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Integrated Management of the Sea Scallop Fishery in the Northeast USA: Research and Commercial Vessel Surveys, Observers, and Vessel Monitoring Systems

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Abstract

The Atlantic sea scallop (Placopecten magellanicus) supports the second most valuable commercial fishery in the northeast USA. We describe the recent history of this resource focusing on the integration of research vessel (R/V) surveys with surveys conducted by commercial fishing vessels (F/V) in 1998 and 1999, fishery observer data, and mandatory, universal electronic monitoring of vessel position.

In December 1994 large areas of Georges Bank were closed to protect declining groundfish stocks; scallop harvesters were also excluded due to historical bycatch in the scallop dredge. Scallop populations in the closed areas rebounded quickly in the absence of fishing, attaining biomass densities and average sizes rarely observed in the past 30 years. While research vessel (R/V) surveys were sufficient to track the general trends, the fine-scale distribution of commercial-sized scallops and levels of bycatch in commercial dredges could not be estimated without more intensive studies. Cooperative fishing vessel surveys involving government, universities, and industry provided sufficient information to characterize the distribution of the scallop resource and the expected levels of finfish bycatch. A limited reopening of one area on Georges Bank in 1999 was accompanied by increased observer coverage (~22% of vessel days), daily reporting of landings and yellowtail flounder bycatch rates, and electronic monitoring of vessel position for the entire fleet.

The combined information from synoptic R/V surveys, intensive F/V surveys, fishery

observers, and electronic monitoring provided a coherent picture of the scallop resource, rich details on fleet behavior, and new insights into strategies for managing bivalve fisheries.

Introduction

Stock assessments typically include a mix of fishery-independent and fishery-dependent sources of information (Hilborn and Walters 1992; NRC 1998; Quinn and Deriso 1999). Fisheries-independent data are commonly obtained from designed surveys conducted by research vessels. Such surveys can be powerful scientific tools because they allow inferences to be drawn about broad geographical regions (Gunderson 1993; Smith 1997). Fisheries- dependent information is obtained from harvesters in a variety of ways including dockside monitoring of landings, reports from at-sea observers, and mandatory reports of landings. The inferential aspects of such data are often constrained by the absence of a probablistic sampling design. For example, dockside monitoring may be restricted to major ports and daytime working hours; landings at minor ports or during nighttime may be under represented. Even if such reports are designed to census the entire population (e.g., mandatory reporting), inferences will be restricted to the areas and times fished, rather than the entire domain of the resource.

While these standard measures require direct involvement of fishermen, the process tends to be passive rather than active. Fishermen are often uncertain about the ultimate fate and use of such information. At one extreme, fishermen may feel that such information is never used or that the methods used by scientists to spatially and temporally aggregate such information are improper. Clearly, much remains to be done to close the gap between fishermen's perceptions and reality of data use. By the same token, scientists have the responsibility to convey this information in a format comprehensible to all stakeholders and to acknowledge the strong and weak points of the assessments. Communication is necessary but not sufficient to bridge the gap between perception and reality. Shared experience is probably the best way for fishermen to understand the limitations and importance of sampling designs, and for scientists and managers to comprehend the implications of management measures. In the present context, we specifically refer to cooperative fishing experiments as "shared experience".

The purpose of this paper is to provide an overview of the positive developments in recent science and management of sea scallops (*Placopecten magellanicus*) in the Northeast United States. These developments include the use of commercial fishing vessels to conduct fine-scale statistical surveys, depletion experiments to estimate commercial gear efficiency, real-time monitoring of vessel catch rates, and continuous satellite monitoring of vessel position and velocity. Many of the results we present are preliminary and have yet to be published in the primary literature. Our objective is to describe the context in which such information is being used and to highlight the future use of such information. Future uses include reductions in finfish bycatch, monitoring of potential habitat impacts and the development of rotational area policies for scallop harvesting.

Background on Sea Scallop Biology and Fishery

Sea scallops, *Placopecten magellanicus*, are found in western North Atlantic continental shelf waters from Newfoundland to North Carolina. Principal USA commercial fisheries in the EEZ are conducted primarily on Georges Bank, and in the Mid-Atlantic offshore region at depths between 40 and 100 m where water temperatures are less than 20° C. In terms of total revenue, the sea scallop fishery is the second most valuable fishery in the Northeast USA with annual values in excess of $100 million USD (Fig. 1). Average price per kg of adductor muscle (meat) increases with average size with small scallops (~10 g) fetching approximately $8.80/kg and large scallops (>45g) valued at about $15.40/kg.

Scallops grow rapidly during the first several years of life. Between ages 3 and 5, scallops commonly increase 50 to 80% in shell height and quadruple their meat weight. During this time span, the number of meats per kg is reduced from greater than 220 to about 50. Maximum size is about 23 cm shell height, but scallops larger than 17 cm are rare. Sexual maturity commences at age 2, but scallops younger than age 4 probably contribute little to total egg production. Spawning occurs in late summer and early autumn; spring spawning may also occur in the Mid-Atlantic region. Eggs are buoyant, and larvae remain in the water column for four to six weeks before settling to the bottom.

Approximately 250 vessels participate in the year round commercial fishery for scallops. Nearly all landings are taken with dredges (89%) and otter trawls (10%). The USA fishery is managed under the New England Fishery Management Council's Fishery Management Plan for Atlantic Sea Scallops (*Placopecten magellanicus*). Current management measures include a moratorium on permits, days-at-sea limits, and restrictions on gear and crew size. Since the 1998 fishing year, vessels have been restricted to a maximum of 120 days at sea. Days at sea are monitored via a satellite tracking system that logs the position of all full-time scallop vessels on an hourly basis. Scallop dredges must use 3.5 inch (89mm) diameter steel rings to reduce capture of smaller scallops. Crew size is limited to seven individuals. As scallops are shucked by hand at sea, the crew size limitation constrains the daily landings rate during periods of high abundance. The minimum ring size was intended to reduce the catch of undersized scallops to improve yield per recruit, but the efficacy of this measure in the fishery was difficult to isolate in stock assessments (e.g., NEFSC 1997). In addition to these effort reduction measures, closed areas have excluded scallops from traditional harvest areas. Three large areas of Georges Bank were closed to scallop fishing in December 1994 to protect groundfish resources (Murawski et al. 2000). Later, in April 1998, two areas in the Mid-Atlantic were closed to protect undersized scallops present in these areas (Fig. 2).

The National Marine Fisheries Service has conducted a stratified random survey of the scallop resource from Virginia to Georges Bank since 1975. Results for the 1998 survey (Fig. 2) illustrate the relative sampling intensity and clearly depict the concentration of scallops in the five closed areas. In general, the relative biomass indices from scallop survey closely track the landings from the fishery (Fig. 3). This is due largely to the intensity of the fishery which rapidly harvests recruiting size classes. The growth potential of sea scallops and the implications of reduced fishing mortality for management have been demonstrated in the closed areas of the Mid-Atlantic and Georges Bank regions (Murawski et al. 2000). Between 1994 and 1998, relative biomass indices from research vessel surveys increased between 5-15 fold in the Georges Bank areas closed to fishing compared to those areas open to fishing. Comparisons of the size structure between 1994 and 1998 for population inside and outside of the closed areas (Fig. 4) reveal the virtual absence of scallops greater than 110 mm shell height except in the closed area. By 1998 nearly 80% of the total scallop biomass resided in the closed areas (Fig. 5). On Georges Bank the closed areas, which historically held about 50% of the total biomass, now had almost 90% of the total. Average densities in August 2000 in Georges Bank closed areas were approximately 4.5 times greater than densities in open areas. Similarly, relative densities of scallops in the Mid-Atlantic were about four times higher than in areas open to fishing (preliminary data from 2000 R/V survey) after only 27 months of closure.

Development of Cooperative Surveys

The rapid increase in scallop biomass on Georges Bank was first reported in January 1997 at the Stock Assess Review Committee (NEFSC 1997). Large biomass increases were also observed during experimental fishing operations by commercial vessels. Together, these reports stimulated the initiation of cooperative fishing vessel (F/V) surveys to estimate the magnitude of scallop biomass available to commercial dredges and to evaluate potential bycatch rates for groundfish. The cooperative studies involved participants from the Center for Marine Science and Technology of the University of Massachusetts-Dartmouth, the Virginia Institute of Marine Science of the College of William and Mary, and the National Marine Fisheries Service. Six commercial fishing vessels participated in the first survey in the summer of 1998. Costs of F/V participation were offset by allowing each vessel to land 14,000 lbs (6,363 kg) of scallop over a period of 14 days. The explicit tradeoff of research time for scallop landings was implemented in subsequent F/V surveys and appears to have been favorably received by all stakeholders. A summary of the fishing vessel surveys conducted since 1998 is given in Table 1. Additional research on gear selectivity and bycatch reduction has conducted on fishing vessels has provided useful data for the management of fisheries in closed areas.

Cooperative surveys conducted with commercial fishing vessels in 1998 and 1999 provided valuable insights into the fine-scale distribution of scallops with increased precision of the survey estimates (Table 1). The sampling design was a replicated systematic survey in which each vessel completed a systematic sample of the entire closed area. A systematic survey was chosen in order to meet the assumptions of spatial analyses (e.g., kriging) and the replicated systematic survey reduced the reliance on any single vessel. It should be noted that the stations for any single vessel were "interleaved" with the stations from other vessels such that the average distance between stations was about the same regardless of vessel. Moreover, about 20 stations were designated as "calibration" stations at which each of the six vessels sampled. The repeat sampling at a single station provided a direct check on relative capture efficiency by controlling for the location effect.

The NMFS R/V scallop survey samples about 15,000 nm^2 with a sampling intensity of approximately 1 station per 30 nm^2. With six commercial fishing vessels focusing on a relative small area of 1,800 nm^2 it was possible to increase the sampling intensity by an order of magnitude to 1 station per 3 nm^2. Comparison of the NMFS and cooperative survey in Closed Area II for the 1998 survey revealed similar estimates of relative density (kg/tow) and but a low coefficient of variation to about 8%. The relative biomass estimate (unadjusted for gear efficiency) in Area II from the NMFS R/V Albatross survey of 11.55 million lb exceeded the fishing vessel estimate of 10.04 million lb by 15%. The differences were largely attributable to the increased selectivity of the NMFS dredge for smaller scallops (Fig. 6). The NMFS dredge which uses 2 inch (51 mm) rings with a 38 mm liner is designed capture recruiting scallops. The reduced selectivity of scallops with shell heights less than the 89 mm rings is also evident in Fig. 6.

Depletion experiments permitted estimation of dredge efficiency and selectivity of commercial dredges. In depletion experiments, vessels towed scallop dredges as close to the same vessel track as possible. Overlap in dredge tracks was monitored with GPS. Declines in catch rates with sampling intensity allow for estimation of dredge efficiency. Analyses of these experiments using traditional Leslie-Davis models yielded an average efficiency estimate of 16% whereas a spatially explicit model (Rago et al., unpublished ms) yielded an average of 40%. The Stock Assessment Review Committee (NEFSC 1999) recommended the use of the spatially explicit model but noted that wide variations in efficiency between areas were likely due to different bottom types (sand vs rock substrate). Additional experiments to test these models are underway.

During 1999 and 2000 additional F/V dredge studies in the Area I, Nantucket Lightship, Hudson Canyon, and Virginia Beach closed areas were conducted (Table 1). These experiments have not yet been compared statistically with the R/V Albatross IV survey.

A video camera system, developed by scientists at the School of Marine Science and Technology (SMAST), University of Massachusetts, was used to derive abundance estimates for scallops in each of the closed areas. Investigators at SMAST used a systematic two stage sampling design in which four replicate 2.2 m^2 images were taken at each site. Stations were located approximately 0.85 nm apart. Using information from historical landings, SMAST and fishermen jointly defined subsets of the closed areas that were most likely to contain scallop beds. Abundance estimates from these studies agreed reasonably well with each other, and the results were incorporated directly into the fishery management process for scallops (NEFMC 1999a, 1999b, 2000--Framework 11, 12, 13, and the 1999 and 2000 scallop fishery management plan Stock Assessment and Fishery Evaluation Report).

Initial Distribution of Scallops and Finfish Bycatch in Closed Areas

The Closed Area II fishing vessel survey provided rich detail on the spatial distribution and size composition of harvestable scallops and the distribution of yellowtail flounder at the time of the survey. The subregion south of 41° 30' N contained a high concentration of large scallops along an axis extending from the southwest corner (41° N, 67° 15' W) to the northeast (41° 30' N, 66° 40' W) (Fig 7). Many of these scallops ranged in size from 25 to 45 g meat weight. Scallops also occurred at high densities to the southwest of this axis but their average size was smaller.

High scallop densities were also observed in the Nantucket Lightship and Area I closed areas (Fig. 8). The regions of highest densities were a much smaller fraction of the total compared to Area II. Much of Area I consisted of bottom too deep for sea scallops. In the Nantucket Lightship area only the region north of 40° 50' and east of 69° 30' contained commercially desirable quantities and sizes of scallops.

Commercial fishing vessel surveys also provided valuable information on finfish bycatch rates (Fig. 9). Commercial scallopers typically fish at speeds in excess of 4.5 knots whereas the NMFS research vessel pulls the dredge at 3.5 knots. The differences in speed, size, and configuration of the dredge make it difficult to extrapolate finfish bycatch rates from research gear to commercial fishing operations. Inasmuch as the Georges Bank areas were closed to protect cod (Gadus morhua), haddock (Melanogrammus aeglefinus), and yellowtail flounder (Limanda ferruginea) stocks, these species were of primary interest to fisheries managers. Cod and haddock occurred in negligible quantities in commercial dredges during the time of the F/V surveys (late summer - early fall). Yellowtail flounder, on the other hand, were largely coincident with scallop populations in Area II (Fig. 9). Densities of yellowtail flounder in Area I and the Nantucket Lightship Area however, were much lower.

The fine-scale sampling grid from the F/V surveys made it possible to develop contours maps of scallop and yellowtail flounder densities and their ratios (Fig. 10). These data provided useful guidance on likely "hot spots" for bycatch and as we shall see, important insights into the behavior of the scallop fleet during the June-November 1999 period when Area II was reopened.

Limited Reopening of Closed Areas in 1999 and 2000

As a result of the cooperative study and other information contained in the standard R/V surveys and observer sea sampling, the New England Fishery Management Council voted to reopen a portion of Closed Area II south of 41° 30' N to limited scallop fishing. The reopening was subject to strict controls that included a total allowable catch of scallops (4,257 mt), a total allowable bycatch of yellowtail flounder (387 mt), individual vessel trip limits (4.54 mt/trip), a restriction on the total number of trips per vessel (3 before Oct. 1; 3 after Oct, 1, 1999), an intermediate decision date for authorization of additional trips (Oct. 1), a requirement for 8 inch (20.3 cm) mesh in the top panel of dredges to reduce yellowtail flounder bycatch, and a requirement that each trip, regardless of its duration, would use 10 of the 120 days-at-sea allotted to the vessel. Moreover, total scallop landings and yellowtail flounder bycatch were to be monitored on a daily basis. Under the plan, the area would be closed whenever the scallop landings or yellowtail flounder bycatch limits were attained. A 10 nm-wide "buffer" area around Area II was closed to improve enforcement of closed areas. The Council also specified a target level of 25% observer coverage for trips to the closed area.

A large number of observers were necessary to attain the necessary coverage of the Area II fishery. Forty-four new observers were trained at government expense in a series of one week sessions prior to the June 15, 1999 re-opening. As an incentive to carry observers and to cover additional costs, vessels were allowed to harvest an additional 200 lb (91 kg) of scallop meats per day fished. The additional revenue allowed the vessels to meet extra costs, pay the observers, and make a modest profit.

The real-time monitoring requirements for this management action were much greater than normal and would have been impossible to achieve without a vessel monitoring system (VMS). Beginning in May 1998, all full and part-time scallop vessels were required to have a VMS to track of days at sea usage. The VMS also allows the vessel to communicate via e-mail to a central site. Messages received at this site can then be routed to appropriate destinations. The vessel location is embedded in each transmission so it is possible to develop a general map of catch rates by location. Data forms were developed at the central site and distributed to all vessels; hence, the basic components of a real-time monitoring system were already in place. VMS position reports are logged and regularly loaded into a database— generating about 200,000 reports per month.

The VMS database was originally designed as an enforcement tool to track time at sea accurately, and to identify possible violations of closed areas. The potential uses of such data for assessment and management, however, are far-reaching. In this paper we present a few examples related to development of a synoptic map of fishing activity. Estimates of area-specific fishing activity can be derived by overlaying a grid of 1 nm^2 squares over a region extending from Georges Bank to Virginia. Total fishing time in each cell was estimated as the sum of vessel-hours where speed is less than 5 knots (scallop vessel typically fish at 4-5 knots). Speed is estimated as the Euclidian distance between successive position reports divided by the time between observations. This estimate of fishing activity includes haul back time as well as any other time spent processing catch or cessation of fishing during bad weather or mechanical breakdowns.

The limited fishery was closely monitored by observers and via electronic reporting of daily catches. Approximately 2,700 mt (meats) of scallops were landed from this area before closure based on attainment of the yellowtail bycatch limit. Approximately 23% of the vessel-days were covered by at-sea observers.

Daily catch reports from fisherman were used to generate detailed maps on the response of the fleet to changes in price, avoidance of high bycatch areas, and abundance of scallops. Available space does not permit a full examination of these factors in this paper but several important features of the scallop fishery in Area II are evident in Fig. 11. Prior to October 1, scallopers generally landed in excess of 1850 lbs/day and avoided the areas of highest yellowtail flounder abundance. On-board observers reported that fishermen were using radio communication to identify and avoid areas of high yellowtail bycatch. Harvesting was focused on the high concentrations of large scallops as depicted in Fig. 7.

On October 1, 1999 scallopers were allowed an additional three trips into the closed area. By that time average catch rates had dropped from a median of about 2700 lbs per day to about 1600 lb/day but only 43% of the 4,257 mt allowable catch had been taken (Fig. 12). Approximately 60% of the allotted yellowtail bycatch limit of 387 mt had been taken, bycatch rates were rising, and it was clear that the fishery would soon be closed when the yellowtail bycatch TAC was attained. Low catch rates in the open areas and the approach of unfavorable autumn weather conditions provided an additional incentive for vessels to participate. Fishing activity increased rapidly after October 1 with nearly 40% of total fishing days used in the 45 calendar days between Oct. 1 and Nov. 5, 1999; the average number of vessels in Area II per day was 33. In contrast, only 18 vessels per day were present during the first 108 days of the fishery. The high concentrations of large scallops had been reduced and active avoidance of yellowtail flounder was not evident. The fleet dispersed broadly over the entire scallop area (Fig. 11b) and yellowtail flounder bycatch rates more than doubled to 0.25 lbs per pound of scallops landed (Fig. 13). Scallop catch rates continued to decline; median landings were about 1,250 lbs per day at the end of the fishery.

In 2000 all three of the Georges Bank closed areas were partially reopened to scallop fishing. To allow for adequate observer coverage in each area, the areas were opened and closed sequentially. As a condition for access to the closed areas, each scalloper was again charged 10 day at sea regardless of trip duration. Each trip into a closed area was restricted to 10,000 lbs. Owing to record levels of recruitment over the entire resource, catch rates in the open areas have been greater than 1,000 lb per day for most of 2000. Hence the incentive to fish in the closed area was reduced somewhat. The higher prices obtained for larger scallops however still made the revenue tradeoff favorable for over 100 vessels that have taken one or more trips into the closed areas by mid-September 2000.

The distribution of fishing effort in 1999 is depicted in Fig. 14. Each panel illustrates the spatial distribution of a quartile of fishing effort. Fishing effort quartiles were estimated for the set of all cells (1 nm^2) in which fishing occurred in 1998 and 1999. Cells below the median hours of fishing activity experienced less than 9 hours of fishing activity per year. The upper quartile of fishing effort was highly concentrated in a zone of about 3000 square miles (Table 3). Estimated mean fishing activity in these areas was about 110 hr in 1998 and 1999. The fishing activity in cells below the median is largely incidental and constitutes only about 4% of the total landings per year. It is hypothesized that such fishing activity is exploratory to recheck old fishing sites or to identify overlooked scallop concentrations. In both 1998 and 1999 the most heavily fished areas produced the 77 to 88% of the total landings. Hence, the VMS data provides a heretofore unknown quantification of the concentration of fishing activity. The implications of this concentration may be important for bycatch and habitat issues (e.g., the environmental "footprint" of fishing effort).

Discussion-What Have We Learned

Fully integrated fisheries management, wherein all participants and stakeholders share information in real time, is probably an unattainable goal. The logistics of fully addressing the relevant biological, economic, and social objectives concerns are probably beyond the grasp of society's institutions. Yet recent experiences with the scallop fishery suggest that substantial progress can be made (Table 2). The basic scientific ingredients include a system for the incorporation of diverse sources of information, development of theory to interpret such information, application of advanced technologies, and experimentation. A key management responsibility is to create an environment in which experimentation is possible. The collection of fisheries information in the context of an experimental or survey design is the essential factor that allows fishermen to appreciate the benefits of science and scientists to understand the fishery. Beyond these broad generalities it useful to reflect on the specific lessons that have been learned through enhanced cooperation with the scallop industry.

The implementation of cooperative experiments has coincided with development of a industry advocacy group known as the Fisheries Survival Fund. This group, representing a large segment of the scallop industry, actively participates in the management process and has supported scientific consultants to advance their interests in scientific fora. Development of organized representation at complex technical meetings is a significant advance. The translation of technical details to operational measures is difficult— much can be lost in the translation. Technical representation at such meetings and guidance on the implications of management measures can avoid unnecessary disagreements. Such indirect consultations with industry, through a consultant or mediator, can help build a level of trust among both groups. Another advantage of that an organized fishermen's group can speak with a common voice and assure that the views of a majority are given serious consideration.

The vessel monitoring system, real time reporting of landings, and the high level of observer coverage led to improved insights into fleet behavior, especially with respect to price and total revenue considerations. Scallopers in Area II optimized their expected profits by fishing mixing the size classes, particularly when prices for the largest size classes dropped. The widespread availability of maps defining the size composition of the resource and a web-based daily reporting of landings and bycatch appear to have facilitated targeting on scallop size classes. A major aspect of the web-based system was the sharing of high quality catch, bycatch and effort data among stakeholders. These data were considered the best science available by all participants. Ad hoc institutions (i.e., groups of allied fishermen) used these data to adjust fishing patterns.

Scallop harvesters also demonstrated an ability to avoid bycatch of finfish. Harvesters communicated via radio to advise others of high yellowtail bycatch areas to avoid. Bycatch rates in 1999 were lower than predicted from the fishermen's own survey in 1998. Extensive coverage by observers and a general match between daily reports of vessels with and without observers, suggested that the lower bycatch rates were not simply artifacts of observer presence. The use of large 8 inch twine tops and active avoidance of high bycatch concentrations led to lower-than-expected yellowtail flounder bycatch rates.

The rapid increase in bycatch rates that occurred after October 1, 1999 corresponded well with the predicted distribution of yellowtail flounder from the 1998 survey. As the fleet dispersed to areas of lower scallop and higher yellowtail flounder abundance the total bycatch estimate rose rapidly. The dispersion of the fleet can be explained in terms of the reductions in the more valuable large scallops and the influence of the impending closure due to attainment of the yellowtail flounder bycatch limit. Since the fishery closure was imminent, the incentive to continue avoidance of bycatch was greatly diminished. For an individual harvester, it made no sense to avoid bycatch since the individual's scallop landings could be reduced. Hence the fishery became less cooperative and more competitive as the quota was approached.

The reduction in catch rates during the course of the fishery also provides important feedback to managers on the magnitude of the exploitable stock. Catch rates declined by more than 50% even though less than half of the scallop quota was taken. As harvest of the entire scallop quota was expected to reduce daily catch rates by about 40%, the observed 50% decline in catch rates suggests that the initial population estimate used by the Council was probably too high (or equivalently, that the efficiency of commercial dredges in the southern portion of Area II exceeded the value of 25% used to estimate the biomass).

Exploitation of high density scallop beds provided additional feedback to managers on the expected effects of day at sea restrictions, gear regulations and crew size. An empirical measure of maximum shucking capacity in the vicinity of 2800 lb/day, even with a 7-man crew, was evident in the 1999 and 2000 closed area fisheries. Similarly, high capture rates per hour suggest that output controls rather that input controls would be the best way to control exploitation rates in closed areas and to fairly allocate the resource to the fleet.

Cooperative ventures between scientists and fishermen had other important externalities. Explicit constraints on finfish bycatch harvest reinforced the notion that scallopers had an important responsibility to the groundfish fleet which does not yet have access to the closed areas. Similarly, the fishing vessel surveys in the closed areas had the potential to disrupt an offshore lobster fishery. Several meetings were held with lobster industry representatives and a plan was devised to move lobster traps as necessary. Survey sampling designs were distributed to lobster fishermen prior to the fishery and the scallopers agreed to reimburse the lobstermen for any damaged traps.

The cooperative studies provided a framework to demonstrate the utility of surveys as a way of estimating abundance. The coherence of estimates from research and commercial dredges, as well as the photographic surveys, suggest that ability to quantify density and predict safe levels of harvest is within the grasp of existing survey tools. Side-by-side comparisons of research and commercial dredges, on a commercial vessel provide the evidence necessary for a skeptical audience of fishermen. At the same time, such evidence increases the utility of fishery-dependent measures for an equally skeptical group of scientists and demonstrated that complementary data (e.g., Fig. 6) could be collected in F/V surveys. As the level of trust builds, neither side is afraid to test their competing hypotheses via experimentation. Smaller scale experiments to test the effects of contact time, vessel speed, rock chains, and twine top configurations were embedded in the experimental designs. Such studies can serve as pilot studies for future work, and at a minimum, demonstrate a willingness to test alternative ideas.

Advances in theory

The cooperative research surveys within the closed areas were perhaps the best possible demonstration of the value of effort reduction. The huge catches, large size, and high quality of the scallops were sufficient to dispel many of the misgivings about the value of closed areas. Gradual reductions in total fishing effort, increased ring size on dredges, and reduced crew size were expected to decrease fishing mortality. The gradual nature and diffuse nature of these effects would be difficult to detect especially in view of normal sampling variability and influence of strong year classes. In the absence of closed areas, any increases in abundance might be ascribed to normal fluctuations in abundance or increases in growth rate rather than reductions in fishing mortality. With closed areas, and their stark density contrast with open areas, the tenability of alternative explanations was greatly reduced.

Monitoring of fleet behavior during the reopening of area II also revealed the importance localized concentrations of scallops on the distribution and intensity of fishing effort. The observed pattern of effort was consistent with the predicted "limiting distribution of fishing effort" described by Beverton and Holt (1957, p. 162). The concentration of effort on high abundance patches also suggests a reason why predicted yields based on *average* densities may not be realized. The ability to locate and exploit scallop beds will tend to maintain high average catch rates, while at the same time, reduce the true average density faster than would be predicted.

The predicted effects of mobile fishing on a sessile resource provide further impetus for the development of rotational fisheries. Rotational area management is likely to offer substantial benefits to yield per recruit, particularly if the aforementioned effects of effort concentration are coupled with increases in growth rates or reductions in incidental mortality. Increases in growth rates may occur if undisturbed scallops do not expend energy to repair shell margins damaged by incidental gear contact. A related issue is the potential increase in reproductive output that may occur when high density patches are maintained rather than dispersed by fishing activity. Although increased yield per recruit was the justification for the 89 mm rings, it wasn't until the closed areas clearly demonstrated the high potential maximum size, low natural mortality, and lack of density dependent growth that all groups perceived the value of such measures.

The limited reopenings of closed areas can be viewed as pilot experiments for the development of rotational area policies and as a gradual transition from input control to effort control. The potential benefits in terms of reduced contact time, reduced habitat impact, and reduced bycatch intimated by these pilot experiments have yet to be fully realized.

Finally, the long term value of the Vessel Monitoring System has been only partially exploited. At a minimum, it provides a common language for fishermen and scientists to gain insights into fishing behavior and resource distribution. Fishermen cannot argue that scientists don't know where the fleet actually fishes and what the catch is. Moreover, scientists cannot dismiss fishermen's observations as anecdotal fragments of the whole. In such circumstance the strengths and weaknesses of each others tenets can be evaluated. Cursory examination of the areal distribution of effort suggests coherence with substrate types. Such coherence may ultimately allow prediction of habitat impacts and bycatch considerations. Managers will find it easier to evaluate the effects of management measures in real time and make short-term corrections when appropriate.

Institutional Issues

Cooperative projects between fishermen and scientists are, for the most part, outside the normal reward systems for both groups. A day spent by a fishermen at a meeting with scientists may be viewed a day without pay; a day similarly spent by a scientist might be viewed as day away from data analyses, preparation of publications, or conducting field work. Obviously these are extreme views but it they illustrate the point.

Cooperative ventures with fishermen must be sensitive to economic considerations. Such projects may be affected by the availability of crew and other resources, constrained by poor weather conditions, and limited by opportunity costs. For example, the returns from participation in a cooperative project must be weighed against the potential revenue that would have been generated in some other fishing activity. Timing is important because of seasonal variations in weather conditions, especially on Georges Bank; delays imposed by administrative factors may prevent studies from ever beginning. Use of available fishing days within a year by fishermen reflect individual decisions involving finances, revenue, safety, expected landings, and personal factors. Fishermen must be realistic that not all projects will have the immediate positive economic advantages as in the scallop example.

On the scientists side, initiation of cooperative projects often incurs significant costs for extra personnel, overtime, insurance, supplies and equipment, data processing, proposal review, contract administration and so forth. In many institutions, the marginal costs of such activities may exceed the flexibility of annual budgets. Limitations of staffing may make it difficult to assemble a team to carry out an additional mission. These studies cannot be viewed as a substitute for fishery independent surveys, but rather as a complement (NRC 1998).

Taken together, the constraints on fishermen and scientist suggest a need for flexibility on both sides. Initiating studies, even before the project details are finalized, may be desirable. Parallel development of study plans, budgets, and timetables requires a high level of trust by all parties. The dynamic process of collaboration and iterative refinement of objectives can act to build a sense of ownership and commitment to seeing the project to its completion. Under this framework, even unsuccessful projects can contribute to improved coordination with the fishing industry and mutual understanding. With respect to the scallop fishery, such coordination will be needed for future studies on reductions in finfish bycatch, measuring habitat impacts, and development of rotational area policies.

Many of the lessons learned are intangible, yet important. Conversations, shared meals, and the common experience of round-the-clock sampling on a fishing vessel can lead to friendships that extend beyond the individuals involved. Misunderstandings among groups are less likely when at least some of the individuals have a deeper understanding of the other group's perspective. Direct contacts between fishermen and scientist have led to greater involvement of fishermen on scientific, advisory and management committees.

The cooperative studies created a valuable partnership among academic and government scientists, and commercial fishermen. Continuation of such studies is likely to become an integral part of future management, particularly as the New England Fishery Management Council moves toward area-based management policies. The closure areas have demonstrated the value of reduced fishing effort as a means of increasing stock biomass and reducing growth overfishing. The importance of these area closures as a source of recruitment has yet to be demonstrated but continuation of cooperative studies should help to answer this critical question.

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We wish to thank the captains and crews of the commercial fishing vessels listed in Table 1. Their dedication, hard work, and skill have made significant advances in scallop biology and management possible. The studies described in this paper drew heavily upon the resources and personnel of the Northeast Fisheries Science Center and Northeast Regional Office of the National Marine Fisheries Service, the Center for Marine Science and Technology, and the Virginia Institute of Marine Science. We thank the many personnel involved for their dedication to these tasks. Members of the Industry Advisers for sea scallop committee of the New England Fishery Management Council, and representatives of the Fisheries Survival Fund also provided valuable input.

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Table 1. Summary of commercial vessel surveys in 1998, 1999 and 2000.

Year	Area	Fishing Vessels	Method	Sample Unit	Number of Survey Stations	Number of Other Stations**
1998	Area II	Celtic Christian and Alexa Eileen Marie Guidance Good News Thor	Dredge	10 minute tow at 4.5 knots, two 15-ft wide dredges	546	1238
1999	Area I and Nantucket Lightship	Santa Maria Kathy Marie	Dredge	10 minute tow at 4.5 knots, two 15-ft wide dredges	148 NLS 93 Area I	238
	Georges Bank	Tradition	Dredge	10 minute tow at 4.5 knots, 15-ft wide commercial dredge and 8-ft wide NMFS research dredge	149	24
	Hudson Canyon Virginia Beach	Courageous	Dredge	10 minute tow at 4.5 knots, two 15-ft wide dredges	137	
	Area I and II Nantucket Lightship	Friendship Edgartown Alpha and Omega II (2) Huntress Liberty	Photo	Four 2.2 m^2 quadrats per station	205- NLS 454 -Area I 126 -Area II	N/A
2000	Georges Bank and Gulf of Maine.	Frontier Mary Anne Liberty Edgartown Friendship	Photo	Four 2.2 m^2 quadrats per station	92 Stellwagon 205 NLS 158 northern South Channel 183 Area I	NA
2000	Hudson Canyon	Alice Amanda	Dredge	10 minute tow at 4.5 knots, two 15-ft wide dredges	163	

**Includes various experimental and non-random stations for depletion experiments, vessel comparison stations, variable duration tows, variable speed tows, and gear comparisons.

Table 2. Summary of data enhancements to scallop stock assessment process since 1998.

Component	Assessments prior to 1998	Supplemental Activities since 1998
Fishery Independent Surveys	NMFS R/V survey: all areas	F/V Surveys in closed areas, 1998-00
		Photo Surveys in closed areas 1999-00
		Efficiency experiments on F/V, 1998-99
		R/V vs F/V comparisons at repeat stations
		Side-by-side comparisons of research and commercial dredges.
Commercial Landings	— Dealer Records on Total weight — Dockside Interviews <1994 — Mandatory Fishing Logs since 1994	— Dealer records stratified by size class — Daily electronic reporting of landings in closed areas
At-Sea Observers	10-20 trips per year	>20% coverage in closed area II in 1999 >45% in closed area II in 2000 >30% in Nantucket Lightship in 2000
Biological Samples of Commercial Landings	Voluntary Shell samples from fishermen	Size categories reported in dealer records
Vessel Tracking System	none	Hourly monitoring of position and velocity for all vessels.
Bycatch monitoring	none	--Daily monitoring of Yellowtail flounder catches monitored in closed areas. --Total allowable yellowtail flounder catch imposed in closed areas
Trip Limits	none	Trip Limits imposed in closed areas, 1999-00
Harvest Quota	none	Total allowable scallop catch imposed in closed areas

Table 3. Summary of hours of fishing activity and catches from Vessel Monitoring System data. Quartiles of fishing activity are based on distribution of total number of hours per 1 nm^3 grid.

Year	Quartiles of Fishing Activity (hr) (Range) [mean]	Number of 1-nm sqr sub-areas in which fishing activity occurred	Total Effort—fishing activity (hr)	Total Catch (lb)**	Percent of Total Catch	Value of Catch ** (million $)
1998	(0.1-1.9) [1.0]	2,533	2,466	64,052	1	0.39
	(2-9.2) [4.4]	2,904	12,716	265,946	3	1.65
	(9.3 - 44) [24.1]	3,810	91,732	1,683,180	19	10.05
	(44.1-855) [105.2]	2,836	298,315	6,647,330	77	39.81
	Total	12,083	405,231	8,670,920	100	52.43
1999	(0.1-1.9) [1.0]	3,181	3,127	159,382	1	0.90
	(2-9.2) [4.1]	3,023	12,287	507,072	2	2.83
	(9.3 - 44) [22.5]	2,026	45,677	1,878,780	9	10.43
	(44.1-855) [119.4]	2,999	357,934	18,085,500	88	98.63
	Total	11,229	419,026	20,665,200	100	112.97

**total catch based on match of VMS data with landings records from commercial dealers. In 1999 the landings were about 91%. In 1998 the match was only 68% in part due to lack of VMS requirement until May 1998

Table 4. Considerations in the use of fishing vessels to support stock assessment and related research

Issue	Traditional R/V Sampling	Use of Fishing Vessels
Survey Design	Typically a stratified design with fixed or random stations, sampling allocated proportional to area at depth, by habitat type or, fish density. Provides a statistically efficient and unbiased metric, with variance proportional to effort if the stratification variables are appropriate and stations are optimally allocated	Stratification variables may not be transparent to fishers, as may be the placement of fixed or, especially, random stations. Often systematic (grid) sampling is used to maximize spatial coverage, and results are easily interprable by fishers (e.g. density maps or contours). Systematic surveys can be superior to stratified if stratification is poorly known or inappropriate.
Data Collection/Vessel Operations	R/Vs typically sample 24 hours per day, with sufficient staff and vessel space to facilitate sampling. Multi-purpose R/Vs generally scheduled years in advance, resulting in limited flexibility to react to specific resource conditions	Berthing and deck/lab space to support continuous sampling operations may be a limitation, particularly if using small boats is a priority. Flexible schedules allow the use of fishing vessels as projects and problems arise
Sampling Gear	Typically non-commercial gear with liners to collect juveniles and pre-fishery recruits. Gear tends to not change over time, and is standardized and mensurated. Usually R/Vs allow "piggy-backing" of sampling my multiple gears (e.g. plankton, fish, water chemistry, acoustics) requiring multiple winches and support resources	Typically uses current industry-standard gear. Acceptance among fishers that latest technology is in use. Fishing with liners or non-commercial gear regarded as affecting gear selectivity. Simultaneous sampling with multiple gears may be problematic due to limited numbers of winches, A-frames, etc.
Statistical Analyses	Statistically efficient designs are employed to facilitate estimates of central tendency and variance. Results are either relative indices, or, with appropriate efficiency estimates, "absolute" stock sizes. Precision could be lower depending on design efficiency station allocation may not be optimal for all species if multiple species targets are indexed with surveys	Population estimates from systematic grids may be problematic: post-stratification, variance estimates and replication are issues. Sampling can be much more intensive and localized to improve estimates in limited parts of the resource (e.g. sub-areas). Single-species surveys can be undertaken with designs, gear and sampling intensity optimized for the species and life stage of interest.
Calibration/Efficiency	Standardization of gear and retention of an R/V over-time are used to minimize between-survey variability in gear efficiency. Fishing power studies are used when gear or vessels are changed in a survey series. Methods of estimating absolute efficiency include improved telemetry, video, and "depletion" experiments Large interannual differences in survey efficiency may occur, but can be offset by time-series smoothing in integrated catch-survey models.	Calibration is the most challenging issue faced in using fishing vessels for surveys since the same vessel/gear may not be available over time to monitor trends, and efficiencies of F/Vs vary. If surveys employ multiple F/Vs then they must be calibrated against each other. Replicate surveys with multiple vessels or fishing power experiments required for calibration. Efficiency varies by vessel and gear, so formal fishing poser studies or gear mensuration is appropriate.
Assessment of Fishery Communities (multiple species, bycatches)	Use of survey gear with small mesh liners precludes direct extrapolation of likely bycatch rates in simulated commercial fisheries. The advantage of small mesh is that sampling of the nekton community may not be as biased against the smaller components as with fishing gear.	Use of current fishing gear allows direct extrapolation of catches and likely bycatches if a fishery develops in the surveyed region. Some surveyed regions will have catch rates too low to support viable fisheries. Fishing gear may be more efficient at catching larger size groups, which may be under represented in small mesh survey gear.

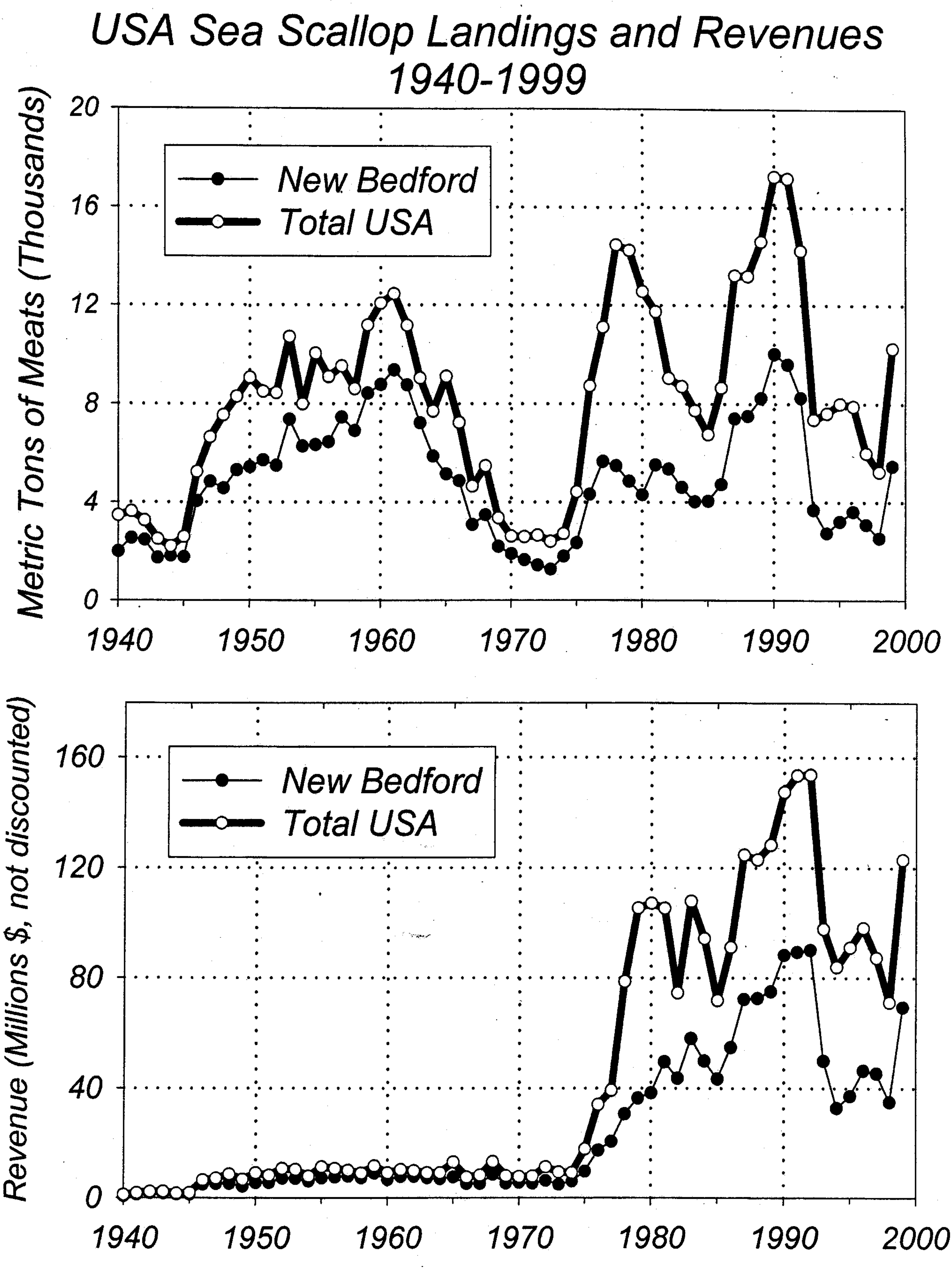


Figure 1. Trends in USA Atlantic sea scallop landings (metric tons, meats) and ex-vessel value (non-deflated $US) during 1940-1999. Data are for the resource as a whole and are given for the port of New Bedford, Massachusetts. Note the sharp increase in landings and value in 1999, much of which was associated with re-opening of portions of closed area II (Figure 2).

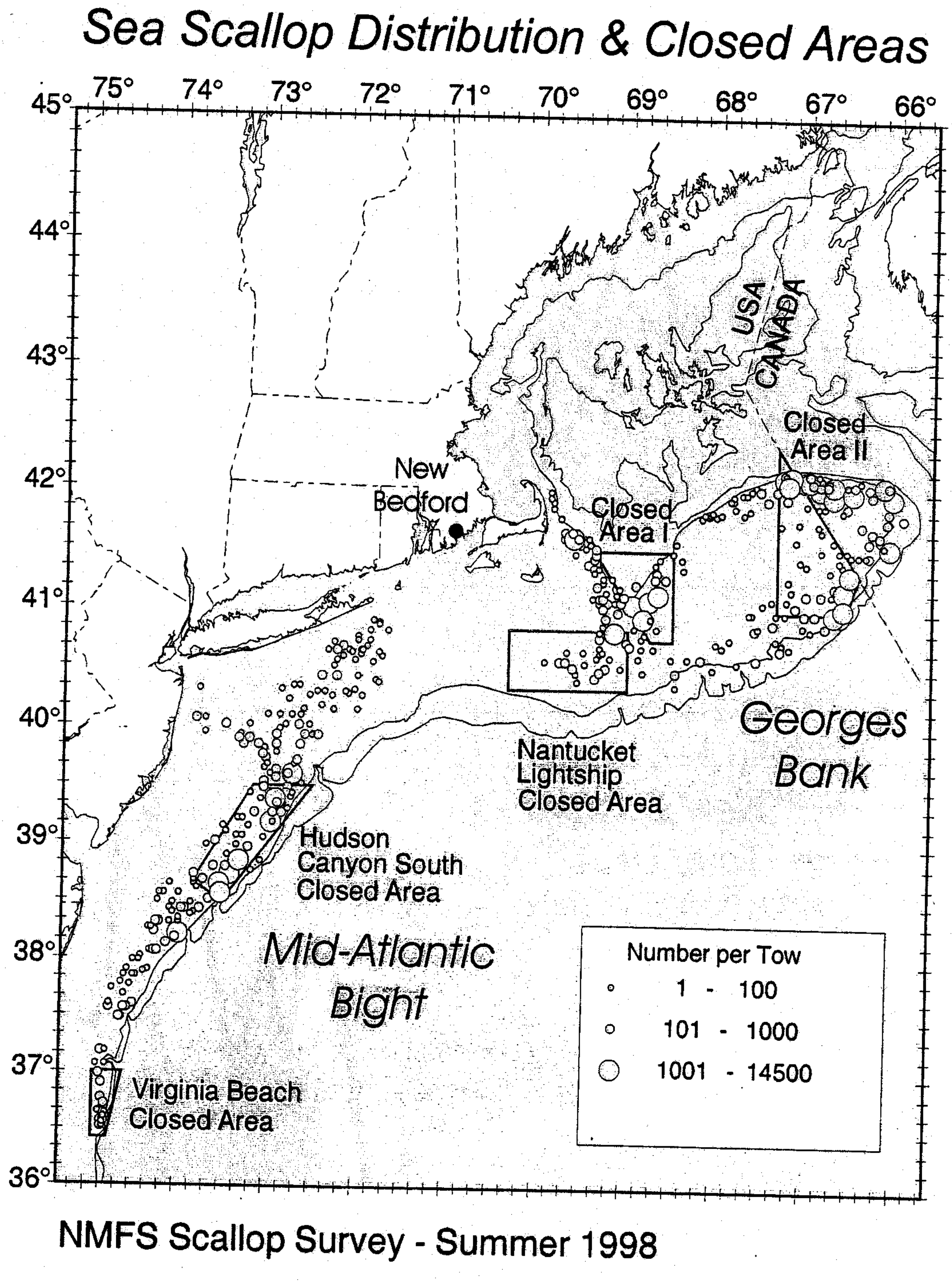


Figure 2. Distribution of Atlantic sea scallop off the Northeast USA, summer, 1998. Data are numbers of scallops (all shell height sizes) per standard 15-minute haul with an 8' wide scallop dredge equipped with 2" steel rings and 38 mm liner.

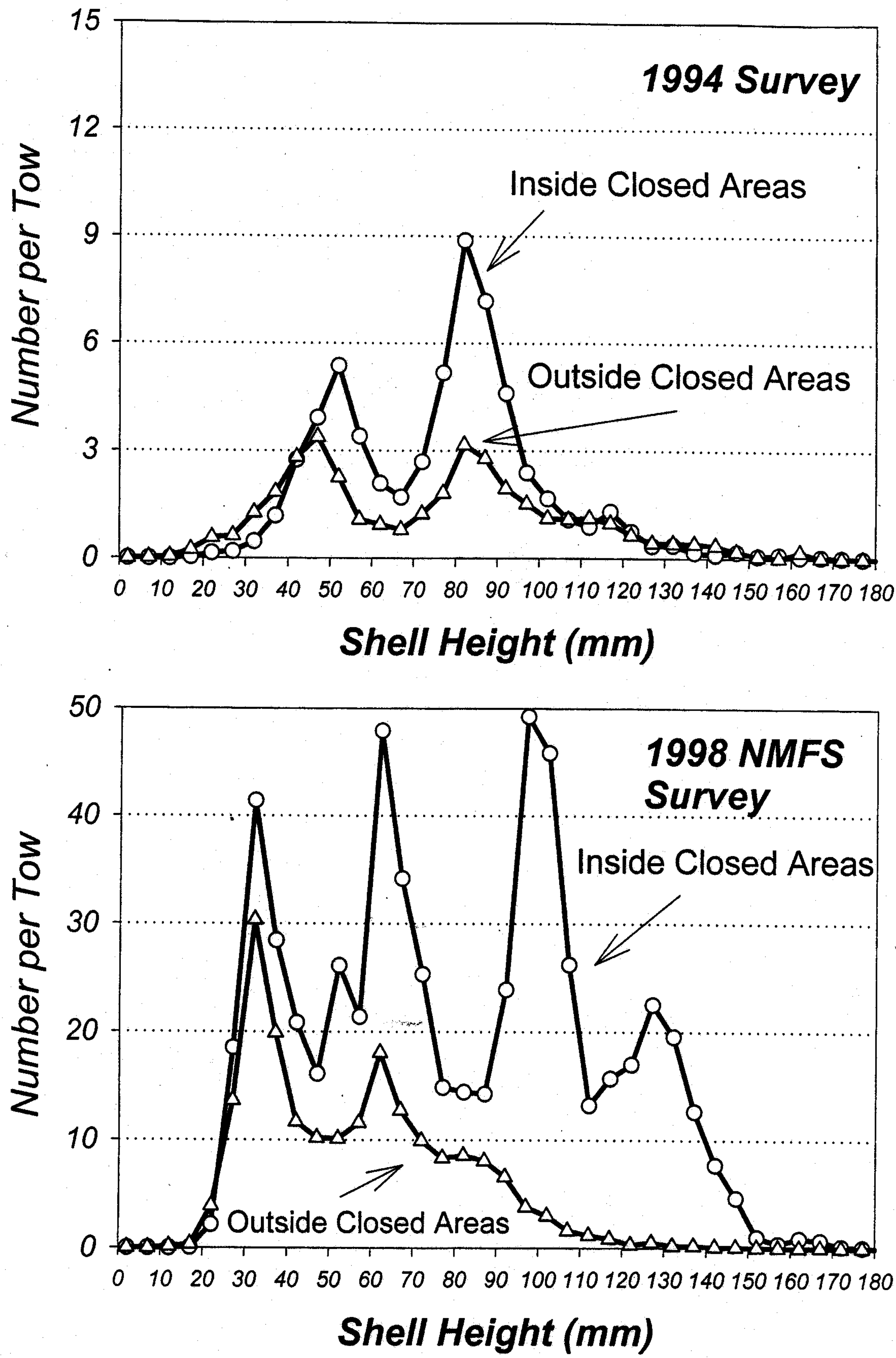


Figure 4. Changes in Atlantic sea scallop shell height frequency between 1994 and 1998. Data in the top panel were collected in summer 1994, prior to the closure of areas on Georges Bank and in Southern New England (Figure 2). Similar data for 1998 are plotted in the lower panel. Data were derived from standardized dredge surveys, and are separated for areas currently within the boundaries of closed areas, and those areas outside closures.

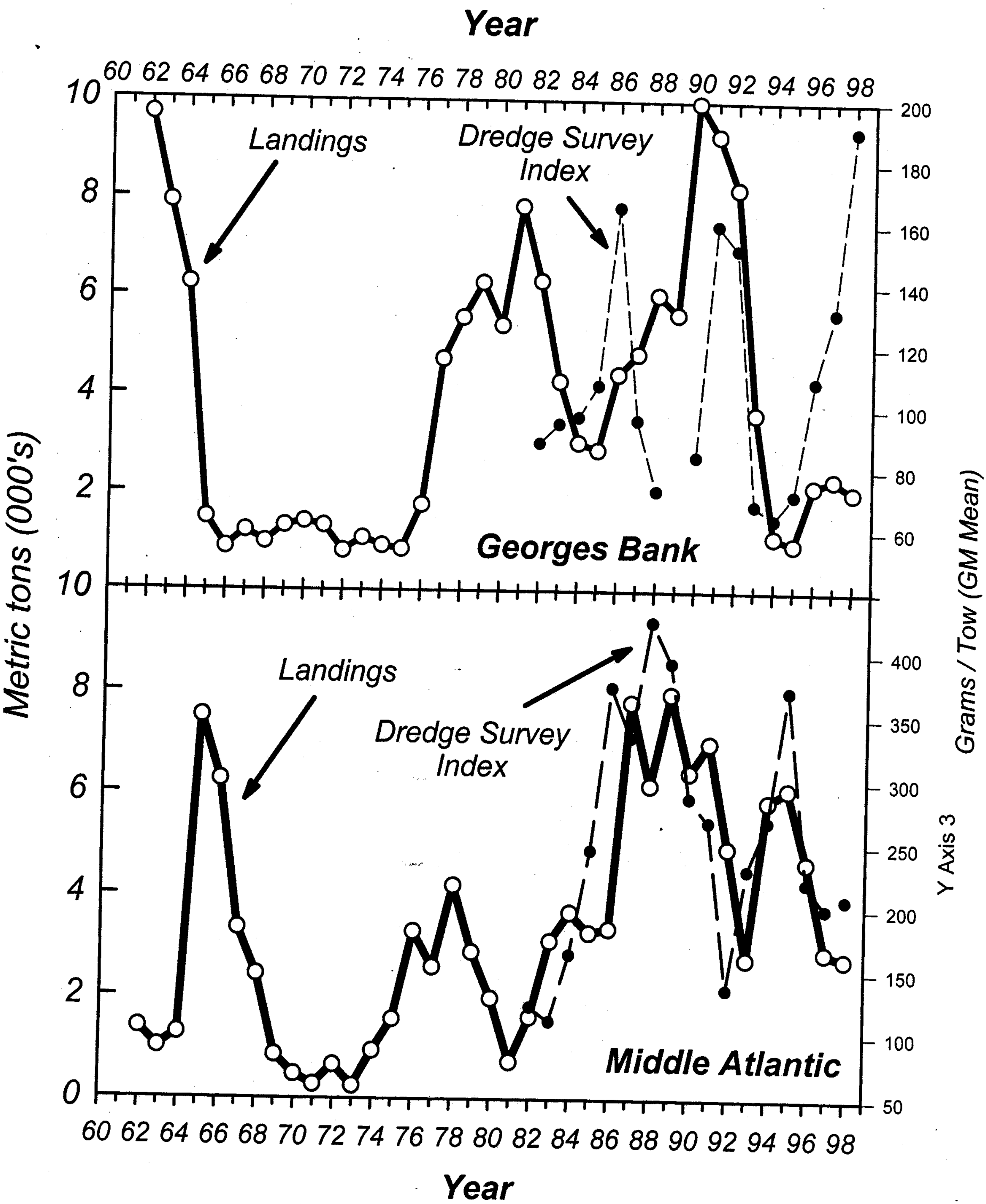


Figure 3. Trends in USA Atlantic sea scallop landings metric tons, meats) and survey indices of abundance, 1962-1998. Data are presented for two separate scallop assessment areas (Georges Bank, Middle Atlantic Bight) off the Northeast USA. Survey indices are the geometric mean of the grams (meats) per standardized 15-minute dredge survey tow.

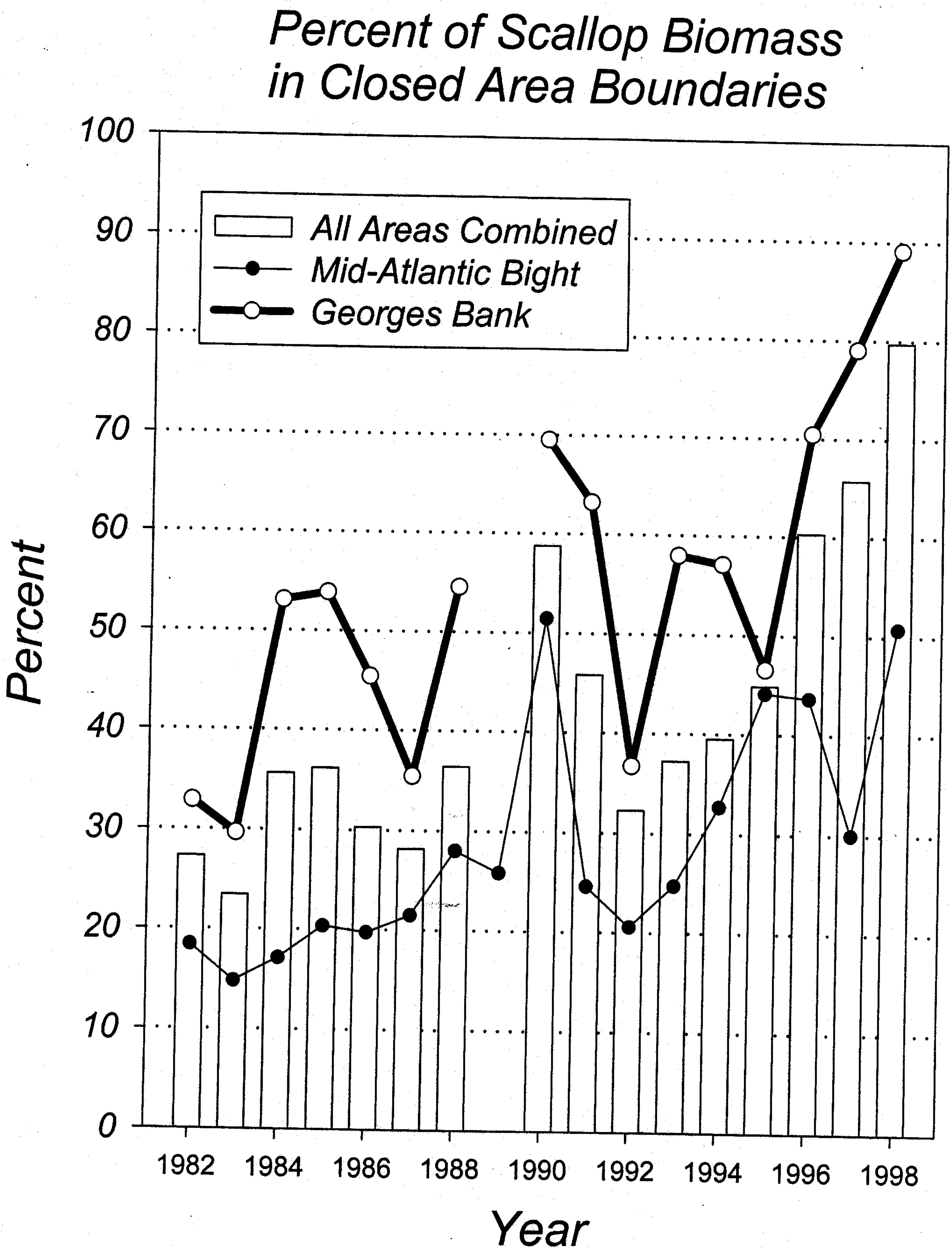


Figure 5. Percent of the Atlantic sea scallop resource (biomass, all sizes) off the Northeast USA located within the boundaries of current closed areas (Figure 2), 1982-1998. Data are from standardized dredge surveys. Closed areas were instituted beginning in 1994.

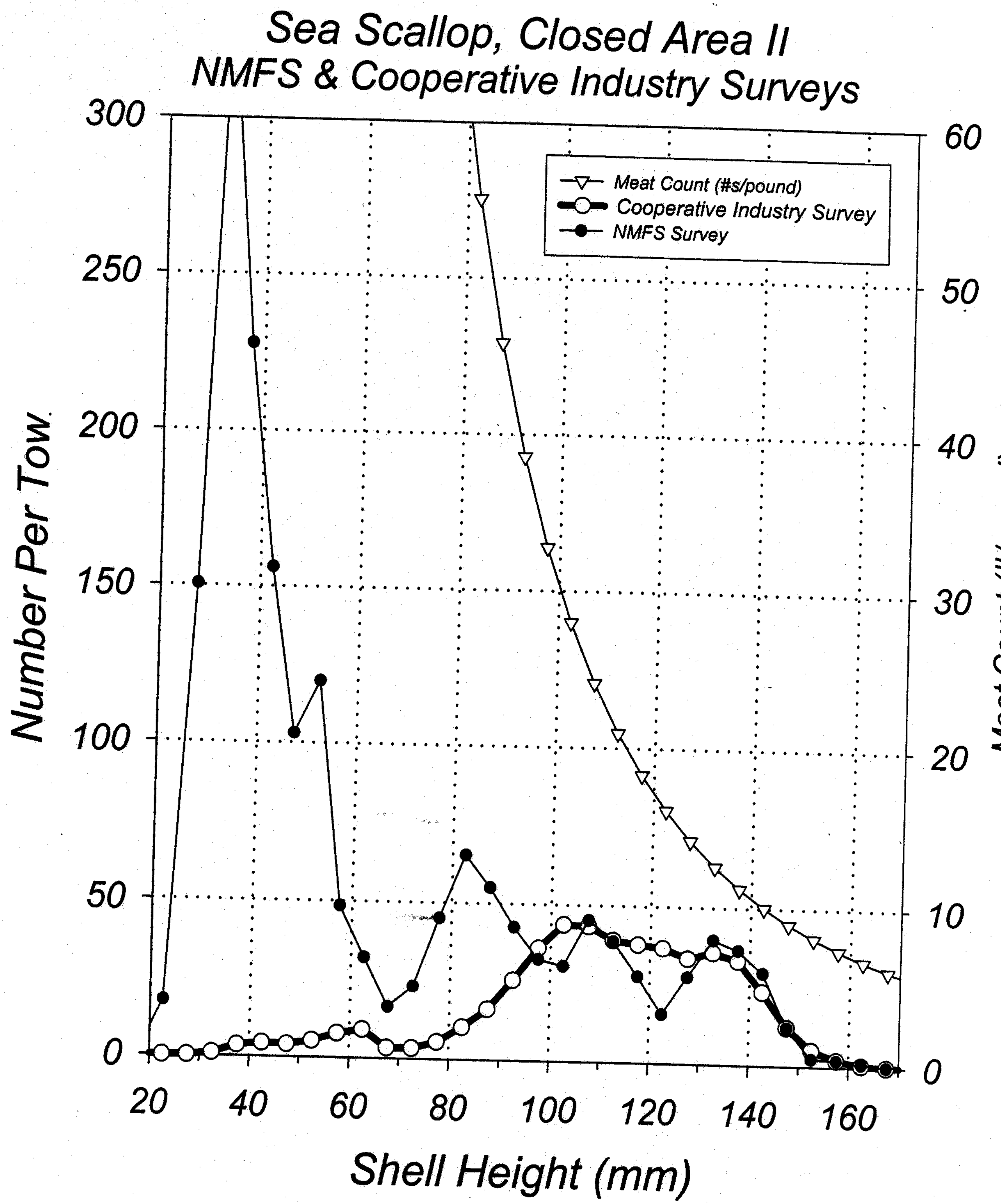


Figure 6. Comparison of size frequency distributions of Atlantic sea scallop obtained by two separate dredge surveys conducted in closed area II (Figure 2) in summer, 1998. The NMFS survey used an 8' wide dredge equipped with 2" steel rings and a 38 mm net liner. The Cooperative-Industry survey was conducted with 2 15' wide dredges equipped with 3.5" rings. NMFS survey data were adjusted to account for the greater total width of dredges, and different tow times between the surveys. The relationship between shell height (mm) and meat count (meats per pound) is also plotted.

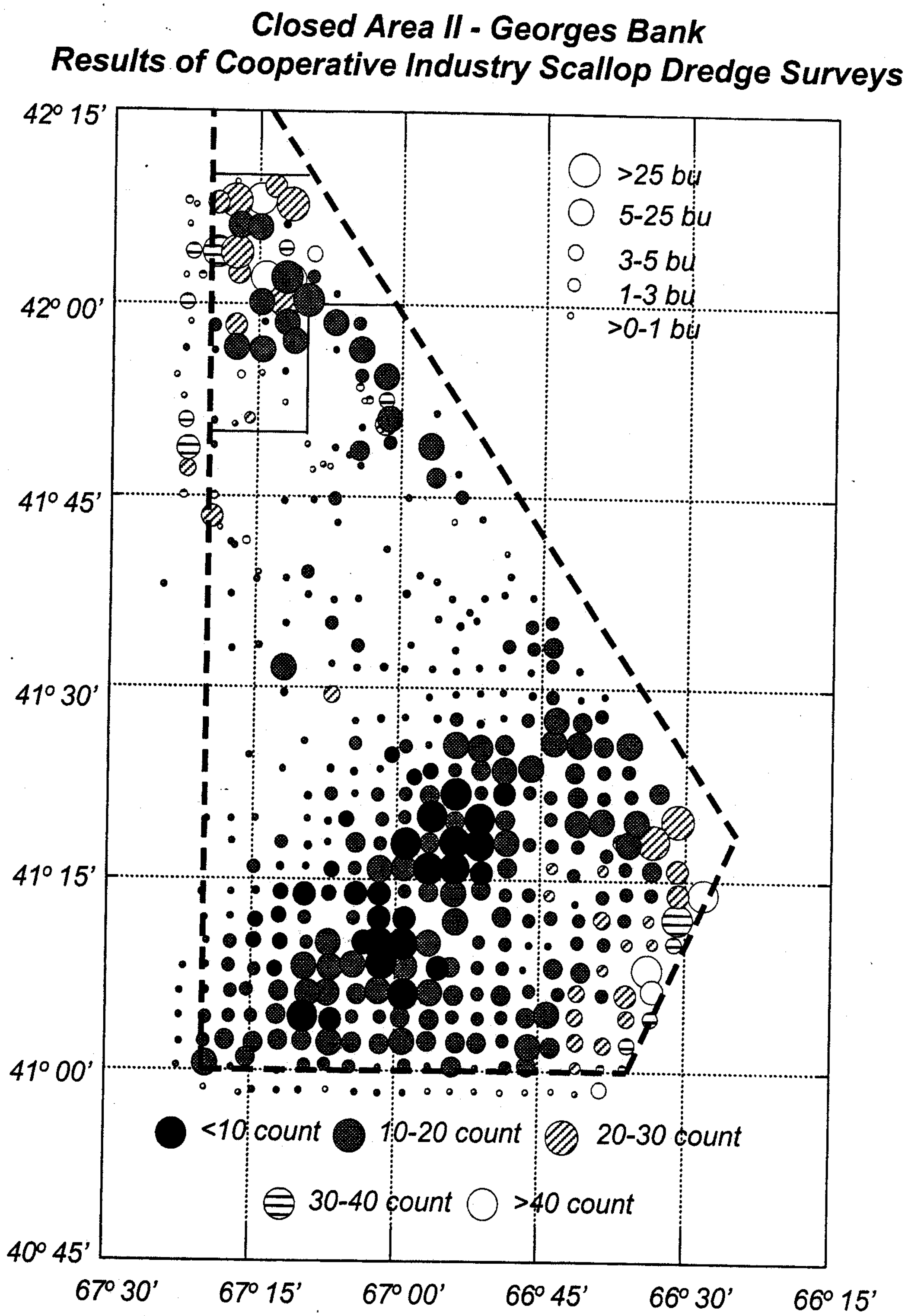


Figure 7. Density distribution of Atlantic sea scallop in closed area II (Figure 2) off the Northeast USA in summer 1998, based on surveys using commercial fishing vessels. Data are the catches (in bushels=35 liters) which were obtained by towing 2 15' wide scallop dredges for 10 minutes at each location. Data are aggregated for all 6 vessels used. Each vessel sampled every sixth survey station. Sizes of the circles are scaled to catch volume, shading varies according to the average meat count (scallop meats per pound) obtained at each station (e.g. <10, 10-19, 20-29, etc.).

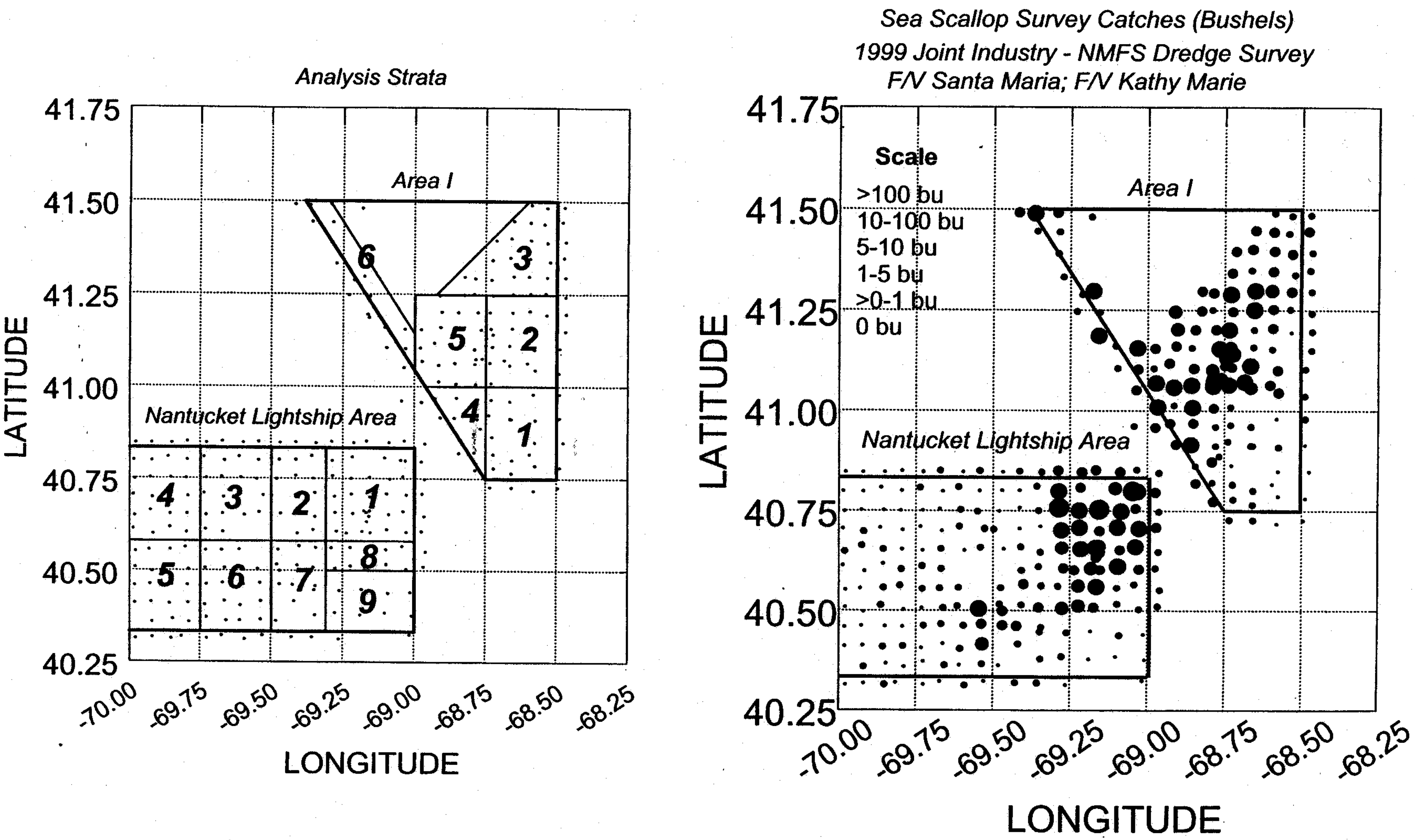
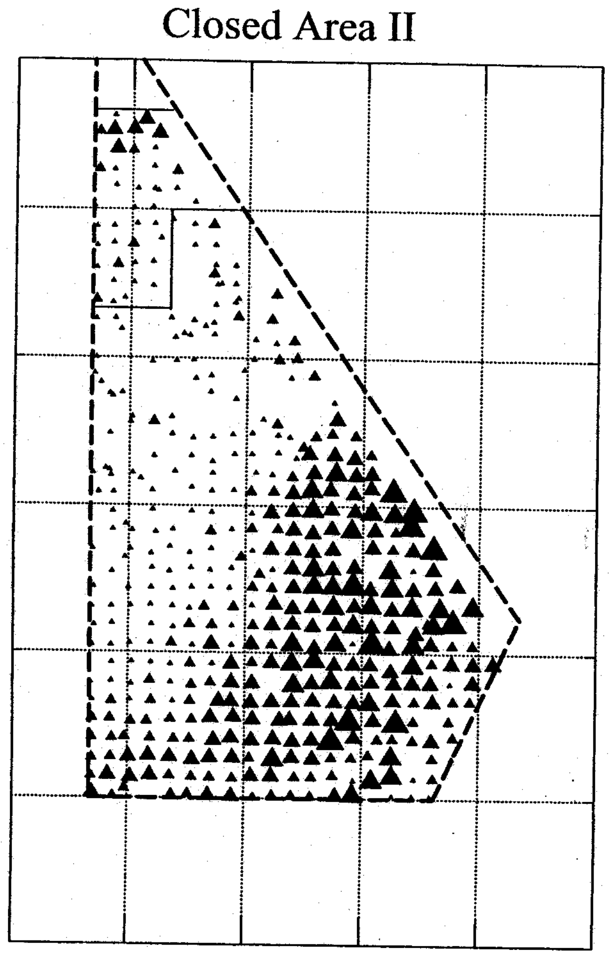


Figure 8. Density distribution of Atlantic sea scallop in closed area I and the Nantucket Lightship Area (Figure 2) off the Northeast USA in summer 1999, based on surveys using commercial fishing vessels (figure on right). Data are the catches (in bushels=35 liters) which were obtained by towing 2 15' wide scallop dredges for 10 minutes at each location. Data are aggregated for both vessels used. Sizes of the circles are scaled to catch volume. Data were collected in a systematic grid and post-stratified to the numbered areas at left. Average catches per haul in each block were weighted by the areas of each to determine an overall catch per tow and proportional distribution of the entire resource in each sub-area.



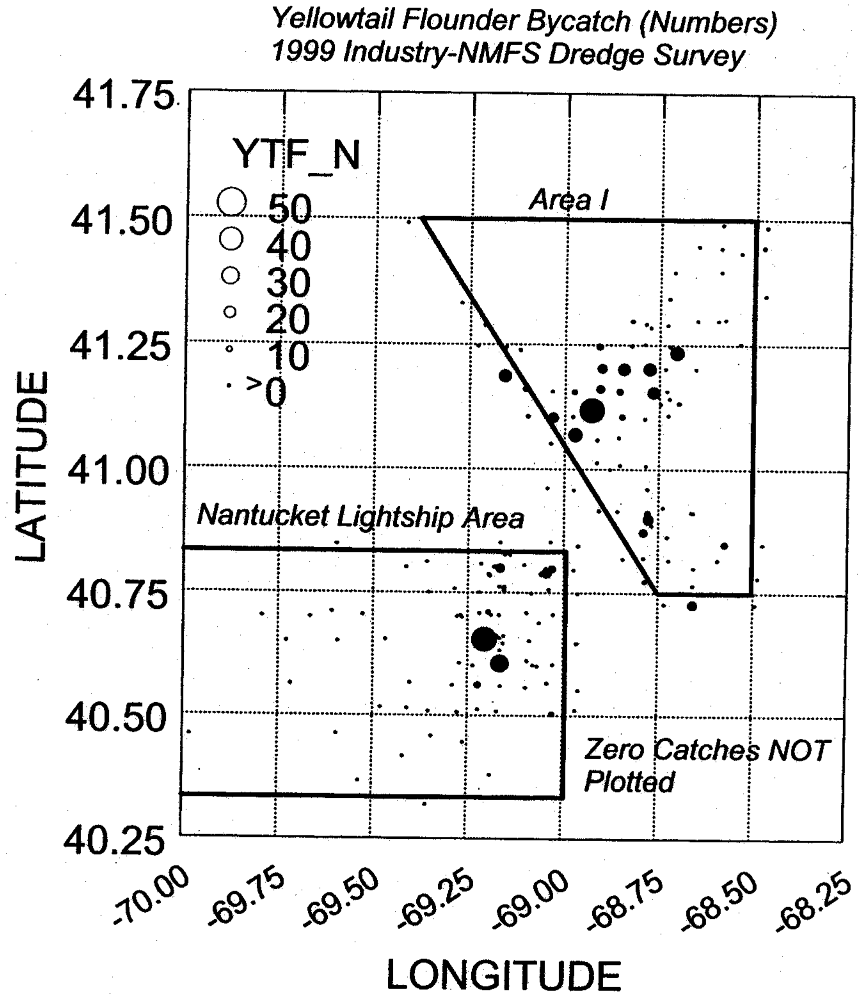


Figure 9. Bycatch of yellowtail flounder taken in cooperative-industry scallop dredge surveys of closed areas on Georges Bank, 1998 and 1999. The figure at left is closed area II (Figure 7), sizes of the triangles are proportional to the number of yellowtail flounder caught in each 10-minute tow with 2 15' wide scallop dredges (1998). The figure at right presents similar information collected in closed area I and the Nantucket Lightship Area in 1999 (Figure 8).

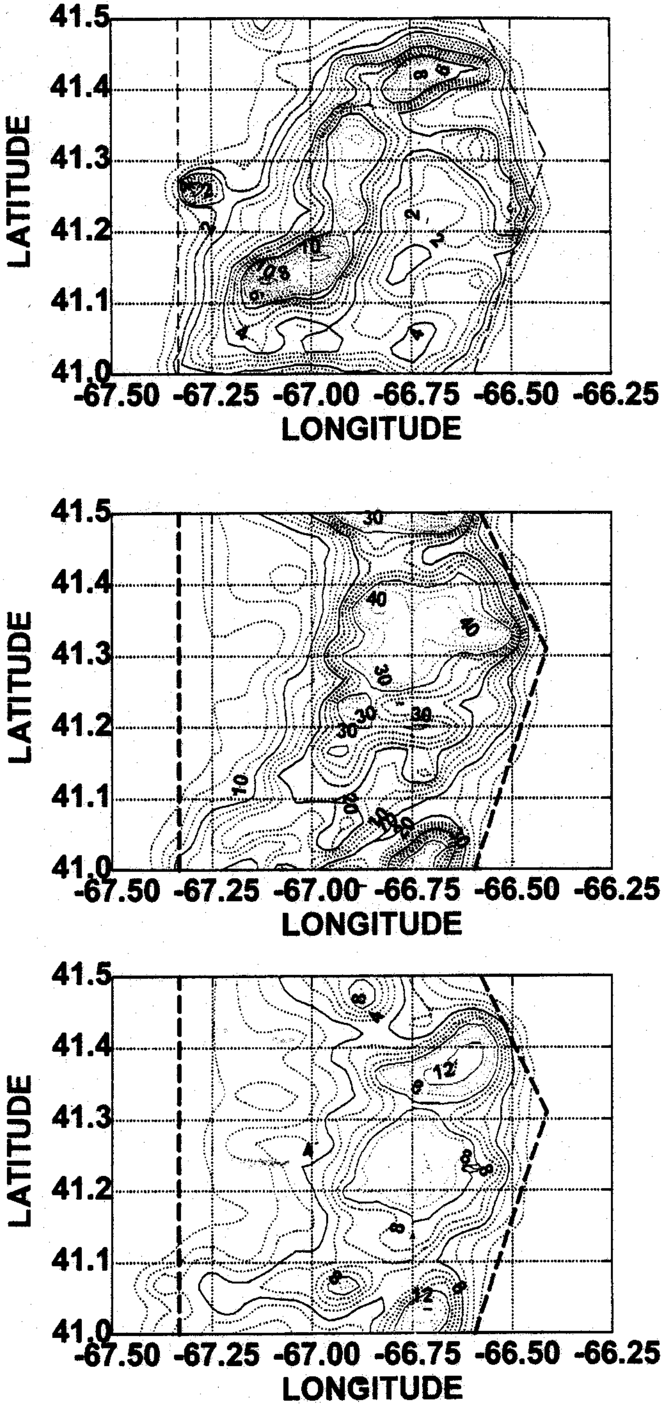


Figure 10. Density maps for scallops (baskets per tow) [top panel] , yellowtail flounder (number per tow) [middle panel], and the predicted bycatch ratio (number of yellowtail flounder per basket of scallops) [bottom panel] for Area II on Georges Bank in 1998. Results are based on 1998 Cooperative Survey.

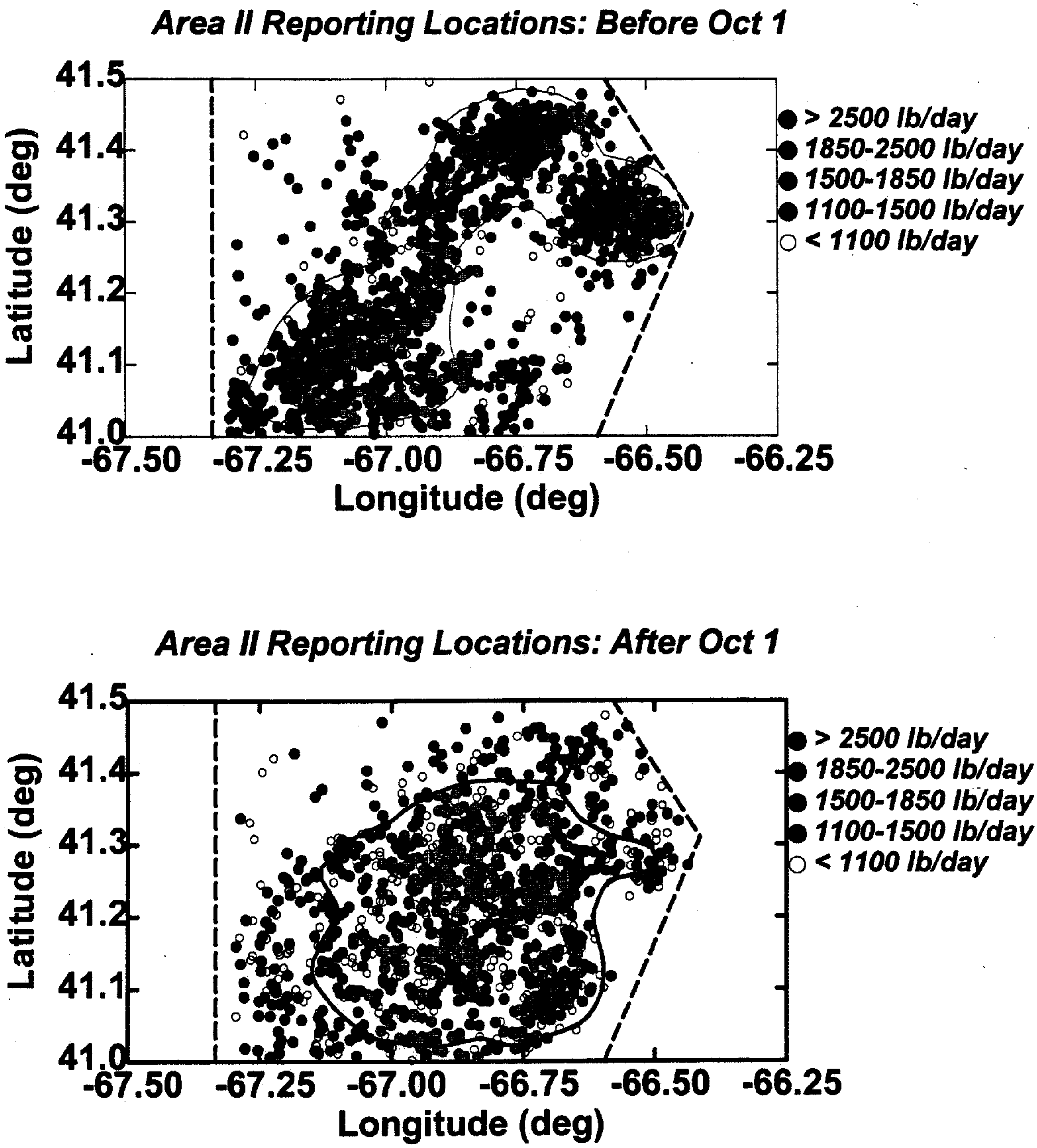


Figure 11. Characterization of scallop catch rates (lbs of meat weight per day) in Area II during 1999 fishery. Top panel depicts catch rates and spatial distribution from June 15 to September 30. Bottom panel depicts catch rates and spatial distribution from October 1 to November 5, 1999.

Trends in LPUE (lbs/day) for Area II, Entire Fleet

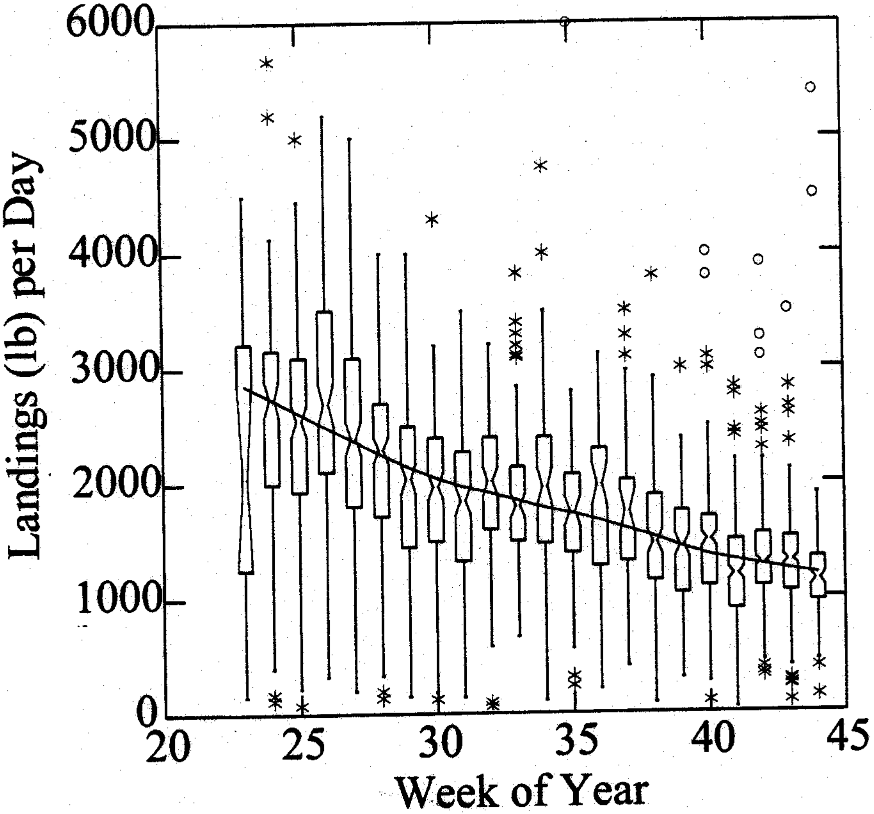


Figure 12. Observed decrease in weekly catch rates for June-November 1999 fishery in Area II. Notched box plots show the median catch rates (notch) and interquartile range (top and bottom of boxes). A lowess smoother (tension factor = 0.75) has been superimposed to help identify changes in slope.

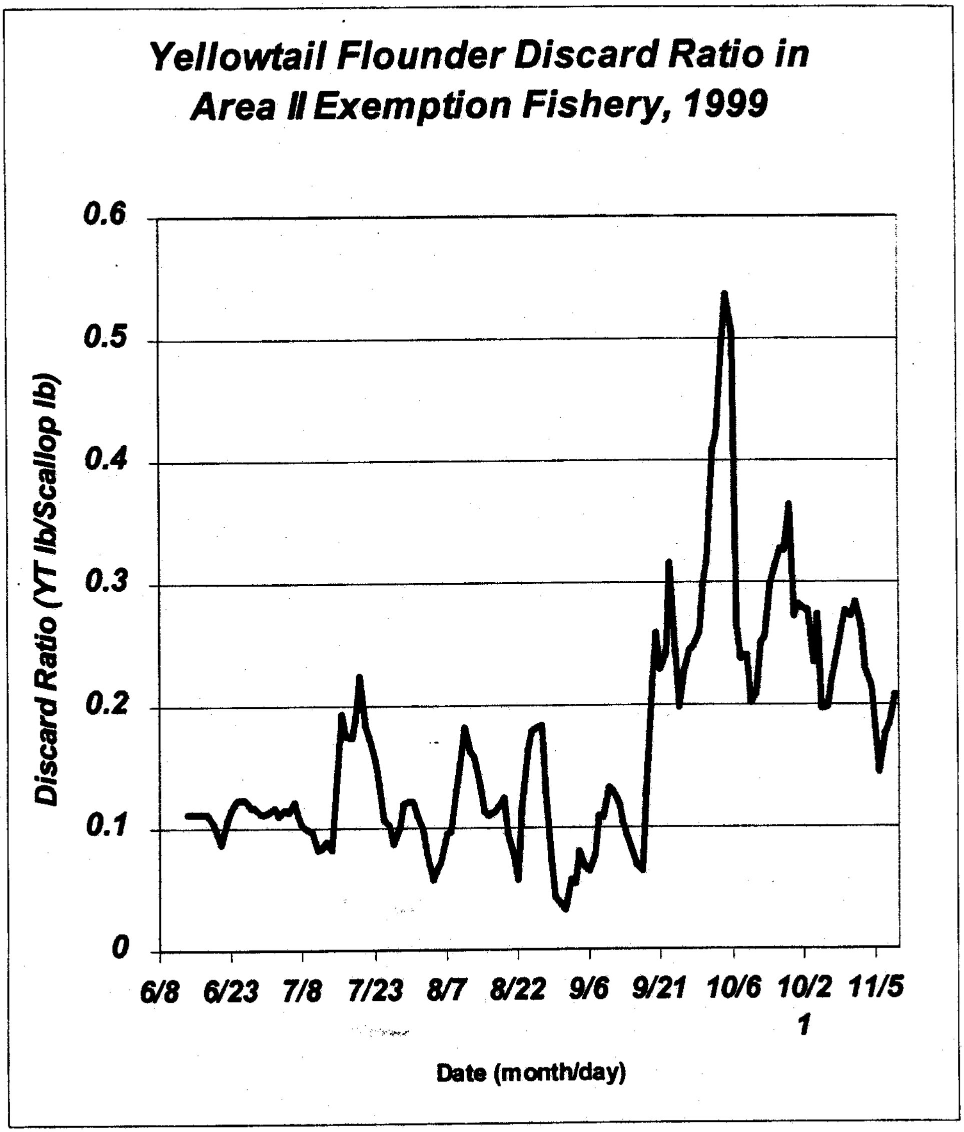


Figure 13. Observed changes in yellowtail bycatch rates (lbs of yellowtail flounder per pound of scallop meats) during the 1999 sea scallop fishery in Area II.

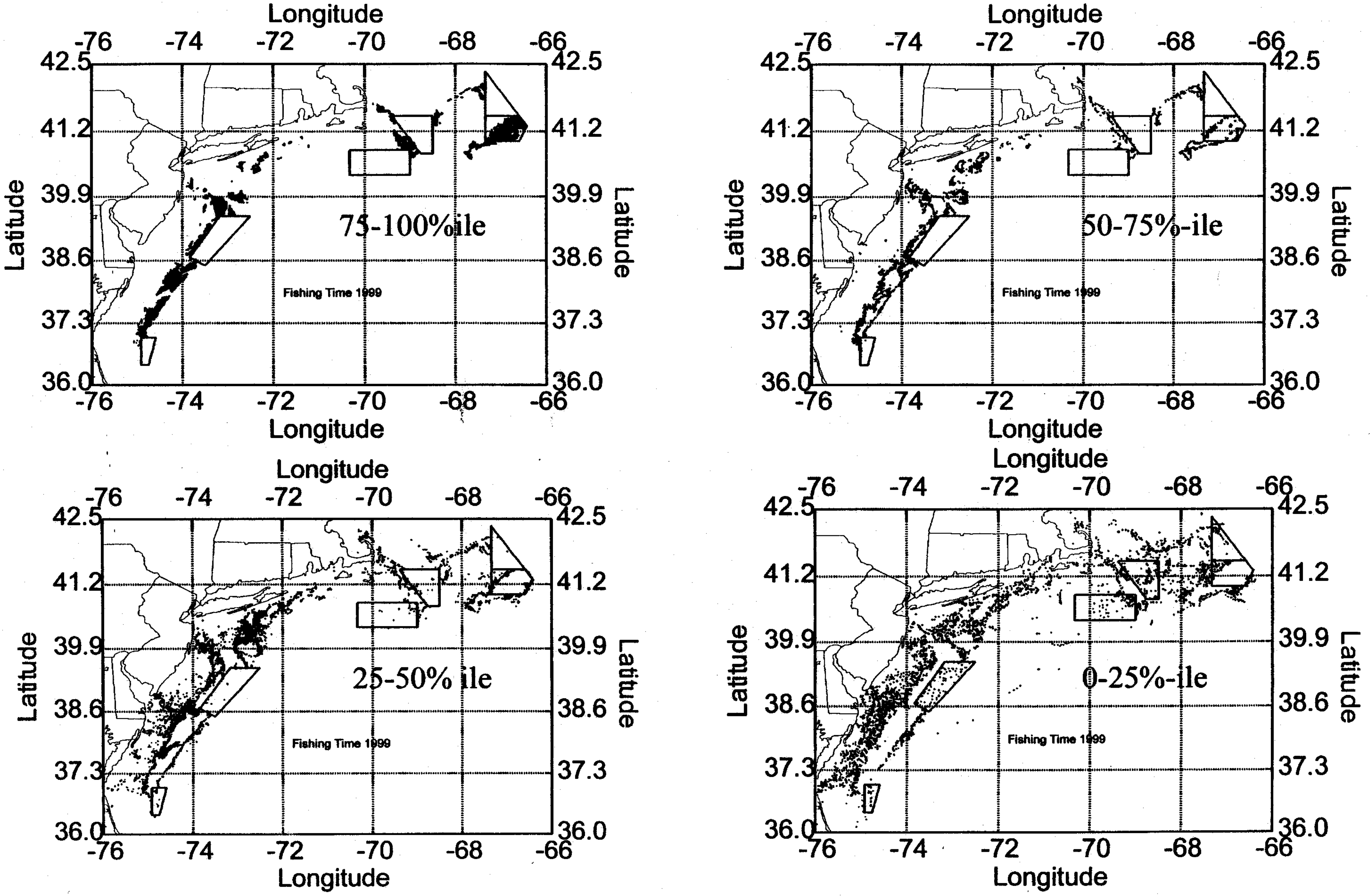


Figure 14. Spatial distribution of fishing effort (hours of fishing activity) by quartile range for the 1999 fishing year. Quartiles are based on distribution of total number of hours per 1 nm^2 grid.