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International Council for the Exploration of the Sea

CM 2004/K:36

Theme Session K on

The Life History, Dynamics and Exploitation of Living Marine Resources: Advances in knowledge.

Estimation of sea scallop abundance using a video survey in offshore USA waters

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Abstract: From 1999 to 2004 SMAST completed 23 video surveys on Georges Bank to provide spatially explicit, absolute estimates of sea scallop density and size distributions in closed areas. Further, these surveys provide information on the sediment and marine benthic habitat associated with the sea scallop fishing grounds. Sea scallop densities have increased in the three closed areas of Georges Bank. These video surveys were expanded to include the sea scallop density and size distributions along the off-shore northeast waters of the United States in 2003. Sea scallop densities in the Mid-Atlantic (26,270 km^2) and Georges Bank (28,523 km^2) ranged from 0.04 to 0.79 and 0.09 to 0.26 scallop•m^{-2}, respectively, and represented approximately 217,520 mt tons of scallop meats (approximately US$2.4 billion). On Georges Bank 82% of the sea scallop biomass was located within the three closed areas, while 36% of the scallop resource in the mid-Atlantic was within the closed areas. In the Georges Bank closed areas the proportion of sea scallop pre-recruits (<90 mm shell height) was low and sufficient to replace the adult population at an instantaneous mortality rate of 0.10 but not at a higher rate. A large number of pre-recruit scallops were observed in the southern portion of the Hudson Canyon closed area extending south into open waters. Sea stars outnumbered sea scallops (approximately 39 to 16 billion, respectively) although most were small (20 to 40 mm arm length). Sea stars may be responsible for sea scallop mortality in the southern portion of Closed Area II. The video survey technique has several advantages over dredge surveys; it is fast, accurate, precise, and provides information on the biology of scallops and the associated habitat without disturbing the sea floor.

Keywords: scallop, video, survey, sea stars

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INTRODUCTION

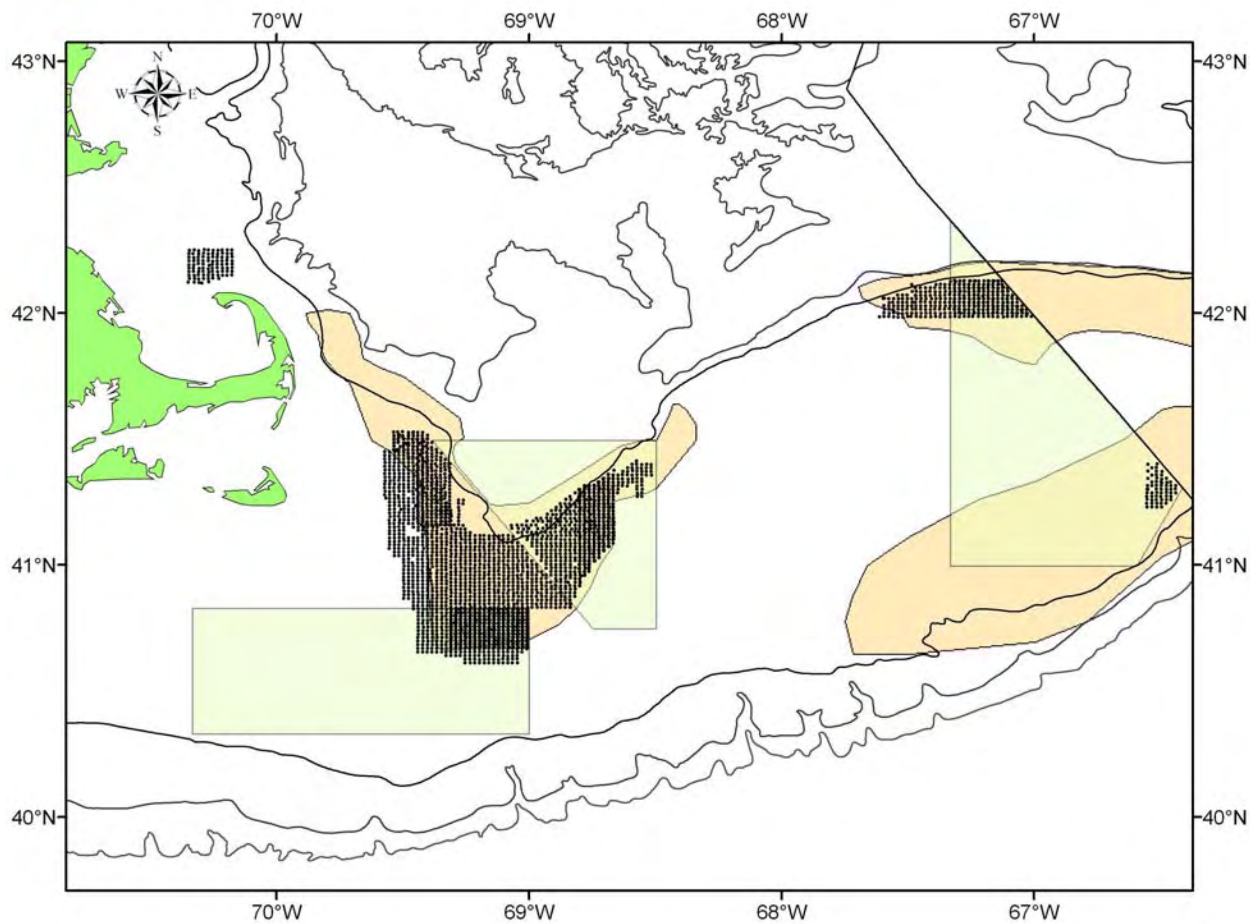
Sea scallops, *Placopecten magellanicus*, support the second largest fishery in the northeastern United States and are managed as two stocks, Georges Bank (29,000 km^2) and the mid-Atlantic (26,000 km^2) (Murawski et al. 2000; Stokesbury et al. 2004). To harvest sea scallops on Georges Bank a fishing vessel (25 - 30 m) usually deploys two New Bedford offshore dredges (Caddy 1989). Each New Bedford dredge weighs about 1870 kgs and has an iron frame that is 4.5 m wide and a 4.5 x 0.8 m bag knit of 89 mm steel rings which holds the scallops (Bourne 1964).

Three large areas on Georges Bank containing approximately 7000 km^2 of historic scallop fishing grounds were closed in 1994 to all mobile fishing gear that may collect groundfish or disturb groundfish habitat (Murawski et al. 2000) (Fig. 1). Densities of sea scallops within these three closed areas have increased to the highest ever recorded (Stokesbury 2002; Stokesbury et al. 2004). To utilize the sea scallop resource in these areas the New England Fisheries Management Council (NEFMC) and National Marine Fisheries Service (NMFS) are developing fisheries management plans that require spatially explicit information.

In 1998, a joint survey by the Center for Marine Science and Technology (now SMAST), NMFS (Woods Hole, MA), and Virginia Institute of Marine Science in association with the fishing industry indicated that high densities of mature scallops occurred in Closed Area II (Murawski et al. 2000). However, the 1998 Closed Area II survey used commercial fishing gear to estimate relative density and spatial distributions of harvestable scallops (>90 mm shell height). These relative densities were converted to absolute densities by applying dredge efficiency estimates calculated from depletion studies. Substrate type, tow speed, tow length, depth, environmental conditions, the small-scale distribution of scallops and their behavior have strong effects on these models and the resulting estimates of dredge efficiency (Caddy 1989, Stokesbury 2002). Therefore, scallop dredge efficiency estimates vary greatly (from 15% to >40%) and this has a profound effect on the accuracy and precision of the absolute scallop density estimate (Stokesbury 2000). Correction factors and several models were created to improve these estimates of efficiency but have not been verified by field observations (SAW 2001).

To avoid the difficulties and assumptions associated with estimating scallop abundance from a dredge sample we created a video sampling system in 1999. This system provides an independent estimate of absolute sea scallop density as well as information on the sea floor and marine benthic community (Stokesbury 2002). From 1999 to 2004 SMAST and members of the commercial sea scallop industry, with additional support from Massachusetts Department of Marine Fisheries and the sea scallop TAC-set-aside program (NOAA grants NA16FM1031, NA06FM1001, NA16FM2416, and NA16FM2416), have completed 23 video surveys on Georges Bank, resulting in >1000 hours of video footage and 27,000 digital images covering >8000 km^2 of sea floor at a 1.6 km resolution (Fig. 1).

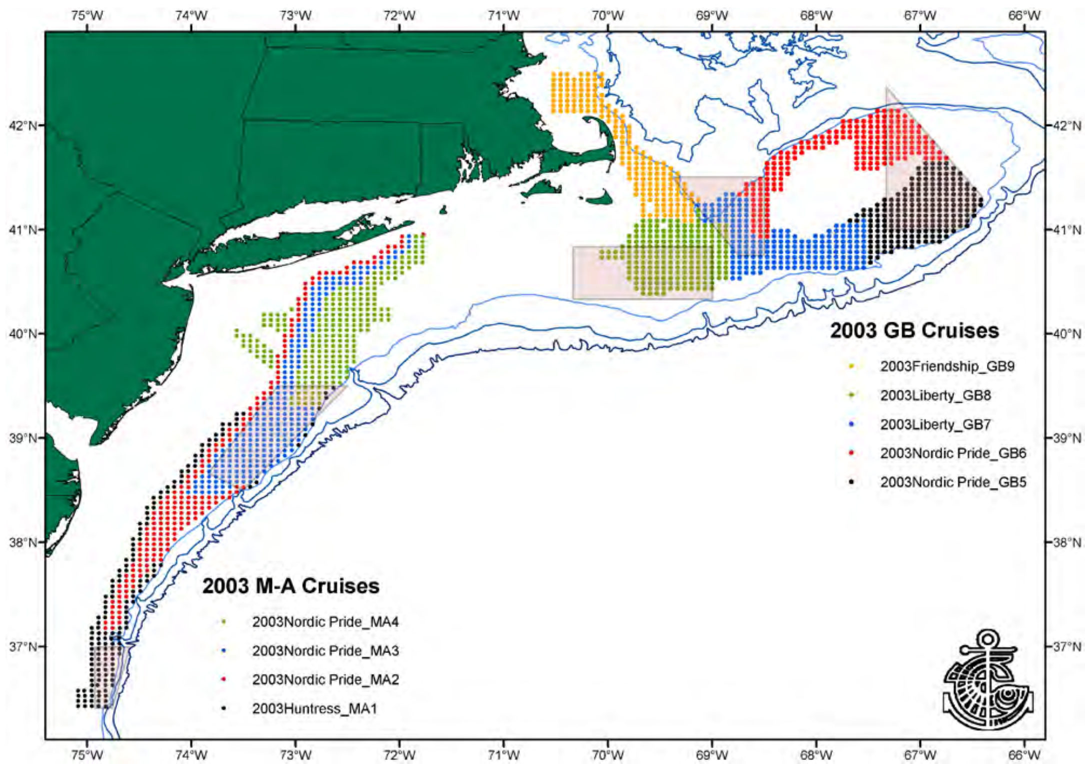
Figure 1. Georges Bank with the closed areas outlined. The historic scallop fishing grounds shaded. The SMAST video stations are represented by black dots, each separated by 1.6 km.



Due to the concern that management decisions were being based on limited data, our steering committee, made up of fishermen, vessel owners and processors, requested that SMAST expand the video survey to encompass the entire off-shore sea scallop resource. This video survey was conducted from 28 May to 23 August 2003 to provide spatially explicit estimates of sea scallop density and size distributions along the off-shore northeast waters of the United States on a 5.6 x 5.6 km grid (Fig 2). We surveyed 1847 stations during nine video cruises.

The objective of this study was to provide spatially explicit, accurate, precise, absolute estimates of sea scallop density and size distributions along the off-shore northeast waters of the United States. A second objective was to provide detailed information on the sediment and marine benthic habitat associated with the sea scallop fishing grounds.

Figure 2. The Industry-SMAST video survey of the mid-Atlantic (M-A) and Georges Bank (GB) sea scallop resource. Stations are separated by 5.6 km. Colored dots represent surveyed stations (colors represent cruises).



METHODS

Commercial sea scallop fishing vessels were used as survey vessels on all of our cruises. The SMAST sampling pyramid, supporting one to three cameras and two to nine lights, was deployed from the survey vessels (Stokesbury 2002; Stokesbury et al. 2004). A mobile studio, including monitors and VHS video recorders, and laptop computers for data entry and survey navigation (software integrated with the differential global positioning system) was assembled in the survey vessel's wheelhouse. The survey vessel stopped at each station and the pyramid was lowered to the sea floor. The video camera mounted on the sampling pyramid provided a 3.235 m^2 (2.8 m^2 expanded to reduce edge effect) quadrat image of the sea floor (Stokesbury 2002; Stokesbury et al. 2004). Footage of the first quadrat was recorded and then the pyramid was raised so the sea floor could no longer be seen. The vessel drifted approximately 50 m and the pyramid was lowered to the sea floor again to obtain a second quadrat; this was repeated four times. Sampling four quadrats at each station increased the sampled area to 12.94 m^2.

Video footage of the sea floor was recorded on VHS tapes. For each quadrat the time, depth, number of live and dead scallops, and latitude and longitude were recorded. After each survey the videotapes were reviewed in the laboratory and a still image of each quadrat was digitized and saved using Image Pro Plus® software (TIF file format). Within each quadrat marcoinvertebrates and fish were counted and the substrate was identified (Stokesbury 2002). When possible fish and macroinvertebrates were identified to species, otherwise animals were grouped into categories based on taxonomic orders. Counts were standardized to individuals m^{-2}.

Sediments were visually identified following the Wentworth particle grade scale from the video images, where the sediment particle size categories are based on a doubling or halving of the fixed reference point of 1 mm; sand = 0.0625 to 2.0 mm, gravel = 2.0 to 256.0 mm and boulders > 256.0 mm (Lincoln et al. 1992). Gravel was divided into two categories, granule/pebble = 2.0 to 64.0 mm and cobble = 64.0 to 256.0 mm (Lincoln et al. 1992). Shell debris was also identified. Quadrats were categorized by the presence of the largest type of particle. This places the highest value on complex sediment structure (Auster and Langton 1999).

Mean densities and standard errors of scallops and sea stars were calculated using equations for a two-stage sampling design (Cochran 1977):

The mean of the total sample is:

(1) $$\bar{\bar{x}} = \sum_{i=1}^{n} \left(\frac{\bar{x}_i}{n} \right)$$

where:

n = primary sample units (stations)

$\bar{x}_i$ = sample mean per element (quadrat) in primary unit i (stations)

$\bar{\bar{x}}$ = the mean over the two-stages

The standard error of this mean is:

(2) $$S.E.(\bar{x}) = \sqrt{\frac{1}{n}(s^2)}$$

where:

$s^2 = \sum^{n} (\bar{x}_i - \bar{\bar{x}})^2 / (n-1)$ = variance among primary unit (stations) means.

As the sampling fractions were small, hundreds of scallops sampled compared to millions of scallops in the area, the finite population corrections were omitted simplifying the estimation of the standard error (Cochran 1977).

RESULTS AND DISCUSSION

Overall, sea scallop densities have increased in the three closed areas of Georges Bank from 1999 to 2004 (Table 1). However, scallop densities within the Nantucket lightship closed area decreased slightly between 2002 and 2004. Densities in Closed Area I decreased between 2000 and 2001 from 0.47 to 0.37 scallops m^2, equivalent to 1260 mt tons, but this was due to the harvest of 1497 mt of sea scallop meat from this area during a limited pulse fishery.

Table 1. Mean sea scallop densities (m^2), standard error (SE) and coefficient of variation (CV), mean scallop meat weight based on shell height frequencies, area sampled (km^2) and estimated weight of sea scallop meat (mt) within the areas, from 1999 to 2004 based on SMAST video surveys conducted on a 1.6 km x 1.6 km grid; Closed Area I (CAI), the northern portion of Closed Area II (CAIIN), and the Nantucket Lightship Area (NLSA).

Year	Scallops m^2	Stations	SE	CV%	meat weight (g)	km^2	Meat weight mt tons
			CAI				
1999	0.40	114	0.052	12.95	22	388*	3398
2000	0.47	155	0.064	13.59	27	383	4895
2001	0.37	157	0.054	14.78	35	388	4961
2004	Cruise planned form 30 August 2004						
			CAIIN				
1999	0.59	126	0.075	12.76	23	311	4284
2001	0.99	127	0.110	11.14	31	314	9472
2004	1.27	138	0.130	10.29	31	341	13180
			NLSA				
1999	0.38	204	0.057	14.95	34	504	6625
2000	0.40	204	0.033	8.25	38	504	7611
2001	0.62	204	0.057	9.31	34	504	10658
2002	0.82	204	0.066	8.08	42	504	17265
2004	0.77	204	0.073	9.50	42	504	16290

* Number of stations in 1999 was low due to poor water visibility but the area was expanded to equal the other surveys.

High-resolution maps of the sea floor within these scallop fishing grounds were also compiled from the video survey data (1.6 km grid). Scallops have evolved to live on a dynamic sand-gravel substrate, which does not support sessile and encrusting invertebrates very well. Previous maps have been on a scale of one sample per 100 nm^2 (Fig. 3). By defining the gravel areas into their subgroups and showing where the substrates and sessile invertebrates do and do not exist some of the conflict over the effects of fishing on habitat may be removed. This can be demonstrated by comparing the map used to consider the different habitat alternatives in the New

England Fisheries Management Council sea scallop and groundfish management plans, Amendments 10 and 13, respectively (Figs. 3 and 4).

Figure 3. The sediment map presently used to assess the different Habitat alternatives in Amendments 10 and 13, sampling frequency is approximately 1 grab sample every 100 nm^2. (Poppe et al. 1989, Map 33 in Amendment 10, New England Fisheries Management Council, Sea scallop plan).

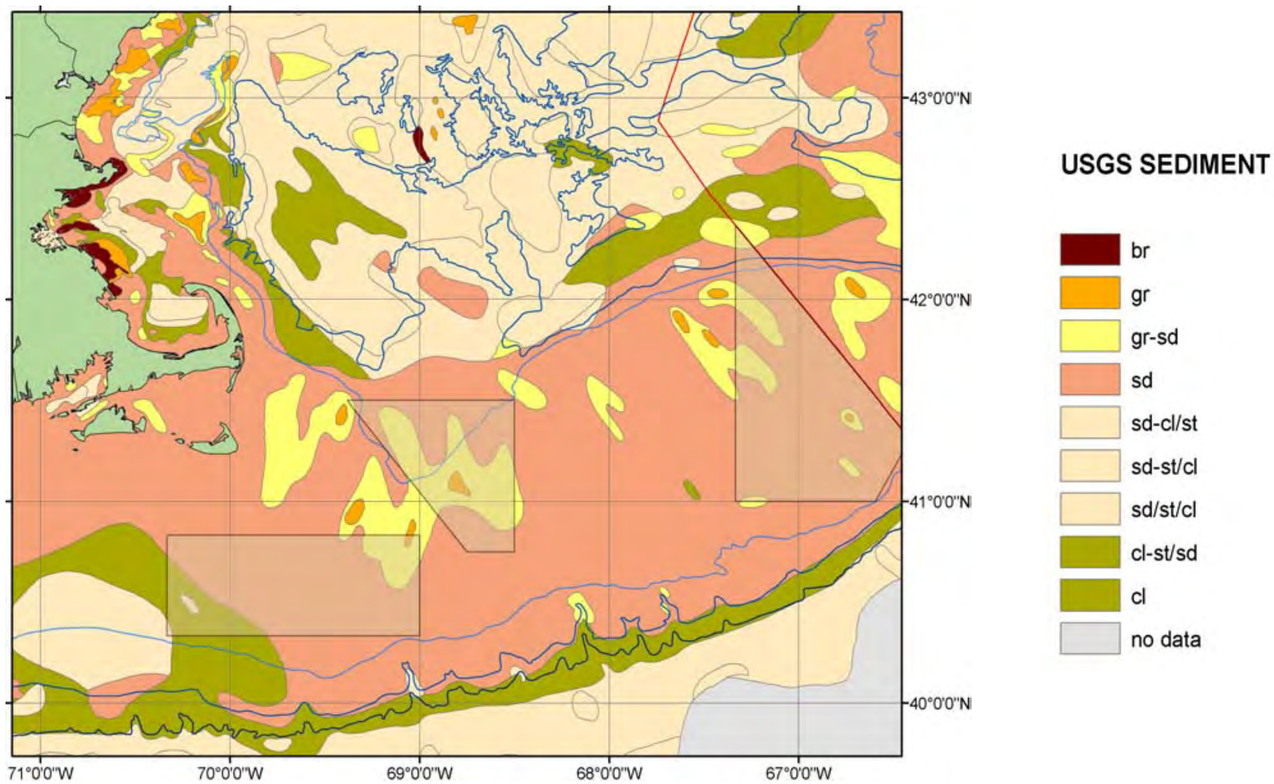
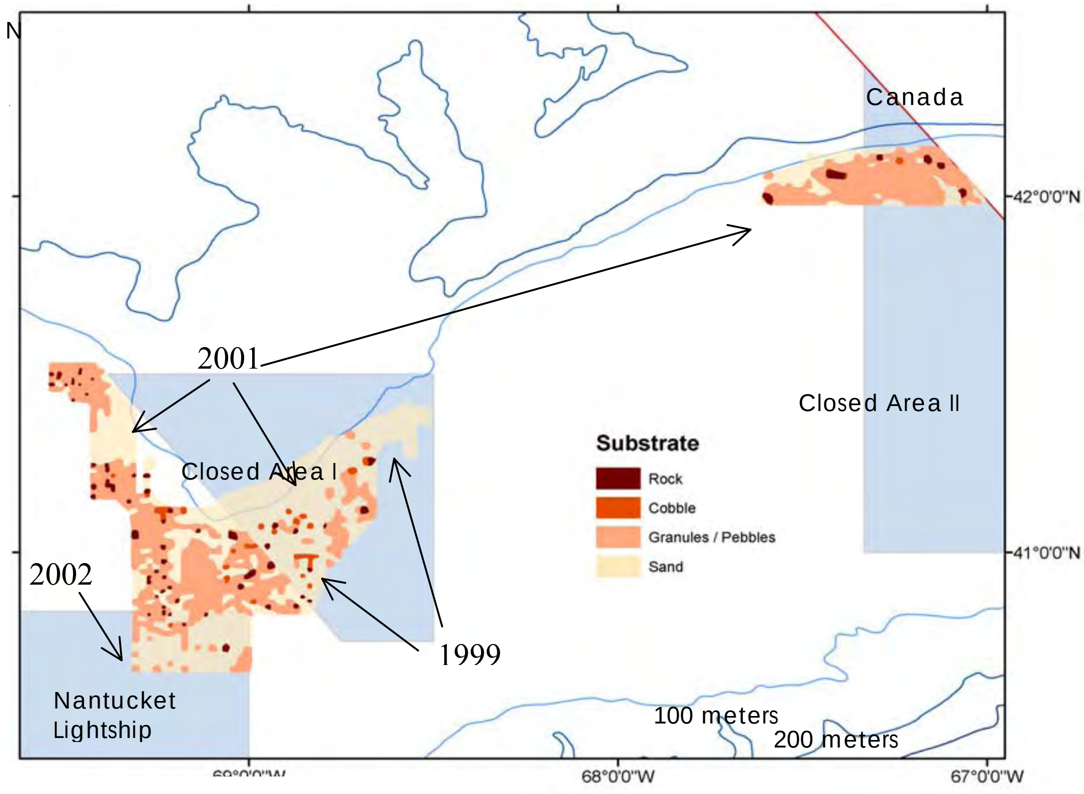


Figure 4. The SMAST video survey sediment map for Georges Bank with data collected between 1999 and 2002 created using the procedure described above, refer to Figure 1 for the 1.5 km station grid.



The 2003 survey of commercial off-shore sea scallop fishing grounds covered 54,793 km^2. Sea scallop densities in the Mid-Atlantic (26,270 km^2) and Georges Bank (28,523 km^2) ranged from 0.04 to 0.79 and 0.09 to 0.26 scallop•m^{-2}, respectively, and represented approximately 217,520 mt tons of scallop meats (approximately US$2.4 billion) (Table 2). Sea scallops were highly aggregated in areas closed to mobile fishing gear. In the Georges Bank closed areas the proportion of sea scallop pre-recruits (<90 mm shell height) was low and sufficient to replace the adult population at an instantaneous mortality rate of 0.10 but not at a higher rate (Fig 5). A large number of pre-recruit scallops were observed in the southern portion of the Hudson Canyon closed area extending south into open waters (Fig 5). Sea stars outnumbered sea scallops (approximately 39 to 16 billion, respectively) although most were small (20 to 40 mm arm length) (Table 2). Sea stars may be responsible for sea scallop mortality in the southern portion of Closed Area II (Stokesbury et al. 2004). In 2004 we are repeating the video survey of the entire US sea scallop stock on the 5.6 x 5.6 km grid.

Figure 5. Shell height frequencies of sea scallops, *Placopecten magellanicus*, in the Nantucket Lightship Area (NLSA), Closed Area I (CAI) and Closed Area II (CAII), Georges Bank open area (GB open), and in the Hudson Canyon (HC) closed area and Mid-Atlantic open area (MA open), n = number of scallops measured (Stokesbury et al. 2004).

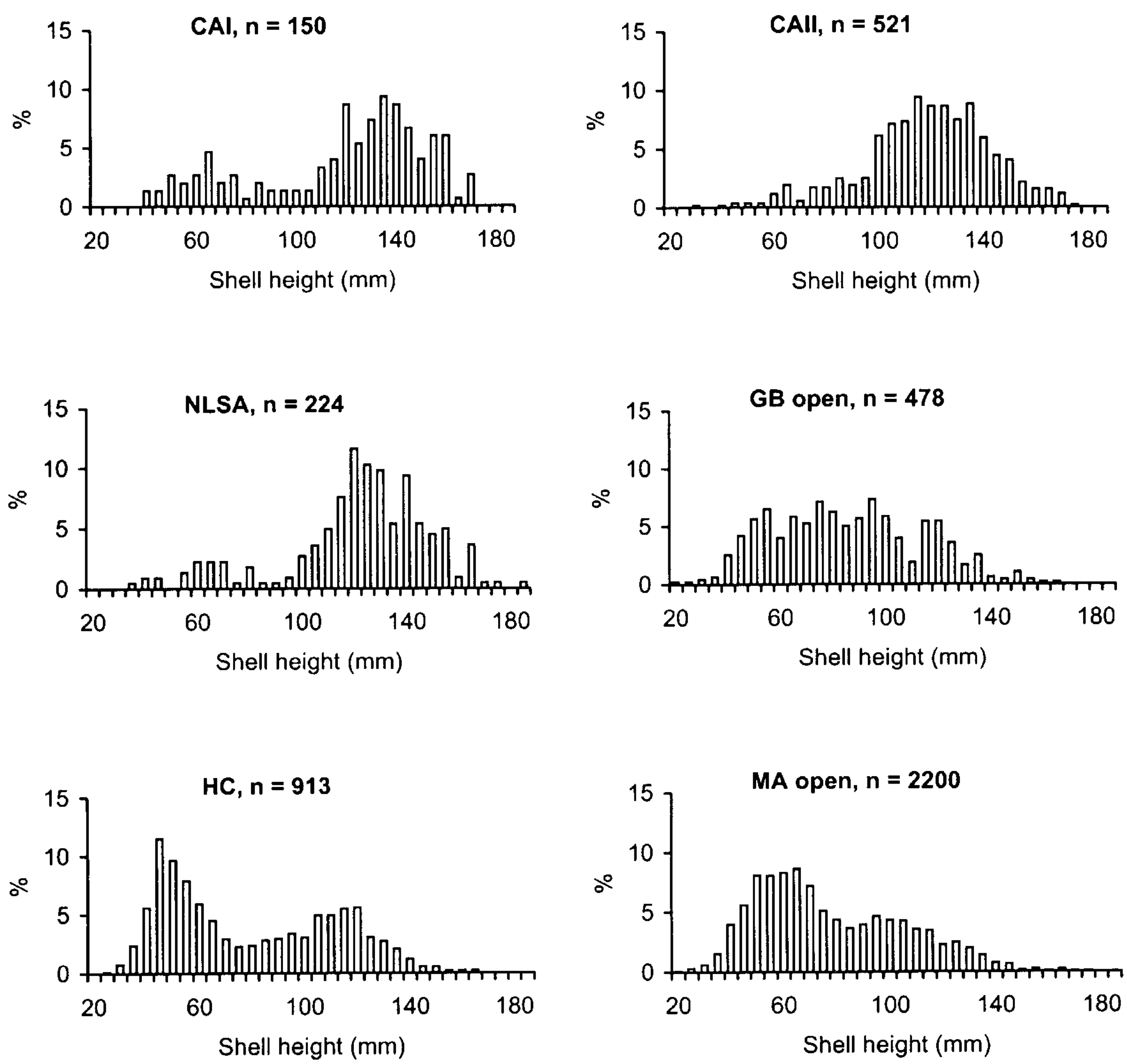


Table 2. Area sampled (km^2), Mean sea scallop and sea star densities (m^2), standard error (SE) and coefficient of variation (CV), number of individuals (million), mean scallop meat weight based on shell height frequencies and estimated weight of sea scallop meat (mt) within the areas from 2003 SMAST video surveys conducted on a 5.6 km x 5.6 km grid.

		Area	Sea stars				Sea Scallops				meat	
	Stations	(km^2)	m^2	SE	CV%	Ind Mil	m^2	SE	CV%	Ind Mil	(g)	mt
Georges Bank												
CAI	97	2994	0.09	0.023	26.8	262	0.16	0.036	22.1	489	30.7	15016
CAII	186	5742	0.13	0.050	38.9	740	0.26	0.045	17.4	1474	33.2	48980
NLSA	128	3951	1.67	0.254	15.2	6618	0.21	0.040	19.4	816	39.8	32465
Open	513	15836	0.34	0.032	9.3	5387	0.09	0.008	9.3	1436	14.5	20823
Total						**13007**				**4215**		**117285**
Mid-Atlantic												
HC	160	4939	0.97	0.131	13.5	4793	0.79	0.250	31.5	3915	9.1	35714
VB	34	1050	0.46	0.111	24.0	487	0.04	0.008	21.1	41	13.1	533
Open	657	20281	1.02	0.063	6.2	20673	0.40	0.076	19.2	8075	7.9	63988
Total						**25952**				**12030**		**100235**
Overall Total						**38959**				**16245**		**217520**

The sea scallop abundance data from these surveys have been used to manage the sea scallop fishery including NEFMC Frameworks 12 (1999), 13 (2000), 14 (2001) and Stock Assessment and Fishery Evaluation Report (2000) and the NMFS, 32nd Northeast Regional Stock Assessment Workshop (SAW 2001). Preliminary maps of the sea floor detailing the substrate and sea scallop distributions are being considered in Amendments 10, 13 and framework 16/39 by the NEFMC and the NMFS. Based on the 2003 scallop data a closure was implemented that will protect the area of high sea scallop recruitment in the southern portion of the Hudson Canyon closed area extending south into open waters. Further, the southern portion of Closed Area II may be opened earlier than scheduled due to the high natural mortality observed in this area (Stokesbury 2002; Stokesbury et al. 2004). In support of the 39th Northeast Regional Stock Assessment Workshop on sea scallops, the sea scallop number and shell height raw data were provided to the NMFS to assist in the stock assessment analyses. The video survey techniques and data were reviewed and discussed at meetings of the NMFS Invertebrate Subcommittee meeting in conjunction with the NMFS scallop survey. In the future, we propose to edit this video library, digitize summary film clips of each station and link the footage to an interactive map. This will allow users to see the habitat and conditions that exist at each location surveyed.

Acknowledgements. We thank B.J. Rothschild for his support and guidance. We thank the owners, Captains, crews, and students who sailed with us. P. Christopher (NMFS) and L. Gavlin (USCG) provided the Letters of Authorization and insured smooth transitions between fishing and surveying for the vessels. Aid was provided by SMAST, the Massachusetts Department of Marine Fisheries, the National Marine Fisheries Service's sea scallop research set-aside program (NOAA award numbers NA16FM1031, NA06FM1001, NA16FM2416, and NA16FM2416) and the sea scallop fishery and supporting industries.

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