54
Jan-Jan	d	0.1598	52	c	0.2006	49
Jan-Feb	d	0.1642	54	c	0.2055	47
Feb-Mar	d	0.1455	49	d	0.1874	51

Table 2. Mid depth (7-24 fathoms) mean GSI for each time period sampled. Different letters between the two neighboring sampling times correspond to a significant change in average GSI between the sampling times.

MID

Time	**Female**	**Mean GSI**	**N**	**Male**	**Mean GSI**	**N**
Feb-Mar		0.1485	18		0.1761	42
Mar-Apr		0.0708	27		0.0911	21
Apr-Apr		0.0708	27		0.0911	21
Apr-May		0.07	31		0.0776	18
May-Jun	a	0.0737	89	a	0.0789	60
Jun-Nov	b	0.0835	114	a	0.0829	85
Nov-Dec	b	0.094	72	b	0.0997	77
Dec-Jan	c	0.1416	72	c	0.1605	78
Jan-Jan	c	0.1557	79	c	0.1863	65
Jan-Feb	c	0.1693	49	c	0.1727	45
Feb-Mar	c	0.166	49	c	0.165	51

Table 3. Deep depth (25-50 fathoms) mean GSI for each time period sampled. Different letters between the two neighboring sampling times correspond to a significant change in average GSI between the sampling times.

DEEP

Time	**Female**	**Mean GSI**	**N**	**Male**	**Mean GSI**	**N**
Feb-Mar	a	0.0998	50	a	0.1007	49
Mar-Apr	a	0.051	50	a	0.0716	28
Apr-Apr	a	0.0586	71	a	0.0645	15
Apr-May	a	0.069	72	a	0.0634	25
May-Jun		0.0758	36		0.0694	14
Jun-Nov						
Nov-Dec		0.0862	28		0.0876	22
Dec-Jan		0.0862	28		0.0876	22
Jan-Jan						
Jan-Feb		0.1349	27		0.1488	23
Feb-Mar	b	0.1312	51	b	0.1353	49

Table 4. Correlation coefficients (r) averaged over sampling time periods between log gonad weight and observable morphological values at each depth.

	R Values	Ln(length)	Ln(width)	Ln(weight)	Ln(live weight)
Female					
	shallow	0.499164	0.371536	0.521779	**0.575884**
	mid	0.094828	0.400248	**0.455809**	0.442094
	deep	0.49245	0.642836	**0.779926**	0.679458
Male	**shallow**	0.418249	0.290094	0.528592	**0.531035**
	mid	0.389247	0.507525	0.596614	**0.634669**
	deep	0.275284	0.43735	**0.532284**	0.424286

Table 5. Regression equations for pooled data on the relationship between log gonad weight and the variables for log live weight and log body weight. Parameters *a* and *b* are intercept and sloe of the model and SE = standard error.

Dependent variable	Independent variable	r^2	a (SE)	b (SE)	p value
Females					
Log (gonad weight)	Log (body weight)	0.52	-2.48 (0.186)	1.2 (0.039)	<0.0001
log (gonad weight)	Log (length)	0.30	-0.64 (0.199)	1.44 (0.073)	<0.0001
Male					
Log (gonad weight)	Log (body weight)	0.35	-1.65 (0.247)	1.06 (0.051)	<0.0001
log (gonad weight)	Log (length)	0.07	-0.29 (0.483)	1.22 (0.157)	<0.0001

Table 6. Summary of survey results for *Cucumaria frondosa* in the Frenchman Bay less than 20 meter depth stratum in the 2005 survey year.

FMLT = Frenchman Bay < 20 m
FMGT = Frenchman Bay > 20 m

2005 SURVEY YEAR

STRATUM: FMLT20 (FRENCHMAN BAY LESS THAN 20 M DEPTH)

N (Assigned stations)	64		
N (Stations successfully towed)	**58**		
N (Unfishable stations due to gear conflict)	1		
N (Unfishable stations due to non-gear issues)	5		
TOTAL AREA (Initial stratum frame)	(715) 500 m^2 grids = 17875 Hectares		
% TOTAL AREA UNFISHABLE (for non-gear reasons)	0.08		
ADJUSTED TOTAL AREA	**16479 Hectares**		
WEIGHTED MEAN SIZE INDEX FOR STRATUM	**341**		
WEIGHTED MEAN COUNT/TOTE FOR STRATUM	**256**		

SURVEY STATISTICS

	STDCATWT (g/m^2 swept)	STDCATVOL (L/m^2 swept)	STDABND (#/m^2 swept)
MEAN*	**57.582**	**0.088**	**0.279**
UPPER BOUND (95% C.I.)	90.127	0.18	0.603
LOWER BOUND (95% C.I.)	38.513	0.054	0.163
SE	11.521	0.022	0.077
UPPER BOUND (90% C.I.)	84.961	0.155	0.537
LOWER BOUND (90% C.I.)	41.251	0.059	0.178
SE	11.600	0.022	0.077
SE (% OF MEAN)	0.201	0.250	0.276

EXPANDED ESTIMATES

	BIOMASS (Kg)	BIOVOLUME (L)	POPULATION EST (n)
TOTAL	**9488659**	**14484615**	**45975059**
UPPER BOUND (95% C.I.)	14851592	29661328	99365449
LOWER BOUND (95% C.I)	6346371	8898398	26859980
UPPER BOUND (90% C.I.)	14000312	25541699	88489629
LOWER BOUND (90% C.I.)	6797552	9722324	29331758
CONVERSION TO TOTES*	**144268**	**193128**	**179773**
UPPER BOUND (95% C.I.)	225808	395484	388541
LOWER BOUND (95% C.I)	96492	118645	105029
UPPER BOUND (90% C.I.)	212865	340556	346014
LOWER BOUND (90% C.I.)	103352	129631	114694

* bootstrapped statistics; 10,000 runs; using "RESAMPLING" program (http://www.uvm.edu/~dhowell/StatPages/Resampling/Resampling.html).

** Conversion factors

1 tote = 65.771 kg (145 lbs; range is really 140-150 lbs)	*65.77 kg*
1 tote = 75L (NMFS; standard conversion for full fish tote)	*75 L*
1 tote = 220 cucumbers (size dependent ranging from 130-256; Feindel, 2002)	*220 cukes*

Table 7. Summary of survey results for *Cucumaria frondosa* in the Frenchman Bay greater than 20 meter depth stratum in the 2005 survey year.

FMLT = Frenchman Bay < 20 m
FMGT = Frenchman Bay > 20 m

2005 SURVEY YEAR

STRATUM: FMGT20 (FRENCHMAN BAY GREATER THAN 20 M DEPTH)

N (Assigned stations)	32		
N (Stations successfully towed)	**21**		
N (Unfishable stations due to gear conflict)	9		
N (Unfishable stations due to non-gear issues)	2		
TOTAL AREA (Initial stratum frame)	(354) 500 m^2 grids = 8850 Hectares		
% TOTAL AREA UNFISHABLE (for non-gear reasons)	0.0625		
ADJUSTED TOTAL AREA	**8296.875 Hectares**		
WEIGHTED MEAN SIZE INDEX FOR STRATUM	**477**		
WEIGHTED MEAN COUNT/TOTE FOR STRATUM	**213**		

SURVEY STATISTICS

	STDCATWT (g/m^2 swept)	STDCATVOL (L/m^2 swept)	STDABND (#/m^2 swept)
MEAN*	**70.602**	**0.095**	**0.247**
UPPER BOUND (95% C.I.)	139.033	0.179	0.536
LOWER BOUND (95% C.I.)	35.603	0.05	0.117
SE	21.267	0.027	0.078
UPPER BOUND (90% C.I.)	126.429	0.168	0.476
LOWER BOUND (90% C.I.)	41.695	0.058	0.139
SE	20.886	0.027	0.078
SE (% OF MEAN)	0.296	0.284	0.316

EXPANDED ESTIMATES

	BIOMASS (Kg)	BIOVOLUME (L)	POPULATION EST (n)
TOTAL	**5857760**	**7882031**	**20493281**
UPPER BOUND (95% C.I.)	11535394	14851406	44471250
LOWER BOUND (95% C.I)	2953936	4148438	9707344
UPPER BOUND (90% C.I.)	10489656	13938750	39493125
LOWER BOUND (90% C.I.)	3459382	4812188	11532656
CONVERSION TO TOTES*	**89063**	**105094**	**96249**
UPPER BOUND (95% C.I.)	175388	198018.75	208865
LOWER BOUND (95% C.I)	44913	55312.5	45592
UPPER BOUND (90% C.I.)	159488	185850	185485
LOWER BOUND (90% C.I.)	52597	64162.5	54165

* bootstrapped statistics; 10,000 runs; using "RESAMPLING" program (http://www.uvm.edu/~dhowell/StatPages/Resampling/Resampling.html).

** Conversion factors

1 tote = 65.771 kg (145 lbs; range is really 140-150 lbs)	*65.77 kg*
1 tote = 75L (NMFS; standard conversion for full fish tote)	*75 L*
1 tote = 220 cucumbers (size dependent ranging from 130-256; Feindel, 2002)	*213 cukes*

Table 8. Summary of survey results for *Cucumaria frondosa* in the Frenchman Bay less than 20 meter depth stratum in the 2006 survey year.

FMLT = Frenchman Bay < 20 m
FMGT = Frenchman Bay > 20 m

2006 SURVEY YEAR

STRATUM: FMLT20 (FRENCHMAN BAY LESS THAN 20 M DEPTH)

N (Assigned stations)	76		
N (Stations successfully towed)	**65**		
N (Unfishable stations due to gear conflict)	3		
N (Unfishable stations due to non-gear issues)	8		
TOTAL AREA (Initial stratum frame)	(715) 500 m^2 grids = 17875 Hectares		
% TOTAL AREA UNFISHABLE (for non-gear reasons)	0.105263158		
ADJUSTED TOTAL AREA	**15993 Hectares**		
WEIGHTED MEAN SIZE INDEX FOR STRATUM	**397**		
WEIGHTED MEAN COUNT/TOTE FOR STRATUM	**237**		
SURVEY STATISTICS			
	STDCATWT *(g/m^2 swept)*	**STDCATVOL** *(L/m^2 swept)*	**STDABND** *(#/m^2 swept)*
MEAN*	**22.724**	**0.032**	**0.095**
UPPER BOUND (95% C.I.)	30.751	0.044	0.133
LOWER BOUND (95% C.I.)	16.747	0.024	0.068
SE	3.352	0.005	0.015
UPPER BOUND (90% C.I.)	29.333	0.042	0.125
LOWER BOUND (90% C.I.)	17.728	0.025	0.072
SE	3.369	0.005	0.015
SE (% OF MEAN)	0.148	0.156	0.158
EXPANDED ESTIMATES			
	BIOMASS *(Kg)*	**BIOVOLUME** *(L)*	**POPULATION EST** *(n)*
TOTAL	**3634345**	**5117895**	**15193750**
UPPER BOUND (95% C.I.)	4918137	7037105	21271250
LOWER BOUND (95% C.I)	2678418	3838421	10875526
UPPER BOUND (90% C.I.)	4691350	6717237	19991776
LOWER BOUND (90% C.I.)	2835314	3998355	11515263
CONVERSION TO TOTES*	**55258**	**68239**	**64109**
UPPER BOUND (95% C.I.)	74777	93828	89752
LOWER BOUND (95% C.I)	40723	51179	45888
UPPER BOUND (90% C.I.)	71329	89563	84353
LOWER BOUND (90% C.I.)	43109	53311	48588

* bootstrapped statistics; 10,000 runs; using "RESAMPLING" program (http://www.uvm.edu/~dhowell/StatPages/Resampling/Resampling.html).

** Conversion factors

1 tote = 65.771 kg (145 lbs; range is really 140-150 lbs)	*65.77 kg*
1 tote = 75L (NMFS; standard conversion for full fish tote)	*75 L*
1 tote = 220 cucumbers (size dependent ranging from 130-256; Feindel, 2002)	*220 cukes*

Table 9. Summary of survey results for *Cucumaria frondosa* in the Frenchman Bay greater than 20 meter depth stratum in the 2006 survey year.

FMLT = Frenchman Bay < 20 m
FMGT = Frenchman Bay > 20 m

2006 SURVEY YEAR

STRATUM: FMGT20 (FRENCHMAN BAY GREATER THAN 20 M DEPTH)

N (Assigned stations)	40		
N (Stations successfully towed)	**33**		
N (Unfishable stations due to gear conflict)	4		
N (Unfishable stations due to non-gear issues)	3		
TOTAL AREA (Initial stratum frame)	(354) 500 m^2 grids = 8850 Hectares		
% TOTAL AREA UNFISHABLE (for non-gear reasons)	0.075		
ADJUSTED TOTAL AREA	**8186.25 Hectares**		
WEIGHTED MEAN SIZE INDEX FOR STRATUM	**464**		
WEIGHTED MEAN COUNT/TOTE FOR STRATUM	**237**		

SURVEY STATISTICS

	STDCATWT (g/m^2 swept)	STDCATVOL (L/m^2 swept)	STDABND (#/m^2 swept)
MEAN*	**26.179**	**0.041**	**0.094**
UPPER BOUND (95% C.I.)	49.030	0.074	0.176
LOWER BOUND (95% C.I.)	15.408	0.024	0.054
SE	6.641	0.010	0.024
UPPER BOUND (90% C.I.)	43.324	0.068	0.158
LOWER BOUND (90% C.I.)	16.873	0.026	0.06
SE	6.663	0.01	0.024
SE (% OF MEAN)	0.255	0.244	0.255

EXPANDED ESTIMATES

	BIOMASS (Kg)	BIOVOLUME (L)	POPULATION EST (n)
TOTAL	**2143078**	**3356363**	**7695075**
UPPER BOUND (95% C.I.)	4013718	6057825	14407800
LOWER BOUND (95% C.I)	1261337	1964700	4420575
UPPER BOUND (90% C.I.)	3546611	5566650	12934275
LOWER BOUND (90% C.I.)	1381266	2128425	4911750
CONVERSION TO TOTES**	**32584**	**44751.5**	**32469**
UPPER BOUND (95% C.I.)	61026	80771	60792
LOWER BOUND (95% C.I)	19178	26196	18652
UPPER BOUND (90% C.I.)	53924	74222	54575
LOWER BOUND (90% C.I.)	21001	28379	20725

* bootstrapped statistics; 10,000 runs; using "RESAMPLING" program (http://www.uvm.edu/~dhowell/StatPages/Resampling/Resampling.html).

** Conversion factors
1 tote = 65.771 kg (145 lbs; range is really 140-150 lbs) *65.77 kg*
1 tote = 75L (NMFS; standard conversion for full fish tote) *75 L*
1 tote = 220 cucumbers (size dependent ranging from 130-256; Feindel, 2002) *220 cukes*

Table 10. Summary of survey results for *Cucumaria frondosa* in the Frenchman Bay less than 20 meter depth stratum in the 2007 survey year.

FMLT = Frenchman Bay < 20 m
FMGT = Frenchman Bay > 20 m

2007 SURVEY YEAR

STRATUM: FMLT20 (FRENCHMAN BAY LESS THAN 20 M DEPTH)

N (Assigned stations)	67		
N (Stations successfully towed)	**61**		
N (Unfishable stations due to gear conflict)	1		
N (Unfishable stations due to non-gear issues)	5		
TOTAL AREA (Initial stratum frame)	(715) 500 m^2 grids = 17875 Hectares		
% TOTAL AREA UNFISHABLE (for non-gear reasons)	0.074626866		
ADJUSTED TOTAL AREA	**16541 Hectares**		
WEIGHTED MEAN SIZE INDEX FOR STRATUM	**462**		
WEIGHTED MEAN COUNT/TOTE FOR STRATUM	**217**		

SURVEY STATISTICS

	STDCATWT *(g/m^2 swept)*	**STDCATVOL** *(L/m^2 swept)*	**STDABND** *(#/m^2 swept)*
MEAN*	**27.085**	**0.038**	**0.097**
UPPER BOUND (95% C.I.)	37.470	0.053	0.151
LOWER BOUND (95% C.I.)	20.122	0.029	0.067
SE	4.085	0.006	0.018
UPPER BOUND (90% C.I.)	35.715	0.050	0.141
LOWER BOUND (90% C.I.)	20.941	0.300	0.072
SE	4.150	0.006	0.018
SE (% OF MEAN)	0.153	0.158	0.186

EXPANDED ESTIMATES

	BIOMASS *(Kg)*	**BIOVOLUME** *(L)*	**POPULATION EST** *(n)*
TOTAL	**4480142**	**6285597**	**16044813**
UPPER BOUND (95% C.I.)	6197929	8766754	24976978
LOWER BOUND (95% C.I)	3328389	4796903	11082500
UPPER BOUND (90% C.I.)	5907634	8270522	23322873
LOWER BOUND (90% C.I.)	3463860	49623134	11909552
CONVERSION TO TOTES*	**68117**	**83808**	**73963**
UPPER BOUND (95% C.I.)	94235	116890	115138
LOWER BOUND (95% C.I)	50606	63959	51088
UPPER BOUND (90% C.I.)	89821	110274	107513
LOWER BOUND (90% C.I.)	52666	661642	54900

* bootstrapped statistics; 10,000 runs; using "RESAMPLING" program (http://www.uvm.edu/~dhowell/StatPages/Resampling/Resampling.html).

** Conversion factors

1 tote = 65.771 kg (145 lbs; range is really 140-150 lbs)	*65.77 kg*
1 tote = 75L (NMFS; standard conversion for full fish tote)	*75 L*
1 tote = 220 cucumbers (size dependent ranging from 130-256; Feindel, 2002)	*220 cukes*

Table 11. Summary of survey results for *Cucumaria frondosa* in the Frenchman Bay greater than 20 meter depth stratum in the 2007 survey year.

FMLT = Frenchman Bay < 20 m
FMGT = Frenchman Bay > 20 m

2007 SURVEY YEAR

STRATUM: FMGT20 (FRENCHMAN BAY GREATER THAN 20 M DEPTH)

N (Assigned stations)	32		
N (Stations successfully towed)	**28**		
N (Unfishable stations due to gear conflict)	4		
N (Unfishable stations due to non-gear issues)	0		
TOTAL AREA (Initial stratum frame)	(354) 500 m^2 grids = 8850 Hectares		
% TOTAL AREA UNFISHABLE (for non-gear reasons)	0		
ADJUSTED TOTAL AREA	**8850 Hectares**		
WEIGHTED MEAN SIZE INDEX FOR STRATUM	**676**		
WEIGHTED MEAN COUNT/TOTE FOR STRATUM	**137.34**		

SURVEY STATISTICS

	STDCATWT *(g/m^2 swept)*	**STDCATVOL** *(L/m^2 swept)*	**STDABND** *(#/m^2 swept)*
MEAN*	**14.428**	**0.020**	**0.036**
UPPER BOUND (95% C.I.)	23.910	0.034	0.063
LOWER BOUND (95% C.I.)	8.271	0.011	0.020
SE	3.432	0.005	0.009
UPPER BOUND (90% C.I.)	21.631	0.031	0.057
LOWER BOUND (90% C.I.)	9.308	0.013	0.023
SE	3.382	0.005	0.009
SE (% OF MEAN)	0.234	0.250	0.250

EXPANDED ESTIMATES

	BIOMASS *(Kg)*	**BIOVOLUME** *(L)*	**POPULATION EST** *(n)*
TOTAL	**1276878**	**1770000**	**3186000**
UPPER BOUND (95% C.I.)	2116035	3009000	5575500
LOWER BOUND (95% C.I)	731984	973500	1770000
UPPER BOUND (90% C.I.)	1914344	2743500	5044500
LOWER BOUND (90% C.I.)	823758	1150500	2035500
CONVERSION TO TOTES*	**19414**	**23600**	**23198**
UPPER BOUND (95% C.I.)	32173	40120	40596
LOWER BOUND (95% C.I)	11129	12980	12888
UPPER BOUND (90% C.I.)	29106	36580	36730
LOWER BOUND (90% C.I.)	12525	15340	14821

* bootstrapped statistics; 10,000 runs; using "RESAMPLING" program (http://www.uvm.edu/~dhowell/StatPages/Resampling/Resampling.html).

** Conversion factors

1 tote = 65.771 kg (145 lbs; range is really 140-150 lbs)	*65.77 kg*
1 tote = 75L (NMFS; standard conversion for full fish tote)	*75 L*
1 tote = 220 cucumbers (size dependent ranging from 130-256; Feindel, 2002)	*220 cukes*

Table 12. Summary of survey results for *Cucumaria frondosa* in the Narraguagus Bay in the 2005 survey year.

FMLT = Frenchman Bay < 20 m
FMGT = Frenchman Bay > 20 m

2005 SURVEY YEAR

STRATUM: NARRAGUAGUS BAY AREA

N (Assigned stations)	30		
N (Stations successfully towed)	**21**		
N (Unfishable stations due to gear conflict)	1		
N (Unfishable stations due to non-gear issues)	8		
TOTAL AREA (Initial stratum frame)	(185) 500 m^2 grids = 4625 Hectares		
% TOTAL AREA UNFISHABLE (for non-gear reasons)	0.266666667		
ADJUSTED TOTAL AREA	**3392 Hectares**		
WEIGHTED MEAN SIZE INDEX FOR STRATUM	**401**		
WEIGHTED MEAN COUNT/TOTE FOR STRATUM	**274**		

SURVEY STATISTICS

	STDCATWT (g/m^2 swept)	STDCATVOL (L/m^2 swept)	STDABND (#/m^2 swept)
MEAN*	**50.770**	**0.059**	**0.209**
UPPER BOUND (95% C.I.)	111.596	0.116	0.460
LOWER BOUND (95% C.I.)	27.115	0.033	0.110
SE	15.565	0.016	0.064
UPPER BOUND (90% C.I.)	99.695	0.106	0.419
LOWER BOUND (90% C.I.)	30.277	0.036	0.123
SE	15.482	0.016	0.065
SE (% OF MEAN)	0.305	0.271	0.311

EXPANDED ESTIMATES

	BIOMASS (Kg)	BIOVOLUME (L)	POPULATION EST (n)
TOTAL	**1721949**	**2001083**	**7088583.333**
UPPER BOUND (95% C.I.)	3784964	3934333.333	15601666.67
LOWER BOUND (95% C.I)	919650	1119250	3730833.333
UPPER BOUND (90% C.I.)	3381322	3595166.667	14211083.33
LOWER BOUND (90% C.I.)	1026895	1221000	4171750
CONVERSION TO TOTES*	**26181**	**26681**	**25874**
UPPER BOUND (95% C.I.)	57548	52458	56947
LOWER BOUND (95% C.I)	13983	14923	13618
UPPER BOUND (90% C.I.)	51411	47936	51871
LOWER BOUND (90% C.I.)	15613	16280	15227

* bootstrapped statistics; 10,000 runs; using "RESAMPLING" program (http://www.uvm.edu/~dhowell/StatPages/Resampling/Resampling.html).

** Conversion factors

1 tote = 65.771 kg (145 lbs; range is really 140-150 lbs)	*65.77 kg*
1 tote = 75L (NMFS; standard conversion for full fish tote)	*75 L*
1 tote = 220 cucumbers (size dependent ranging from 130-256; Feindel, 2002)	*220 cukes*

Table 13. Summary of survey results for *Cucumaria frondosa* in this project.

FMLT = Frenchman Bay < 20 m
FMGT = Frenchman Bay > 20 m

SUMMARY CHART FOR 2005-2007 SEA CUCUMBER SURVEY YEARS

		SURVEY YEAR		
		2005	2006	2007
FRENCHMAN BAY (Total)	*EST. TOTES*	276022	96578	97161
	BIOMASS (METRIC TONS)	15347	5777	5757
Shallow stratum (less than 20 m depth)	*n*	64	76	67
16479 hectares	*MEAN (SE)**	57.6 (11.6)	22.7 (3.352)	27.1 (4.1)
	*EST. TOTES***	179773	64109	73963
	BIOMASS (METRIC TONS)	9489	3634	4480
	mean size index	341	397	462
Deep stratum (greater than 20 m depth)	*n*	32	40	32
8297 hectares	*MEAN (SE)*	70.6 (20.9)	26.2 (6.6)	14.4 (3.4)
	EST. TOTES	96249	32469	23198
	BIOMASS (METRIC TONS)	5858	2143	1277
	mean size index	477	464	676
Narraguagus Bay	*n*	30		
3392 hectares	*MEAN (SE)*	50.8		
	EST. TOTES	25874		
	BIOMASS (METRIC TONS)	1722		
	mean size index	401		

Uncorrected for dredge efficiency
* mean standard catch weight (grams cucumber per meter squared swept area)
** based on weighted mean count per tote for stratum

Table 14. Summary of BACI experiment.

Plot	Substrate	1-3 days	1 wk	1 month	3 months	8 months
Exp. A	Soft	17	7	36	8	74
Control A	Soft	55	15	64	64	22
Exp. B	Hard	14	38	33	46	49
Control B	Hard	234	144	100	164	84

Figure 1: Historical landings (metric tons) of the Maine sea cucumber fishery.

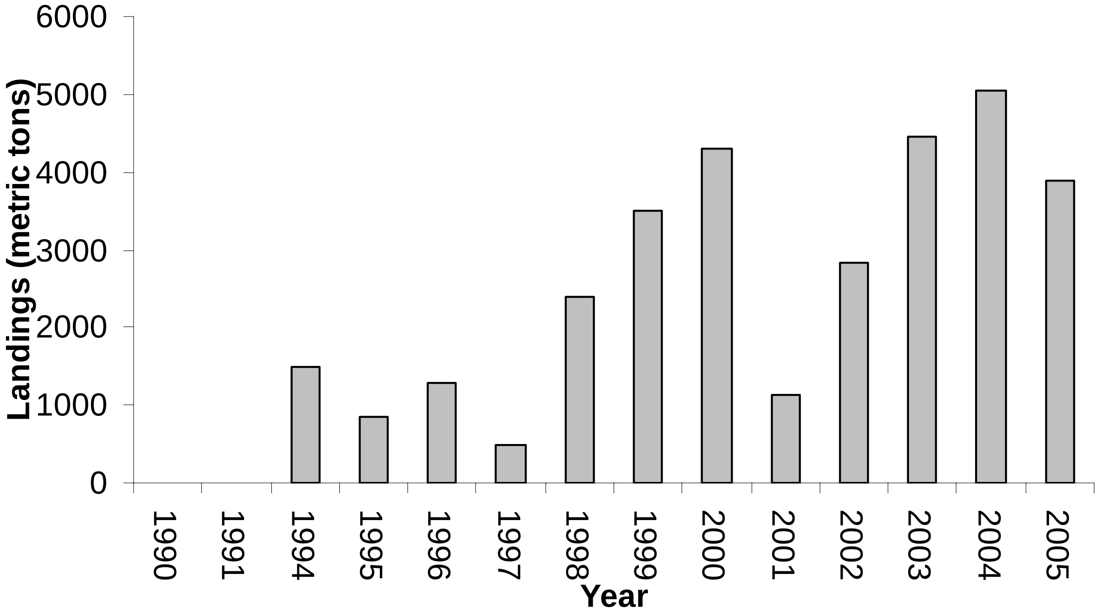


Figure 2. Historical landings (value) of the Maine sea cucumber fishery.

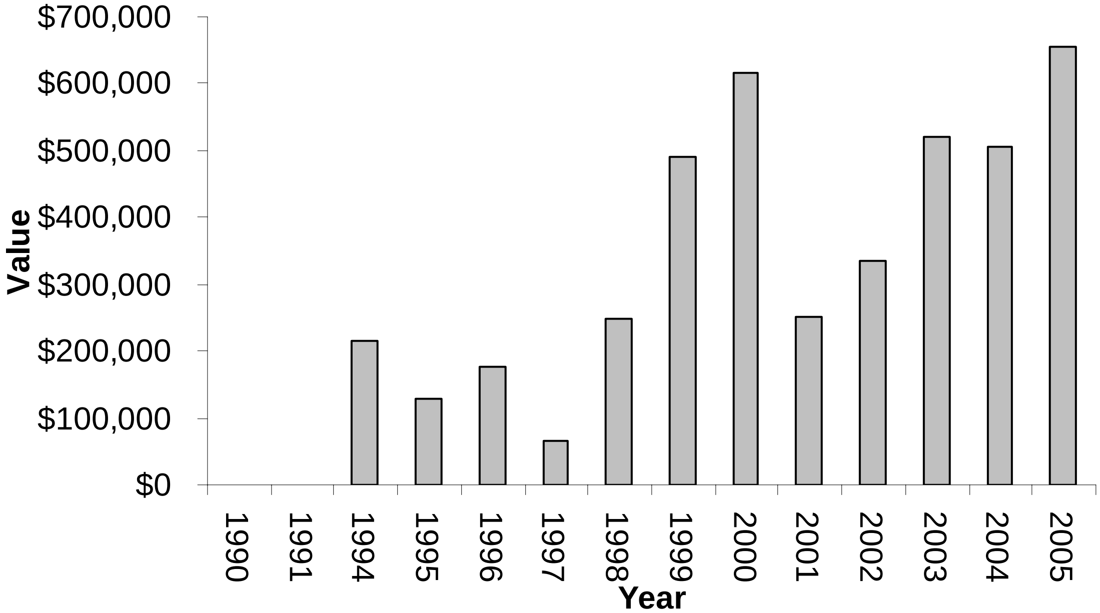


Figure 3. Frenchman Bay and the Gulf of Maine data source: Maine Department of Marine Resources.

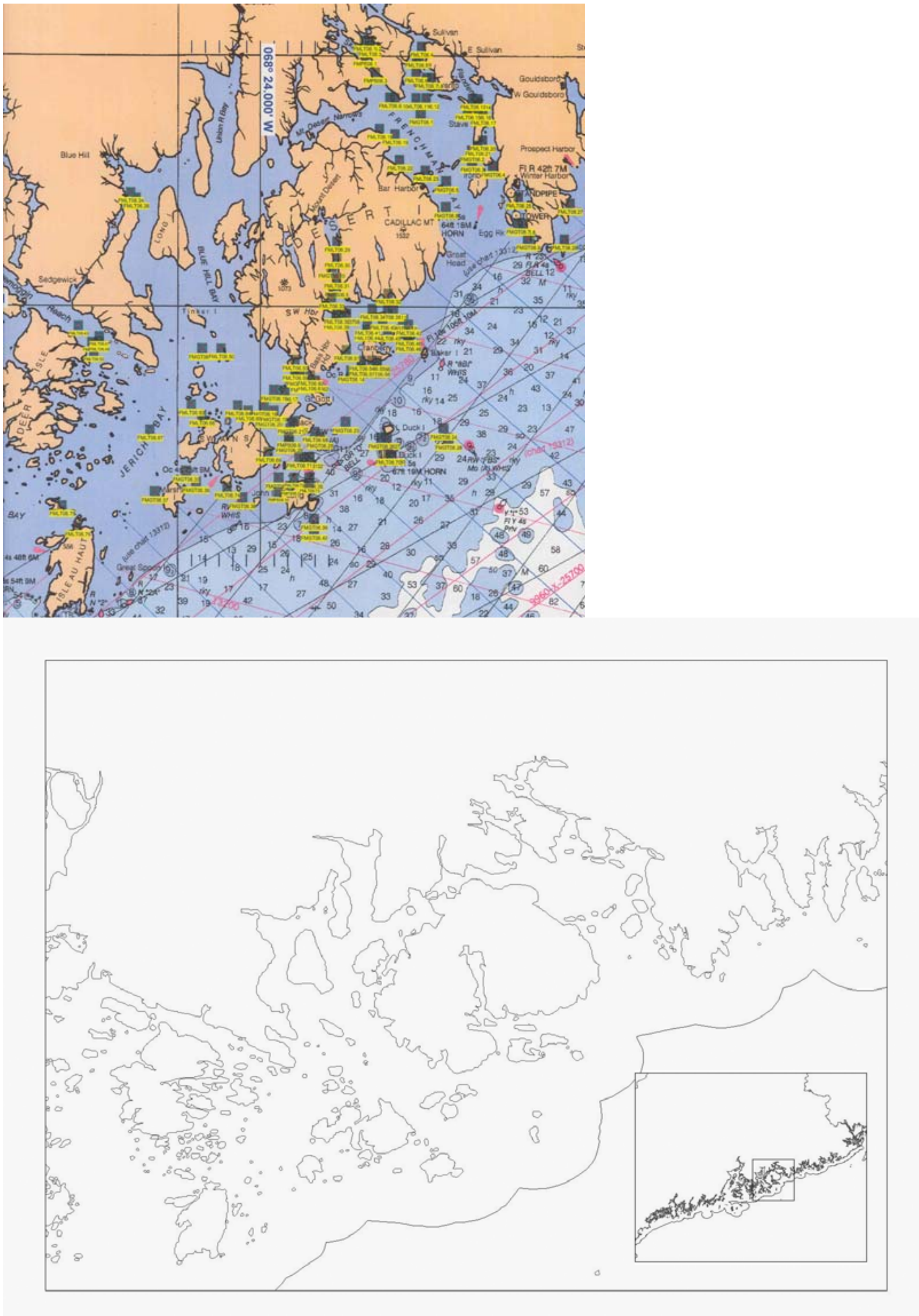
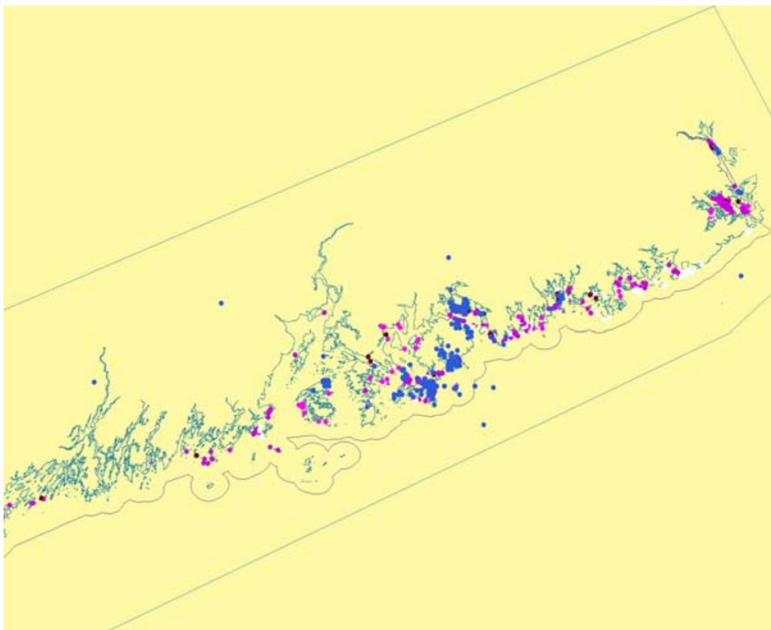


Figure 4. Reported sea cucumber locations in the Gulf of Maine based on harvester log books and scallop survey data.



Blue= Logbook locations, Brown=High abundance (scallop survey data)
Pink = Low/Med abundance (scallop survey data), White = (no cucumbers; scallop survey data)

Figure 5. 500 m grids around all known commercial cucumber density locations (within 1000 m).

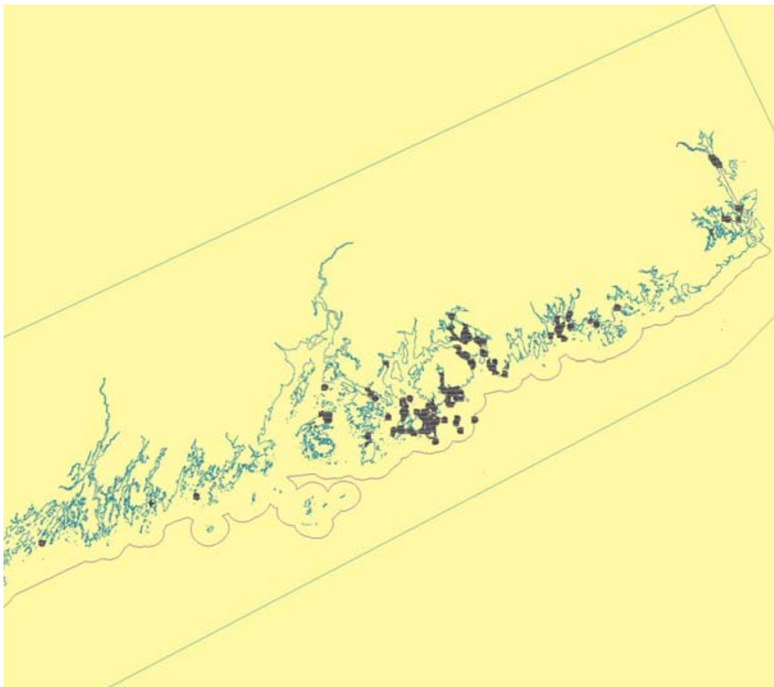
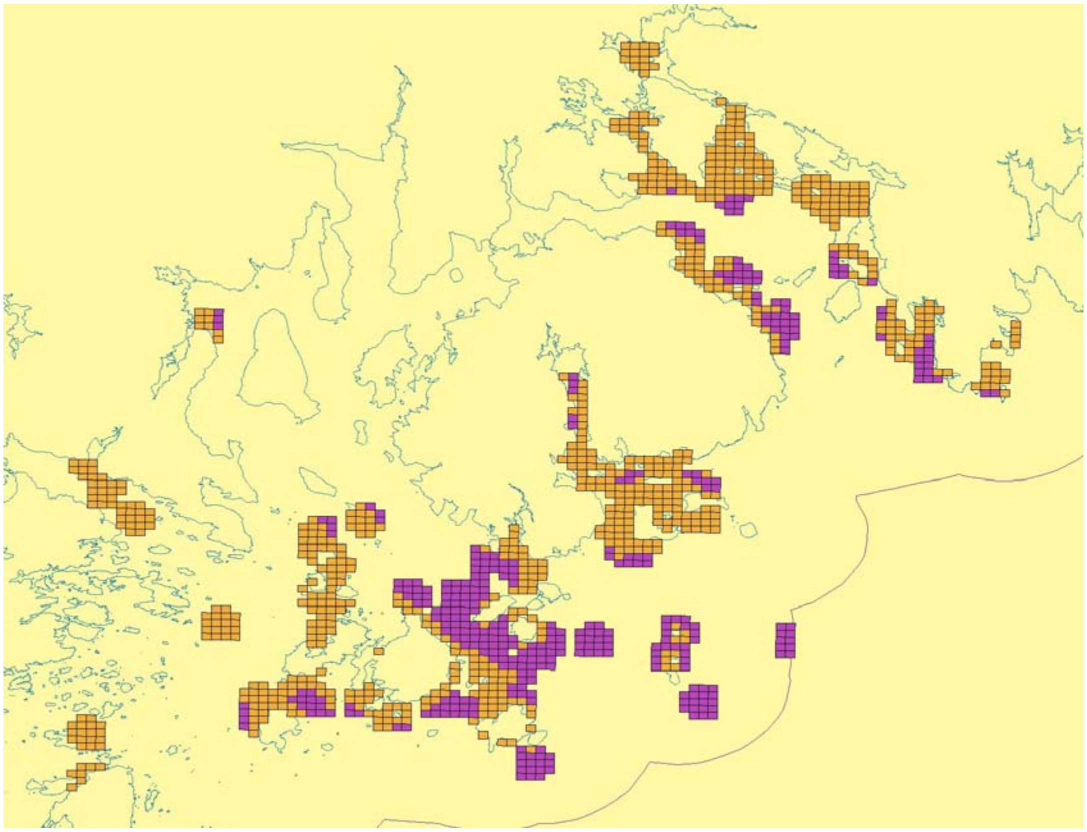


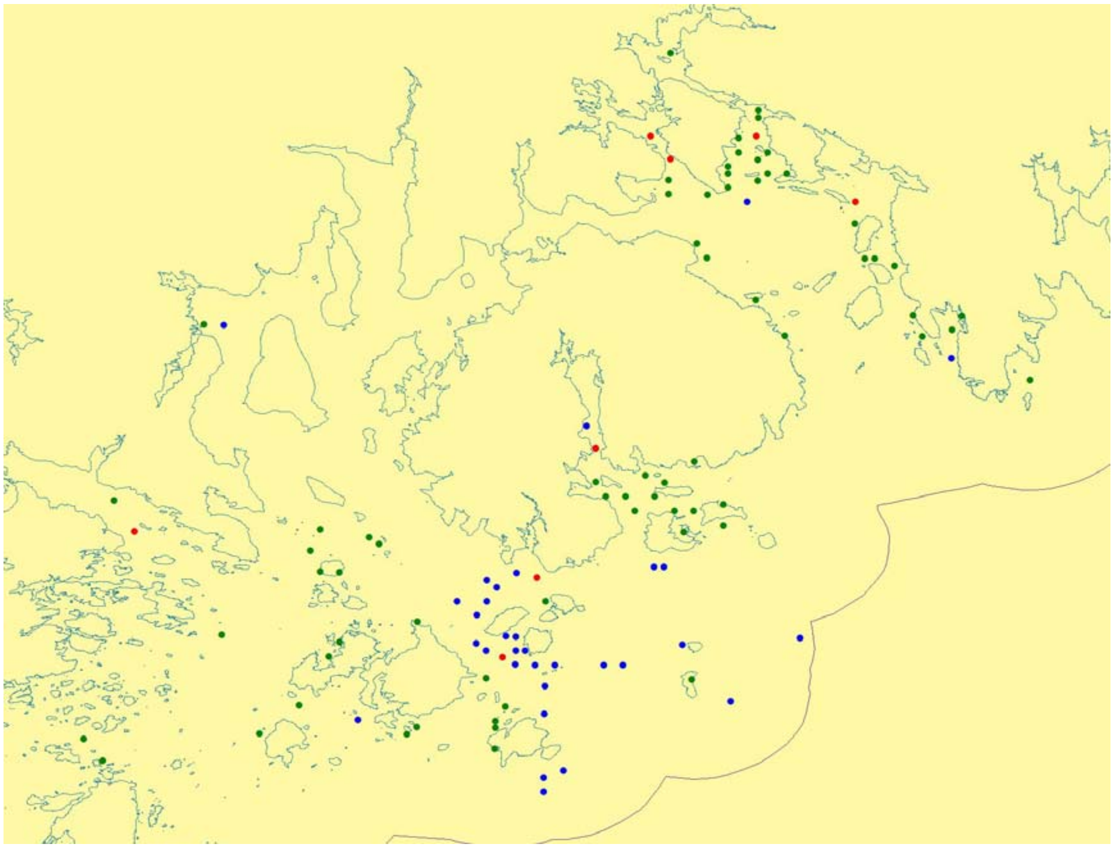
Figure 6. Frenchman Bay survey areas defined based on the historical fishing areas.



Orange = cucumber areas less than 20 m deep

Purple = greater than 20 m deep

Figure 7. Frenchman Bay area sampling stations in the 2005 sampling season.



Green = shallow water sites

Blue = deepwater sites

Red = initially selected fixed stations.

Figure 8. Percent gonad weight at all depths for each date sampled. Bar on the top is one standard error.

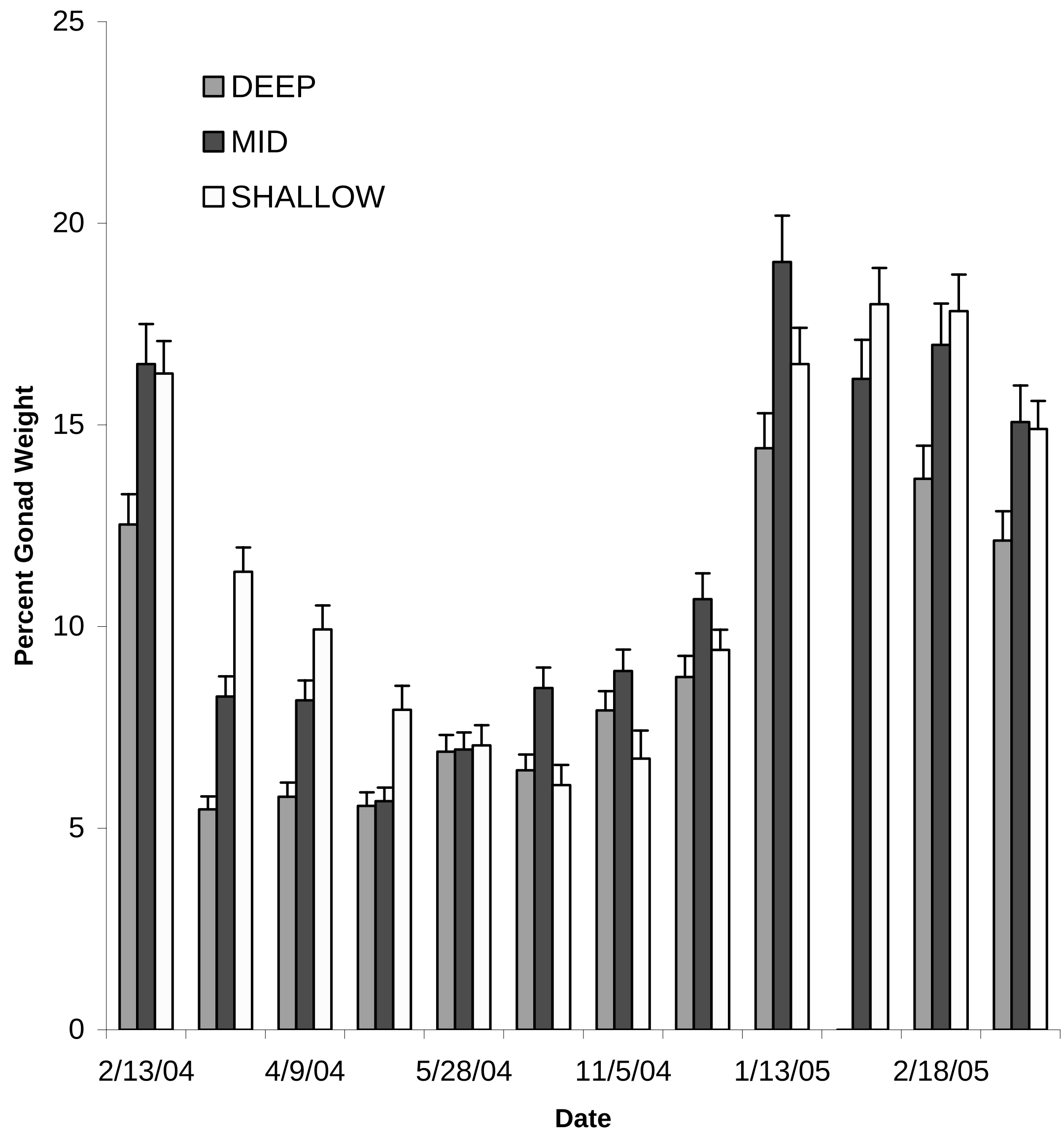


Figure 9. Average sea cucumber length over time for each depth. Bar is one plus and minus standard error.

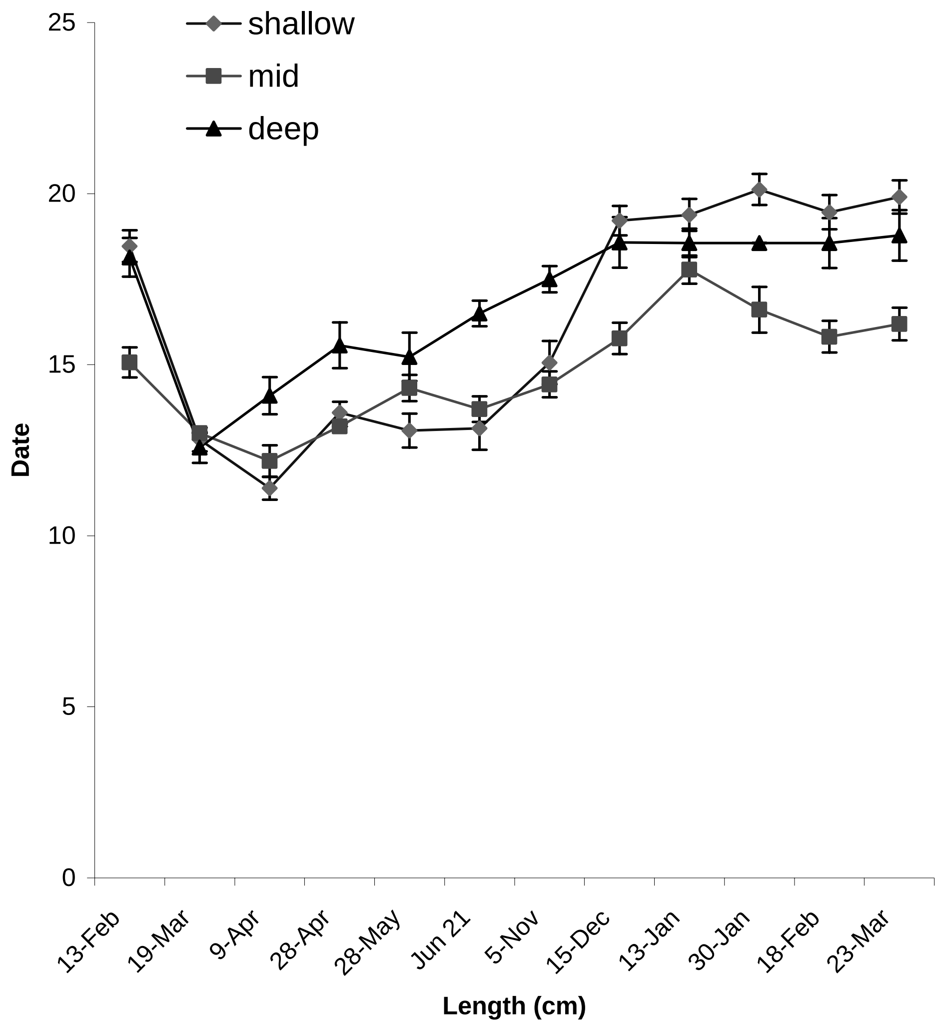


Figure 10. Seasonal variations in correlation coefficient (r) between each of the four morphological variables of female *C. frondosa* versus the log gonad weight.

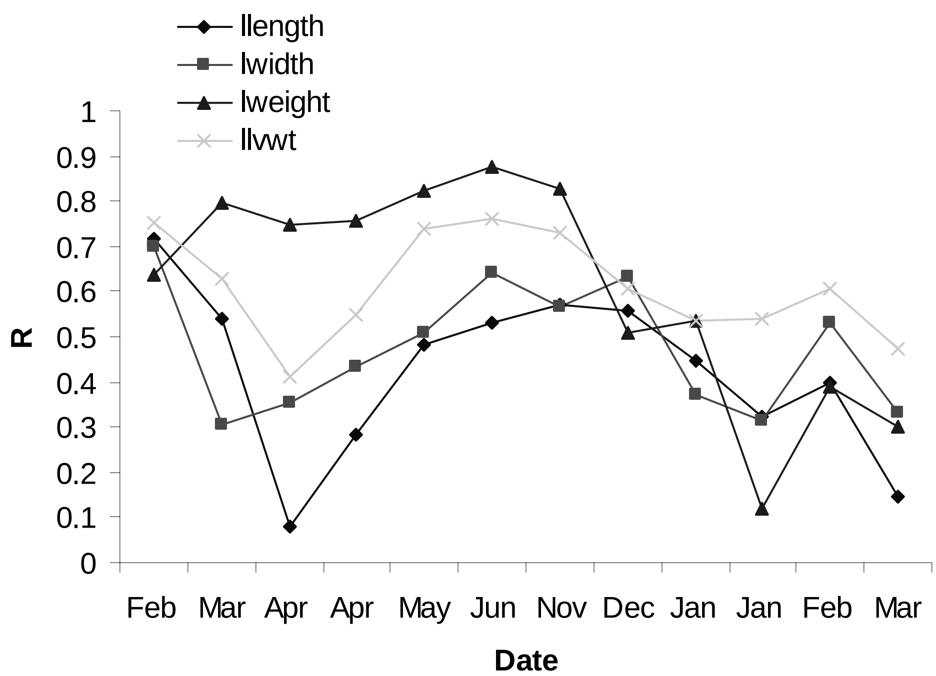


Figure 11. Seasonal variations in correlation coefficient (r) between each of the four morphological variables of male *C. frondosa* versus the log gonad weight.

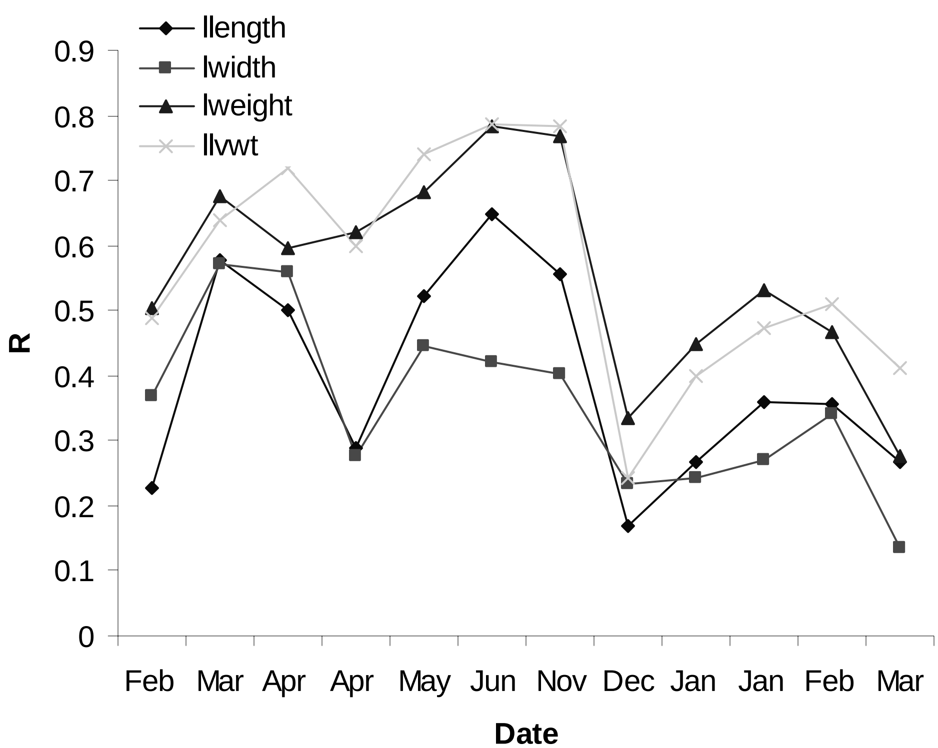


Figure 12. Plot of log gonad weight and log body weight for females.

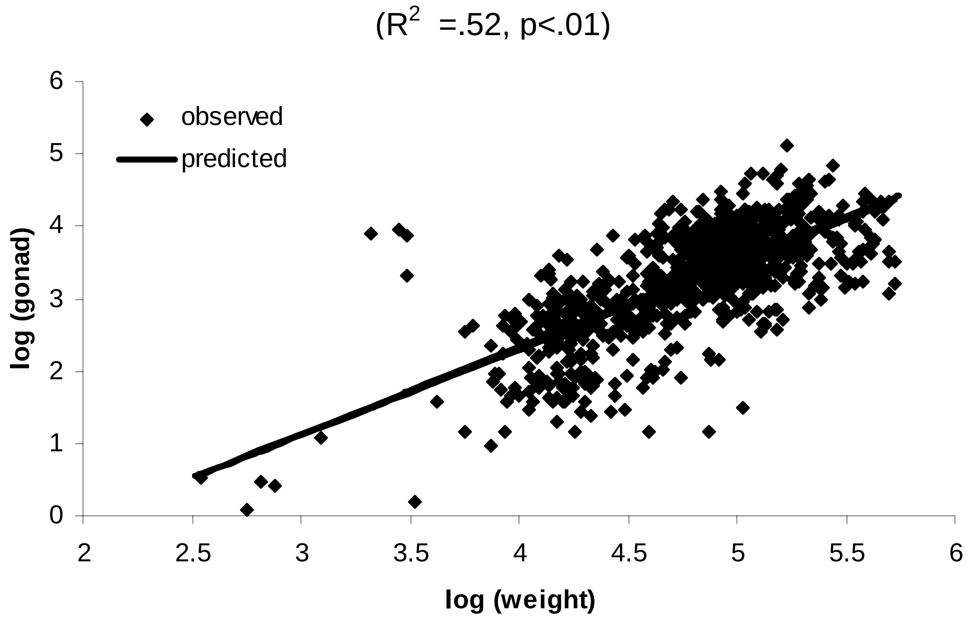


Figure 13. Plot of log gonad weight and log length for females.

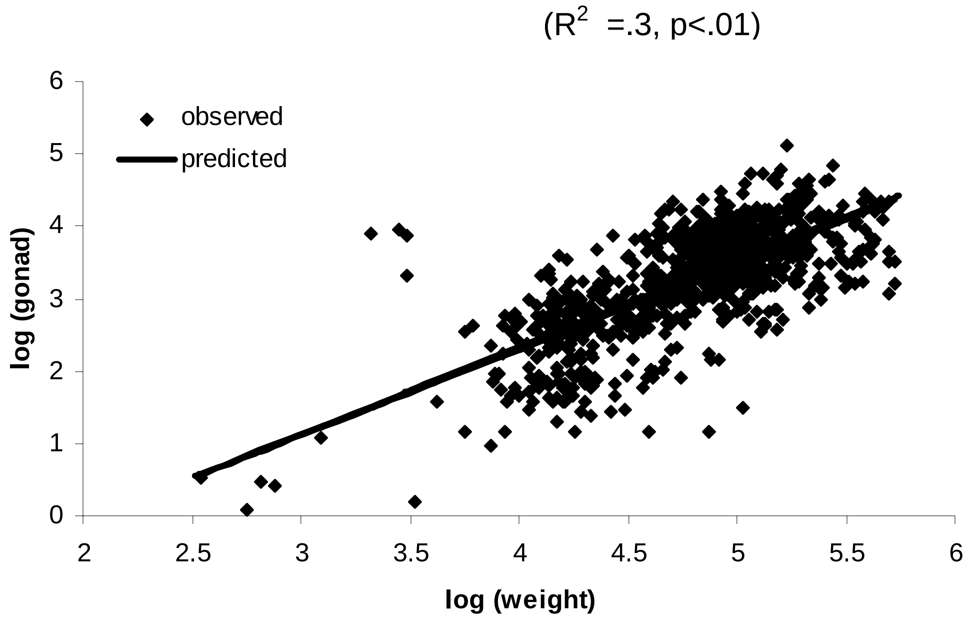


Figure 14. Plot of log gonad weight and log body weight for males.

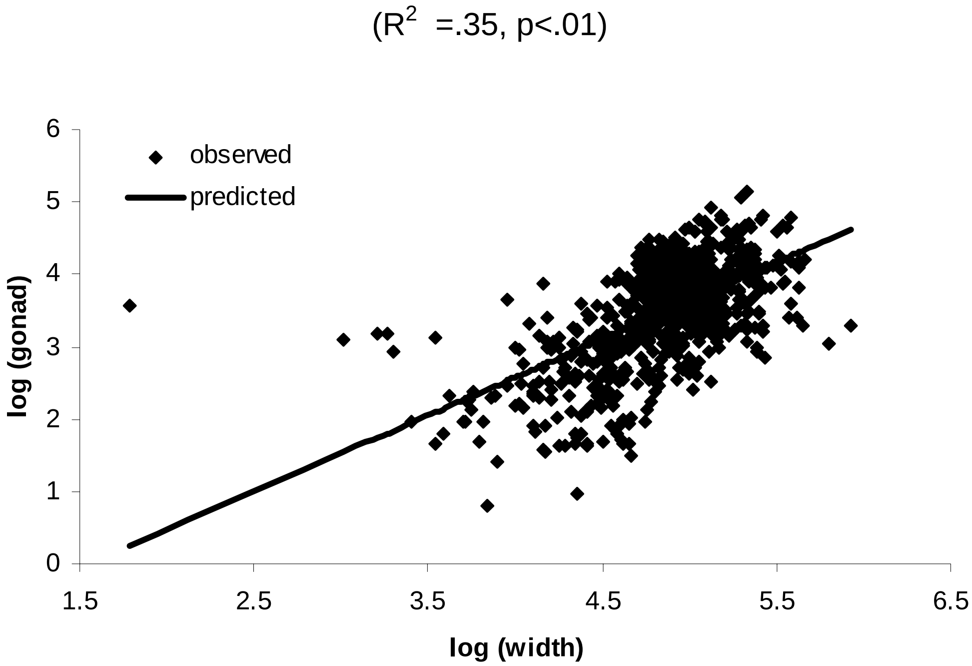


Figure 15. Plot of log gonad weight and log length for males.

(R^2 =.07, p<.01)

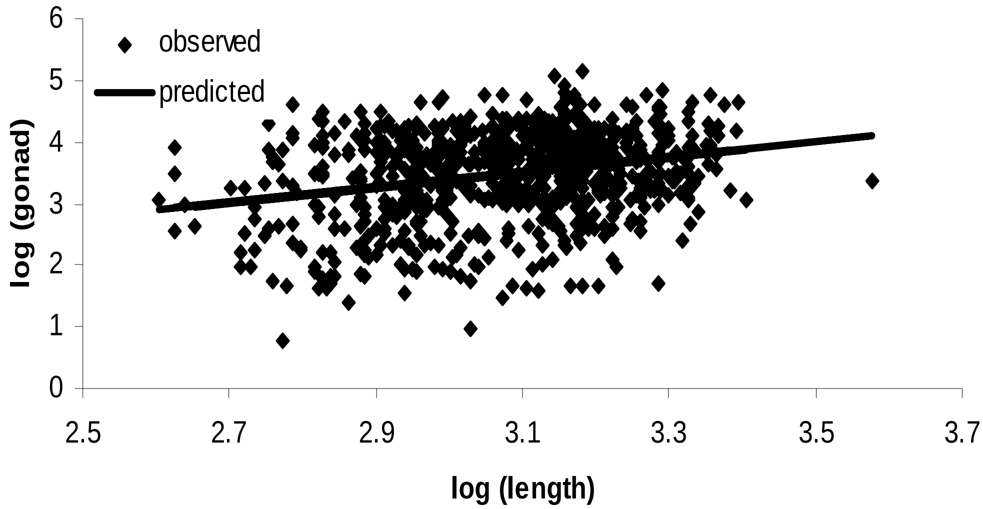


Figure 16. Average air temperature ^{0}F winters 1989-2005. Data source: Maine Department of Marine Resources.

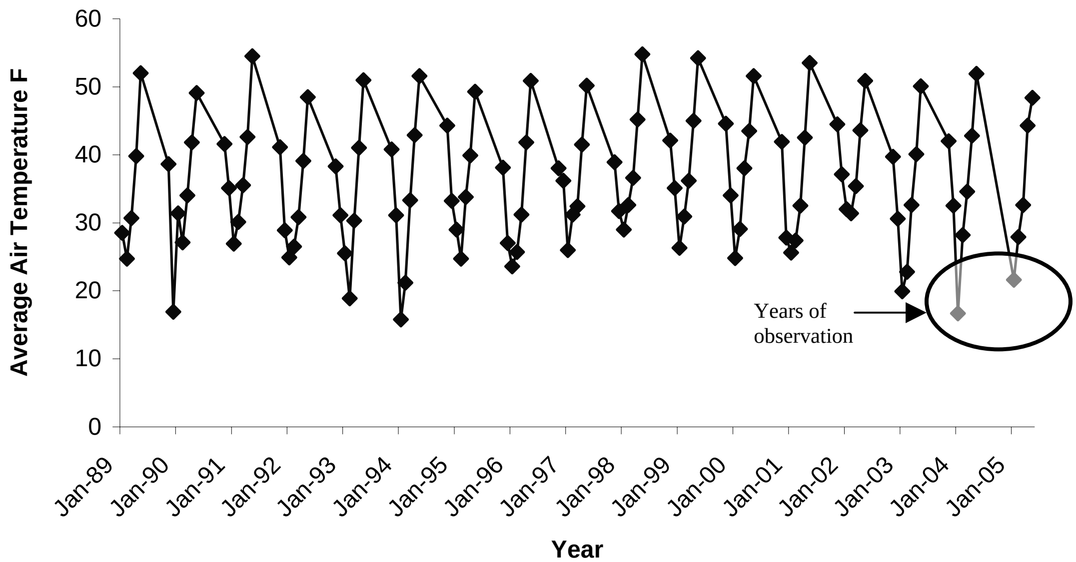


Figure 17. Average sea surface temperature ^{0}F winters 1989-2005. Data source: Maine Department of Marine Resources.

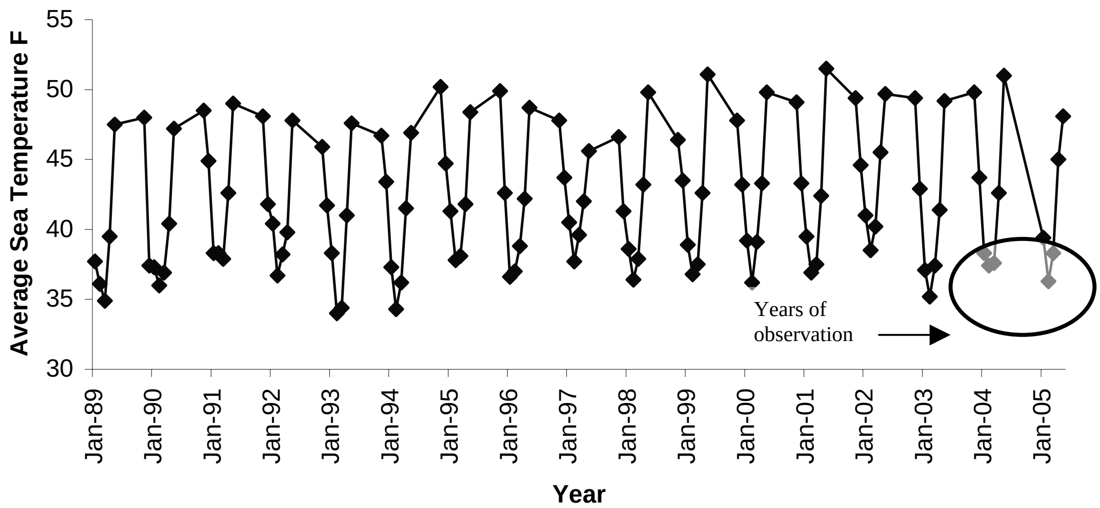


Figure 18. Average bottom surface temperature ^{0}F winters 1989-2005. Data source: Maine Department of Marine Resource.

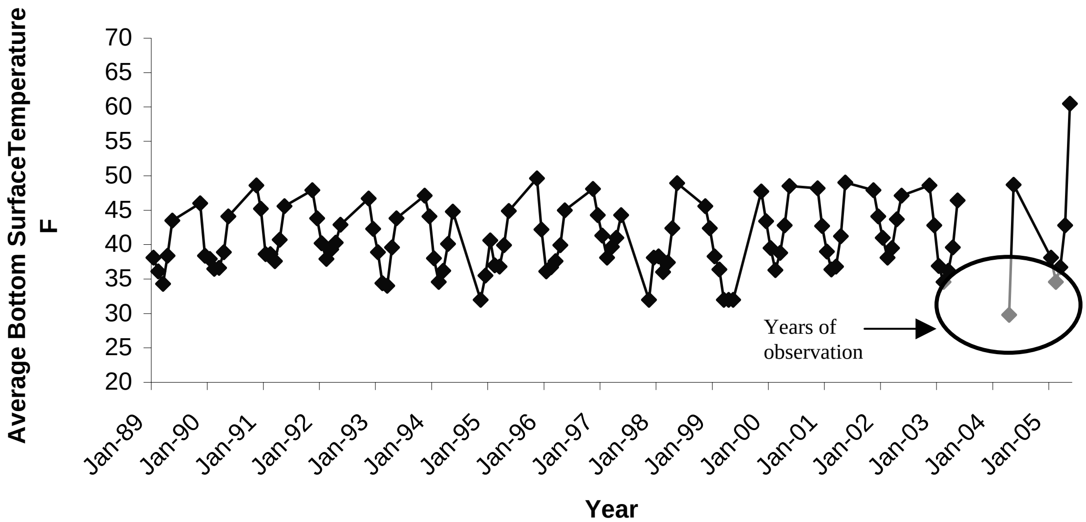


Figure 19. Survey results for Frenchman Bay in the 2005 survey season.

Standard catch volume is represented by the size of the circle surrounding the plotted point for each sampled site. UF = unfishable; FMLT = Frenchman Bay < 20 m; and FMGT = Frenchman Bay > 20 m.

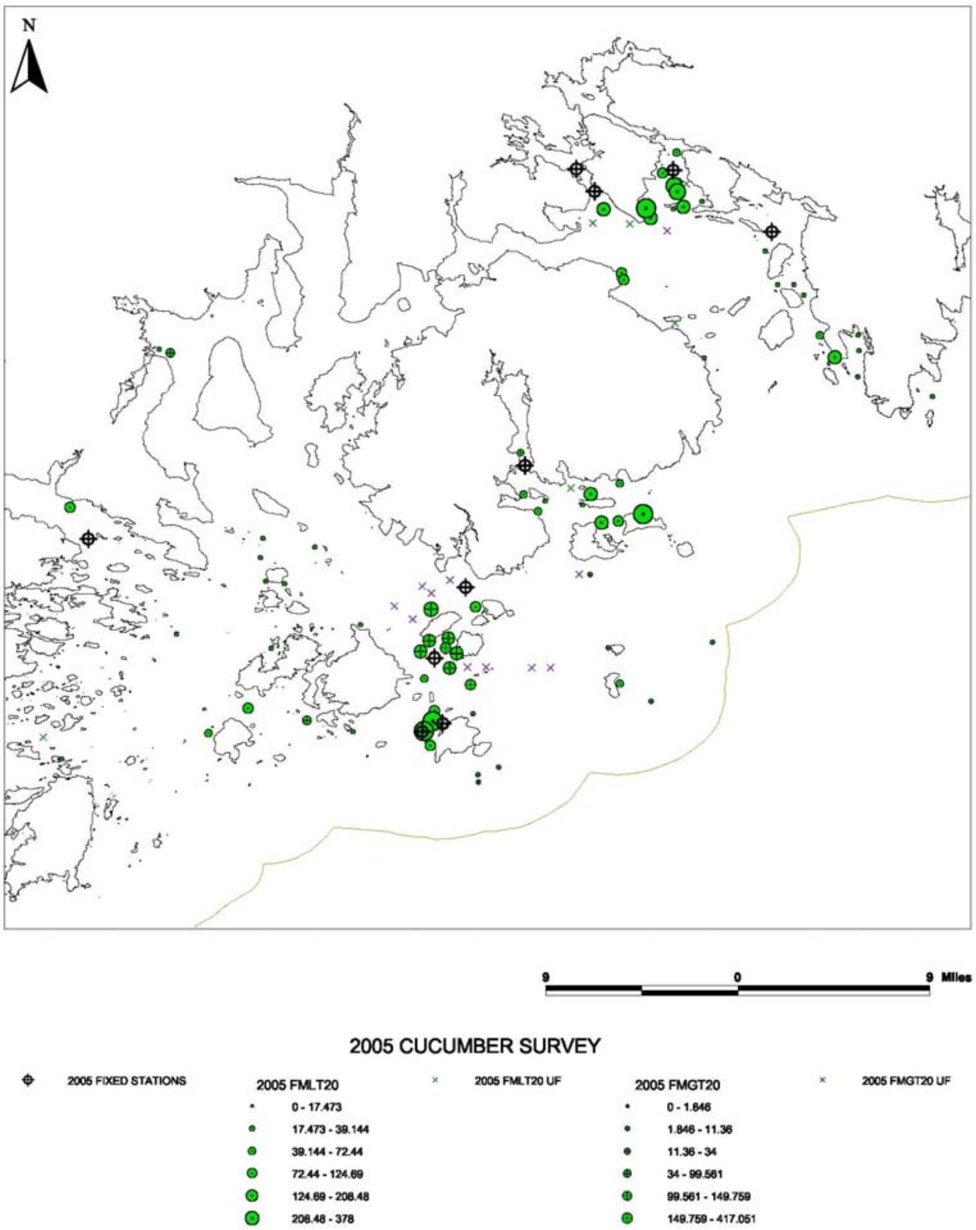


Figure 20. Survey results for Frenchman Bay in the 2006 survey season.

Standard catch volume is represented by the size of the circle surrounding the plotted point for each sampled site. UF = unfishable; FMLT = Frenchman Bay < 20 m; and FMGT = Frenchman Bay > 20 m.

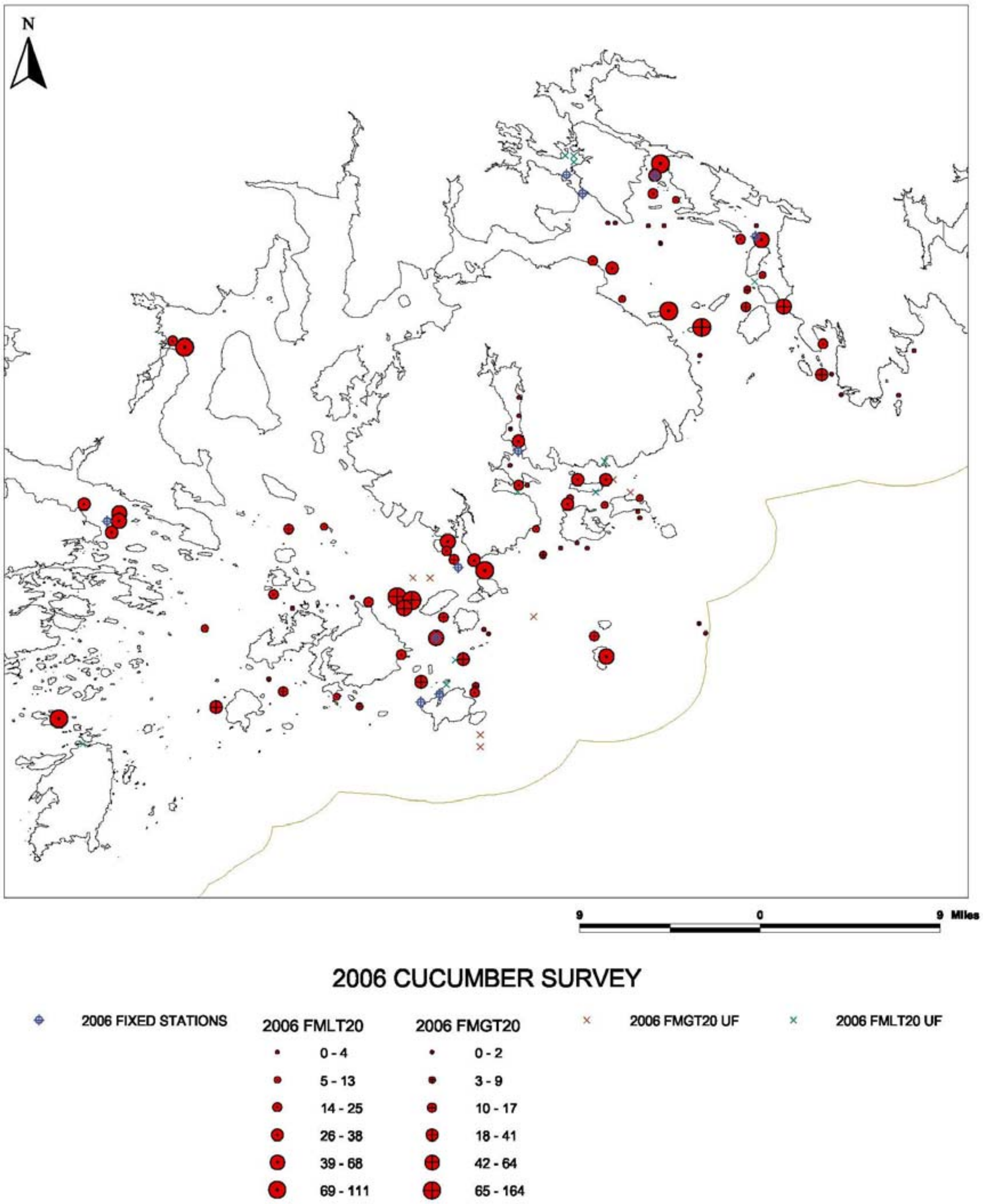


Figure 21. Survey results for Frenchman Bay in the 2007 survey season.

Standard catch volume is represented by the size of the circle surrounding the plotted point for each sampled site. UF = unfishable; FMLT = Frenchman Bay < 20 m; and FMGT = Frenchman Bay > 20 m.

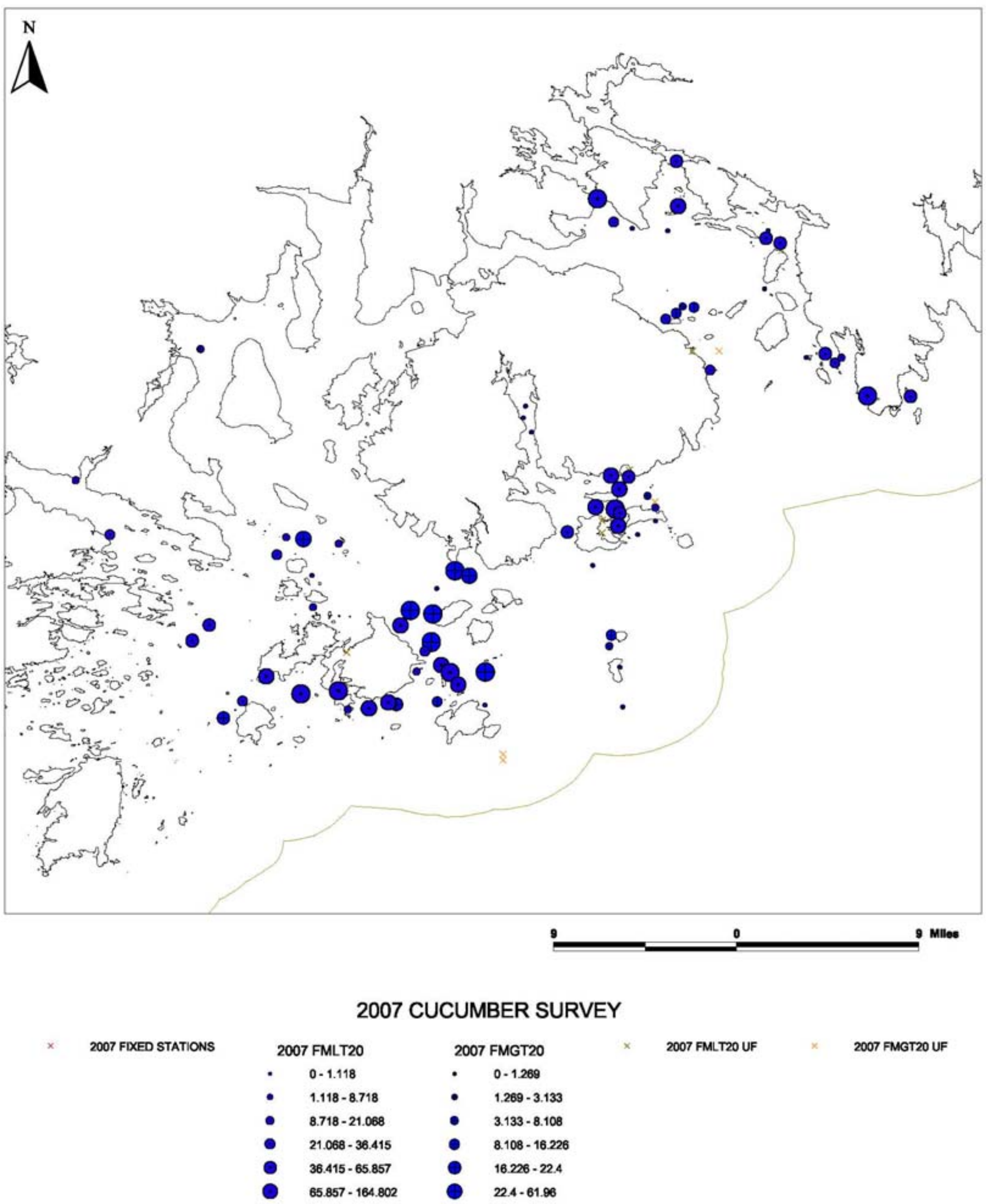


Figure 22. Frenchman Bay survey of combined 2005 - 2007 survey seasons.

Standard catch volume is represented by the size of the circle surrounding the plotted point for each sampled site. UF = unfishable; FMLT = Frenchman Bay < 20 m; and FMGT = Frenchman Bay > 20 m.

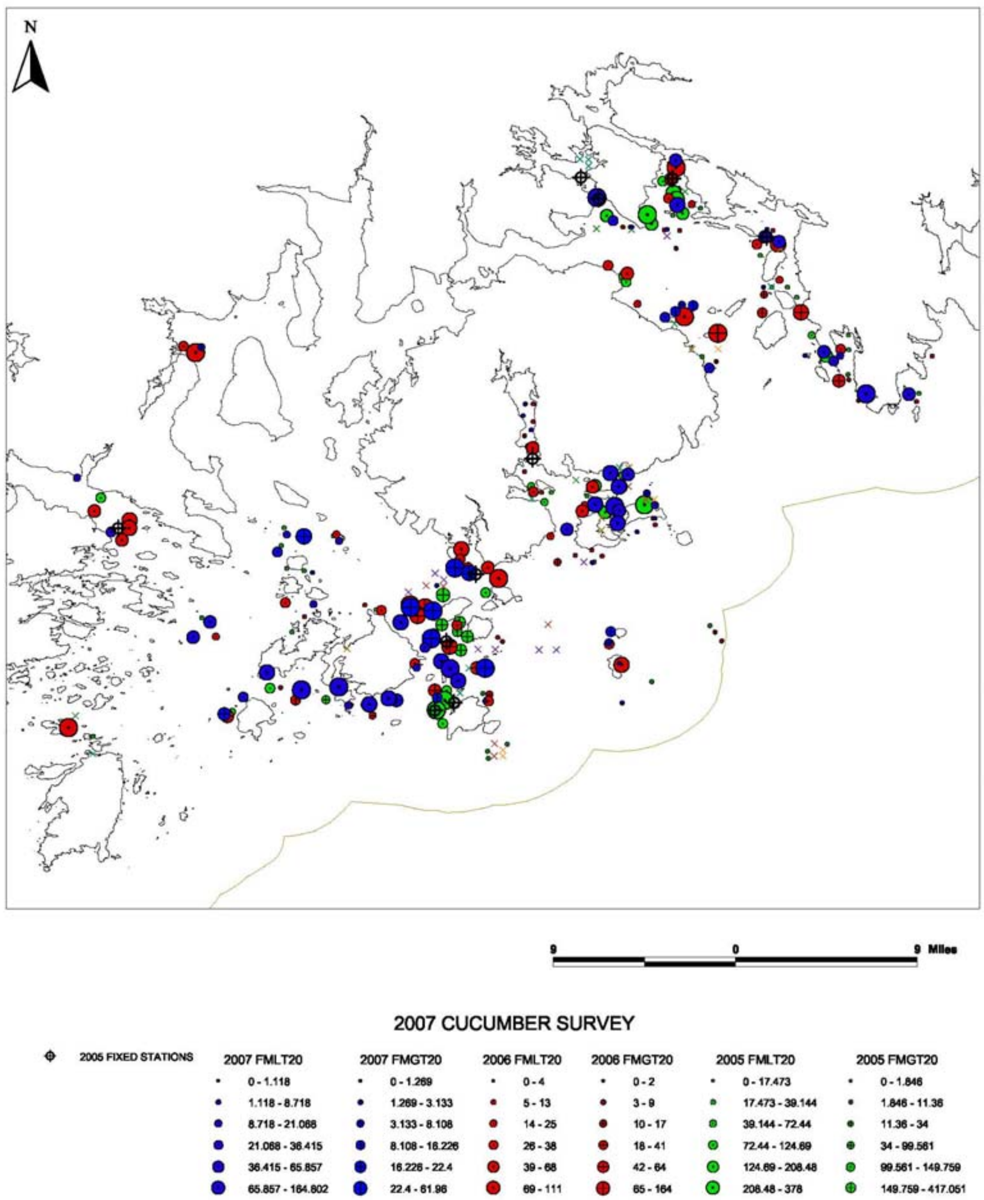


Figure 23. Narraguagus Bay for the 2005 survey season.

Standard catch volume is represented by the size of the circle surrounding the plotted point for each sampled site. UF = unfishable; and NB = Narraguagus Bay

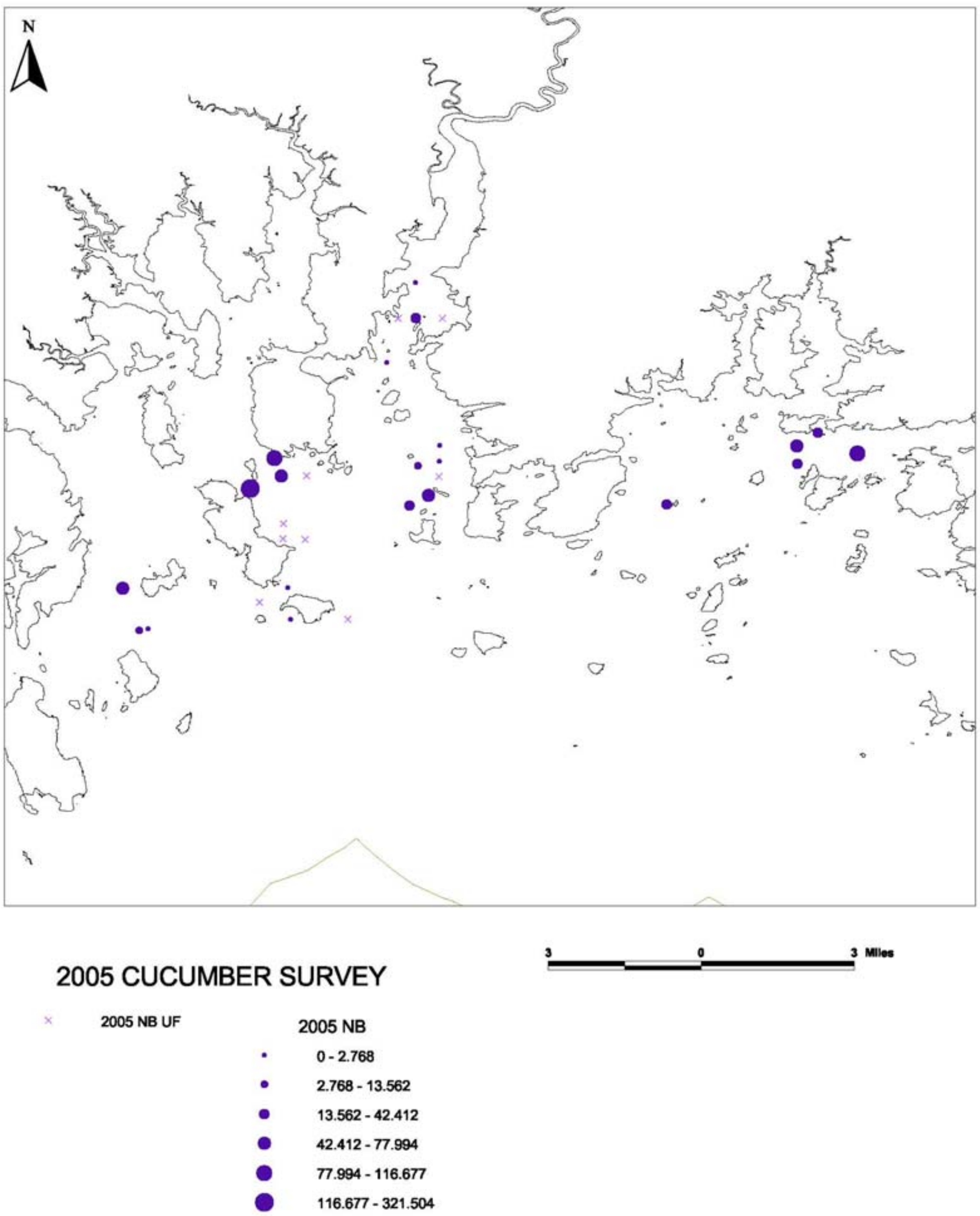


Figure 24. Number of Sea Cucumbers by Bottom Sediment Type