Final Report

Sea Scallop Research

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Project Title: **Examining the effect of the 2004 pulse fishing event on the Georges Bank closed area benthic community.**

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1. Project Summary

Objectives: We hypothesized that the pulse fishing event of 2004 and 2006 in the Nantucket Lightship Area and 2005 event in Closed Area I would impact the marine benthic community. To test this hypothesis we examined the scallop abundance, spatial distribution on several scales (cm, m, km), associated macroinvertebrate benthic community and substrate in the closed areas of Georges Bank that were and were not exposed to the fishing event, before and after the fishery. We measured changes in species composition, density and distribution of macroinvertebrates and fish, and sediment type.

Methodology: We conducted a Before-After-Control-Impact study monitoring the openings of the Georges Bank closed areas as proposed in Amendment 10 and Joint Framework 16/39. We previously surveyed portions of the closed areas of Georges Bank during the summer of 2004 before the openings (NOAA grants). We proposed to conduct three additional video surveys in Georges Bank closed areas after the 2004 fishing season. We resampled the stations surveyed during the summer of 2004. The sampling procedure for these surveys was a multistage design with stations separated by 1.57 km. These surveys detailed the distribution of substrate, depth, live scallops, dead scallops, and macroinvertebrates (sponges, starfish, filamentous fauna). We analyzed the data collected during the video surveys to compare areas of low and high scallop density.

Rationale: The New England Fisheries Management Council and the National Marine Fisheries Service have implemented Amendments 10 and 13 for sea scallop and groundfish management, respectively. Both of these management plans contain a series of alternatives to protect essential fish habitat. The impacts of a rotational fishing plan, such as Amendment 10, on the sea floor habitat and the abundance and recovery rates of the target species have been speculated but not studied and tested. We conducted the first and largest BACI experiment on a scallop fishery when we monitored the Georges Bank closed areas during the 2000 sea scallop exemption fishery. However the fishing effort, particularly in the Nantucket Lightship area was much lower in 2000 than in the 2004 opening. Further the control areas have remained closed and now represent habitats that have been undisturbed by fishing for 10 years. Determining the impact of these rotational opening will be critical to future management plans, and frameworks as well as the upcoming Habitat Omnibus.

Conclusions:

1. A mass mortality of sea scallops occurred between 2004 and 2005 in the Nantucket Lightship Closed Area. Scallop density in the North-east corner declined by 50%. Only 6% of the decline was explained by fishing mortality.
2. Changes in the number of fish and macroinvertebrate categories and the density of individuals within each category in the areas impacted by the limited short-term sea scallop fishery were similar to changes in the control areas that remained closed to fishing. Sediment composition shifted between surveys more than epibenthic faunal composition.

2. Project Description:

a. Project goals and objectives: We hypothesized that the pulse fishing events of 2004 and 2006 in the Nantucket Lightship Area and 2005 event in Closed Area I would impact the marine benthic community. To test this hypothesis we examined the scallop abundance, spatial distribution on several scales (cm, m, km), associated macroinvertebrate benthic community and substrate in the closed areas of Georges Bank that were and were not exposed to the fishing event, before and after the fishery. We measured changes in species composition, density and distribution of macroinvertebrates and fish, and sediment type.

b. The relationship of the project to management needs or priorities identified by the Council: The research outlined in this report will enhanced the understanding of the scallop resource, essential fish habitat, the impact of pulse fishing on sea scallops and scallop bed habitat, and contributed to the body of information on which management decisions are made. It addresses critical regional and national issues described in the Federal Register Vol. 68, No. 12, 17 Jan. 2003 and referred to in Federal Register (Vol 69, No. 73, Thursday April 15, 2004, page 19983-4, Full Announcement Text) including:

1. Identifying the physical and biological variables associated with scallop and essential fish habitat (considered high priority by the council). These video surveys will provide detailed maps of the substrate and macroinvertebrate communities in areas exposed to rotational pulse fishing as proposed in Amendment 10 and Framework 16.
2. Improving information concerning scallop abundance estimates (considered high priority by the council). These surveys will be in areas that have high scallop densities that will be exposed to an intense short term fishery.
3. Evaluating the distribution, size composition, and density of scallops (considered high priority by the council).
4. Conducting fishing industry-supported high-resolution surveys that include distribution, recruitment, mortality and growth rate (such as size frequency) information. These surveys are conducted with industry, from industry vessels and provide a great deal of information on scallop distribution and the benthic marine habitat.
5. Processing and analyzing data that will be and have already been collected. The new information collected from these three survey cruises will be compared to the 2004 surveys in the same areas prior to the fishing event.
6. Detailing sea scallop life-history information (especially on age-and area-specific natural mortality and growth) and to identify stock-recruitment relationships.
7. Develop high resolution sediment maps of sea scallop fishing areas. The new information collected from these three survey cruises will be coupled with our existing SMAST video database. Further we are mapping our surveys using GIS software and using spatial analysis to compare and contrast the different habitats we have observed.

This study has direct implications for present and future management plans including Amendments, Frameworks, and the Habitat Omnibus. These data are key to fisheries management decisions and we will present our results to the appropriate NEFMC PDTs (scallop, habitat, and multispecies) and the NEFSC of the NMFS.

3. Methods

The 12 harvest trips were all completed before the end of the fishing year (2/28/05), the date below is the one on the checks received by the University.

Date	F/V Conducting Harvest Trip (12 DAS)
1/25/2005	Warrior
1/26/2005	Resolution
2/7/2005	Liberty
2/9/2005	Araho
2/11/2005	Guidance
2/24/2005	Diligence
2/25/2005	Mary Anne
2/25/2005	Barbara Anne
2/25/2005	Venture
2/25/2005	Celtic
2/28/2005	Edgartown
3/16/2005	Resolute

Before each cruise I contacted Mr. Pete Christopher or Mr. Don Frie of the NMFS who provided a letter of authorization for the research and harvest cruises and notified the Coast Guard of our activities. Upon returning to port I contacted the NMFS again and provided an account of the cruise (Weight sheets are presented in support document 1).

The BACI study consisted of 2 experiment areas, each containing an impact area exposed to fishing and an undisturbed control area (Table 1). These areas were surveyed using the same procedures as the 1999-2003 surveys (Stokesbury 2002, Stokesbury et al 2004). The surveys used a centric systematic sampling design positioning stations on a 1.57 km grid to measure the density of scallops m^{-2} on the sea floor with a precision of 5 to 15 % for the normal and negative binomial distributions, respectively (Stokesbury 2002).

Experiment I used the Nantucket Lightship Area (NLCA) as the impact area and the northern portion of Closed Area II (CAIIN) as the control area (Figure 1). Mean depth, proportions of granule/pebble substrate, area covered by sea scallops, mean numbers of scallops m^{-2} within scallop aggregations, and total number of scallops were similar in the impact and control areas (Stokesbury 2002, Stokesbury and Harris 2006). The northern portion of Closed Area II remained closed, while a limited short-term fishery was implemented in the Nantucket Lightship impact area during the 2004 and 2006 fishing years (Table 1). We surveyed these before and after each of these harvests (Table 1).

Experiment II was located in the central portion of Closed Area I (CAI) (Figure 1). These areas are dominated by sand substrate. Framework 13 to the Atlantic Sea scallop FMP shifted the original access area boundaries used in the previous BACI examination (Stokesbury and Harris 2006) to the south. The entire area was impacted at the beginning of the harvest as the initial access area boundaries were in place. However, an emergency management action was implemented during the 2005 limited short-term fishery and shifted the access area boundaries to a smaller area (Figure 1b, Scallop Fishing Permit holder letter dated 31 October 2005). Therefore, the 2004 boundaries were used in the analysis where a central portion was impacted (CAI impact) and areas north and south were closed and thus used as a control area (CAI control). We surveyed these areas in 2004 and 2006 (Table 1).

Commercial sea scallop fishing vessels were used as survey vessels. The surveys were conducted with a DeepSea multi SeaCam 2050® underwater video camera mounted vertically on a pyramid, 1575 mm above the sea floor, providing a 3.24 m^2 quadrat (Stokesbury et al. 2004). Four quadrats were sampled at each station, increasing the sample area to 12.94 m^2. The time, depth, number of live and dead scallops, latitude and longitude were recorded at each station. After each survey the videotapes were reviewed in the laboratory and a still image of each quadrat was digitized. The field data were verified and the shell height (mm) of each scallop was measured in the still image using Image Pro Plus® software. 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. Unidentified fish were grouped as "other fish." Counts were standardized to individuals m^{-2}. Sponges, hydrazoa/bryozoa and sanddollars were recorded as present or absent within a quadrat.

Fish and macroinvertebrate densities (m^2) and standard error were calculated for each survey using equations for a multi-stage sampling design (Cochran 1977, Stokesbury 2002). 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). The 95% confidence intervals were calculated using $\bar{\bar{x}} \pm t_{\alpha}S.E.(\bar{\bar{x}})$ (Cochran 1977).

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 placed the highest value on complex sediment structure (Auster & Langton 1999).

The percent similarity coefficient was used to quantify the differences between benthic communities before and after fishing by comparing the number of species present and

their relative proportions between areas (Krebs 1989). Each category was standardized as a percentage of the total organisms observed. The minimum value was selected for each category from the two samples, 100% equals identical samples. This is one of the best quantitative similarity coefficients of community structure available as sample size and species diversity have little effect on it (Krebs 1989). The counts of individuals and species collected were tested for normality and homogeneity of variance; as most of the data sets failed these tests, a log (x+1) transformation was applied before statistical tests (Green 1979, Zar 1996). A standard one-way ANOVA was used to compare differences in mean individuals m^{-2} within each category between surveys for each area.

4. Results and Relevant Conclusions

Experiment I a – CAIIN (Control) and NLCA (Impact)

Before vs. After: Control Area (July 2004 vs. October 2005)

We observed 14 categories of fish and macroinvertebrates in the control area, in both 2004 and 2005. The sea scallop and sea stars comprised 83.6 and 81.6% of all of the individuals in 2004 and 2005, respectively (Table 2). Hermit Crabs, hake and other fish increased significantly in density (Table 3, Figures 2 & 3). Sponges, haddock, and sculpin decreased (Table 3, Figures 2 & 3). The similarity index for all categories was high at 93.4% (Table 2).

The sediment composition differed significantly ($\chi^2 = 13.9$, df = 3, p = 0.003, power 0.050: 0.904). Cobble increased from 15.8 to 23.2%, while sand/shell debris decreased from 21.3 to 16.8% and boulders decreased from 4.4 to 3.2% (Figure 4). Granule/pebble substrate remained the same. The sediment composition percent similarity index was 92.5%.

Before vs. After: Impact Area (May 2004 vs. October 2005)

The 2004 fishery harvested 1134 t of scallop meats equaling 25 million scallops assuming a mean individual meat weight of 0.0458 kg (Stokesbury et al. in press, Support Document 2). We observed 15 categories of fish and macroinvertebrates in the impact area in 2005 and 12 in 2005 (Table 2). Sea scallops and sea stars represented 85.0 and 75.5% of all individuals in 2004 and 2005, respectively (Table 2). Mean sea scallop density declined significantly from 2004 to 2005, representing a mass mortality (Stokesbury et al. in press, Support Document 2).During the mass mortality sea scallop densities declined by 50 % from 0.76 (± 0.146 CI) to 0.38 (± 0.0981 CI) scallops m^{-2} (t' = 4.298, df = 355, two-tailed $p < 0.001$) (Table 3, Figure 2 & 3). Hermit crab densities increased from 0.01 to 0.04 individuals m^{-2} from 2004 to 2005 (Table 3, Figures 2 & 3). Density of hake, ocean pout, and sculpin decreased significantly (Table 3, Figures 2 & 3). The similarity index for all categories was 85.7 % (Table 2).

The sediment composition differed significantly between 2004 and 2005 ($\chi^2 = 14.7$, df = 3, p = 0.002, power 0.050: 0.922). Cobble decreased from 6.3 to 2.4%, granule/pebble

substrate increased from 25.6 to 27.8%, and sand/shell debris and boulders remained the same (Figure 4). The sediment composition percent similarity index was 96.1%.

Experiment I b – CAIIN (Control) and NLCA (Impact)

Before vs. After: Control Area (October 2005 vs. August 2006)

In both 2005 and 2006, 14 fish and macroinvertebrate categories were observed (Table 7). The sea scallop and sea stars comprised 81.6 and 87.4% of all individuals, respectively (Tables 7). The mean densities of sea scallops and sea stars increased significantly from 1.01 to 1.50 and 0.06 to 0.48 individuals m^{-2}, respectively (Table 4, Figures 5 & 6). Mean densities of sand dollars, bryozoans/hydrozoans, skate, ocean pout, and sculpin also increased, while haddock and other fishes decreased in density (Table 4, Figures 5 & 6). The similarity index for all categories was 82.3 (Table 7).

The sediment composition differed significantly between 2005 and 2006 ($\chi^2 = 45.7$, df = 3, $p < 0.001$, power 0.050: 1.000). Granule/pebble substrate and sand/shell debris increased from 56.8 to 66.8% and 16.8 to 21.7%, respectively (Figure 7). Boulders decreased by 53% from 3.2 to 1.5% and cobble decreased from 23.3 to 10.0%. The sediment composition percent similarity index was 85.1%.

Before vs. After: Impact Area (October 2005 vs. August 2006)

The number of fishes and macroinvertebrate categories increased from 12 to 15 in 2005 and 2006, respectively (Table 7), with sea scallop and sea stars representing 75.5 and 80.2% of all individuals, respectively (Table 7). Densities of both sea scallops and sea stars increased significantly from 2005 and 2006 by 36 and 72%, respectively (Table 4, Figures 5 & 6). Numbers of sponges, sand dollars, bryozoans/hydrozoans, hake, flounder, ocean pout, and sculpins increased (Table 4, Figures 5 & 6). The similarity index for all categories was 80.1%.

The sediment composition differed significantly between 2005 and 2006 ($\chi^2 = 11.45$, df = 3, $p = 0.010$, power 0.050: 0.827). Cobble increased from 2.4 to 5.5%, while granule/pebble substrate decreased from 27.8 to 24.6% (Figure 7). Sand/shell debris and boulders remained the same. The sediment composition percent similarity index was high at 96.8%.

Temporal variations

We were not able to repeatedly sample the control area before or after the short-term fishing impact, therefore only the impact area was used to examine short term shifts in faunal densities and sediment composition just prior to and immediately after the fishery.

Before vs. Before: Impact Area (October 2005 vs. June 2006)

We observed 12 categories of fishes and macroinvertebrates in the impact area in 2005, and 15 in June 2006, with sea scallop and sea stars comprising 75.5 % of all individuals in 2005 and 69.3% in 2006 (Table 7). Bryozoans/hydrozoans, hake, haddock, ocean pout, and sculpins increased in density (Table 6, Figures, 5 & 8). The similarity index for all categories was 91.6% (Table 7).

The sediment composition differed significantly between 2005 and 2006 ($\chi^2 = 120.4$, df = 3, $p < 0.001$, power 0.050: 1.000). Sand/shell debris increased from 68.0 to 89.2%, while granule/pebble substrate decreased by 73% from 27.8 to 7.4%. Cobble also decreased from 2.4 to 1.5% and boulders remained the same (Figure 7). The sediment composition percent similarity index was low at 78.7%.

Before vs. After: Impact Area (June 2006 vs. August 2006)

This area was surveyed immediately before and after the limited short-term fishery in June and August 2006 (Table 1). In both June and August 2006, 15 fish and macroinvertebrate categories were observed (Table 7). The sea scallop and sea stars comprised 69.3 and 80.2% of all individuals observed in June and August 2006, respectively (Table 7). Mean densities of sea stars significantly increased from 0.20 to 0.68 individuals m^{-2} (Table 6, Figures 5 & 8). Crabs, hermit crabs, sand dollars, and flounders also increased, while Bryozoans/hydrozoans decreased from 0.15 to 0.10 individuals m^{-2} (Table 6, Figures 5 & 8). The similarity index for all categories was 75.9% (Table 7).

The sediment composition differed significantly between June and August of 2006 ($\chi^2 = 118.1$, df = 3, $p < 0.001$, power 0.050: 1.000). Granule/pebble substrate increased from 7.38 to 24.6% and cobble also increasd from 1.5 to 5.5%. Sand/shell debris decreased from 89.2 to 67.9%, while boulders remained the same (Figure 7). The sediment composition percent similarity index was 78.7%.

Experiment II – CAI (Control) and CAI (Impact)

Before vs. After: Control Area (August 2004 vs. June 2006)

In the control area, the number of fish and macroinvertebrate categories increased from 13 to 15 (Table 8). The sea scallops and sea stars comprised 56.8 and 39.3% of all individuals observed in 2004 and 2006, respectively (Table 8). Sea stars were typically the second most abundant species observed in all areas, however hermit crabs and bryozoans/hydrozoans were more abundant than sea stars in 2006, as densities increased significantly from 2004 to 2006 (Tables 5 & 8, Figures 9 & 10). Mean densities of hake and other fishes decreased significantly (Table 5, Figures 9 & 10). The similarity index for all categories was 70.6%, the lowest value measured for any of the areas surveyed (Table 8).

The sediment composition differed significantly between 2004 and 2006 ($\chi^2 = 13.69$, df = 3, p = 0.003, power 0.050: 0.898). Granule/pebble substrate increased from 4.3 to 10.1% (Figure 11). Sand/shell debris decreased from 91.3 to 87.5% and cobble and boulders also decreased from 2004 to 2006 (Figure 11). The sediment composition percent similarity index was 94.2%.

Before vs. After: Impact Area (August 2004 vs. June 2006)

In both 2004 and 2006, 14 fish and macroinvertebrate categories were observed (Table 8). Sea scallops and sea stars represented 73.8 and 53.2% of all individuals in 2004 and 2006, respectively (Table 8). Hermit crabs, sponge, bryozoans/hydrozoans and sculpins increased significantly from 2004 to 2006, while hake, skates, haddock and other fish decreased (Table 5, Figures 9 & 10). The similarity index for all categories was 72.6% (Table 8).

The sediment composition differed significantly between 2004 and 2006 ($\chi^2 = 10.80$, df = 3, p = 0.013, power 0.050: 0.800). Granule/pebble substrate increased from 28.7 to 34.6% (Figure 11). Sand/shell debris decreased from 65.0 to 60.3% and cobble and boulders also decreased from 2004 to 2006 (Figure 11). The sediment composition percent similarity index was 94.0%.

Conclusions:

Sea scallops and sea stars were the most abundant macroinvertebrates observed, comprising over 70% of all fish and macroinvertebrate categories in experiment I and over 40% in experiment II. Sea scallop density appears stable in the northern portion of Closed Area II and Closed Area I between 2004 and 2006. However, in the Nantucket Lightship Area the sea scallop density decreased by 50% between 2004 and 2005 representing a mass mortality. Mean scallop density increased slightly though not significantly between 2005 and 2006.

Similar to the previous BACI experiment (Stokesbury and Harris 2006), changes in the number of fish and macroinvertebrate categories and the density of individuals within each category in the areas impacted by the limited short-term sea scallop fishery were similar to changes in the control areas that remained closed to fishing. Sediment composition shifted between surveys more than epibenthic faunal composition.

In the control area of Experiment I the number of taxonomic categories remained constant before and after each of the limited fisheries. However, in the impact area the number of taxonomic groups decreased after the 2004 fishery, before increasing and returning to the original number of categories. The number of individuals within many of the categories did not change significantly. Sea scallops, sea stars, sponges, ocean pout, and sculpins decreased after the first fishery, and then increased after the second fishery in both areas. Hermit crabs increased each year the NLCA. Bryozons/hydozoans in the NLCA increased from 2004 to June 2006, followed by a decrease after the second fishery. The similarity index suggested that shifts in the number of categories and density of each category were similar. However, the sediment composition in both the control and impact areas shifted significantly. The largest shift in both sediment composition and taxonomic category occurred in the impact area between 2005 and June 2006 before the second limited fishery.

In the impact area of Experiment II the number of taxonomic categories remained the same before and after the limited fishery, while in the control area the number of categories decreased. The number of individuals within categories varied in both the control and impact areas. Hermit crabs, bryozoans/hydrozoans, and sculpin increased in both areas after the fishery, whereas, hake and other fishes declined. The similarity index for all categories suggested that shifts in the number of categories and density of each category were similar. However, the sediment composition in both the control and impact areas shifted significantly.

This research was presented at the following national and international conferences::

- **Sea Scallop*, Placopecten magellanicus,* Mass Mortality in the Nantucket Lightship Marine Protected Area of Georges Bank.** ICES Annual Science Conference in Maastricht, the Netherlands in September 2006

  Kevin D. E. Stokesbury, Bradley P. Harris, Michael C. Marino II and Jacob I. Nogueira

  Abstract
  A mass mortality of sea scallops in the Nantucket Lightship Marine Protected Area on Georges Bank, USA occurred between 2004 and 2005. The population of sea scallops in this area, covering 3951 km2, declined by 35%. In the northeast corner (504 km2) of the Nantucket Lightship Area, where the largest aggregations of sea scallops occur, the density declined by 50%. The scallops that perished were large, ranging from 110 to 180 mm shell height. Only 8% of the decline in the northeast corner was explained by fishing mortality. The biomass lost during this mass mortality was equivalent to approximately 7015 mt (15.3 million lbs) of harvestable scallop meat, worth about US$ 134 million (ex-vessel). Synergistic effects of senescence, parasitism of shell borers and prokaryotic infection are likely factors causing the scallop mass mortality.

- **Measuring population dynamics on appropriate biological scales; a case study examining sea scallop mass mortality.** American Institute of Fisheries Research Biologists 50th Anniversary Symposium, Seattle, WA in February 2007

  Michael C. Marino II, Bradley P. Harris, Jacob I. Nogueira and Kevin D.E. Stokesbury

  Abstract
  Effective spatially and temporally specific management requires a change in thinking towards fisheries data and models. We employed a video survey to collect spatially specific, absolute sea scallop, *Placopecten magellanicus*, abundance and size distribution data on the Northeastern continual shelf of the USA. This technique allowed us to track the scallop population dynamics on the appropriate scale for biological processes. This allowed us to observe a mass mortality of scallops occurring between 2004 and 2005 in the Nantucket Lightship Closed Area (NLCA), a Marine Protected Area in the Great South Channel. Sea scallop density declined by 50%. The scallops that perished were old, large individuals, with 80% greater than 130 mm shell height. Only 6% of the decline in the northeast corner was explained by fishing mortality. Approximately 6484 t of harvestable scallop meat, equivalent to US$ 100 million (ex-vessel) were lost. These data enabled us to estimate an instantaneous natural mortality rate of 0.47, approximately five times higher than the assumed instantaneous rate. Traditional dredge surveys produce relative biomass estimates (kg/tow) and may not detect large changes in scallop density due to the impact of individual growth

on biomass. Further, this mass mortality event raises questions regarding how well an equilibrium model will perform as spatially specific management strategies are implemented. The yield-per-recruit model currently used applies stock-wide parameters from a heavily fished population, with few large, old individuals, to specific areas containing high densities of large scallops. This new technology provides data required to implement new spatially and temporally specific management strategies.

We submitted a full manuscript of the mass mortality findings to Marine Ecology Progress Series on 30 Nov 06, which has been accepted for publication (14 May 2007):

> Stokesbury, K.D.E., B.P. Harris, M.C. Marino II and J.I. Nogueira. In review. *Sea scallop mass mortality in a marine protected area.* Mar. Ecol. Prog. Ser. (Support Document 2)

Furthermore, we are preparing another manuscript summarizing the findings of the 2004 and 2006 Before-After-Control-Impact experiments for submission to Marine Ecology Progress Series.

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Table 1. Timeline of SMAST video cruises on fine scale (1.57 kilometers between stations) from 2004 to 2006.

Location	**Experiment I**		**Experiment II**	
	Control area CAIIN	**Impact area NLCA**	**Control area CAIS**	**Impact area CAIN**
Before limited scallop fishery				
1st Survey	8-16 Jul 2004	16-19 May 2004	26-31 Aug 2004	26-31 Aug 2004
Limited Scallop Fishery				
		Nov 04 - Feb 05		15 Jun 05 - Jan 06
After limited scallop fishery				
2nd Survey	21-22 Oct 2005 (closed portion)	15-20 Oct 2005	15-20 Jun 2006	15-20 Jun 2006
Before limited scallop fishery				
3rd Survey		8-13 June 2006		
Limited Scallop Fishery				
		Jun 06 – July 06		
After limited scallop fishery				
4th Survey	14-18 Aug 2006	18-20 Aug 2006		

Table 2. Percent similarity index for epibenthic community observed in Expt Ia on Georges Bank. Lines indicate survey years used to calculate % similarity index.

Categories	Control Area		Impact Area	
	Before 2004	After 2005	Before 2004	After 2005
Scallops	79.93	77.08	63.67	50.50
SeaStars	3.63	4.49	21.28	25.00
Crabs	0.03	0.04	0.03	0.20
HermitCrab	2.31	6.80	0.88	5.63
Sponges	5.17	3.53	2.53	3.12
Sand dollars	0.69	0.22	2.05	3.02
Bryozoans / Hydrozoans	6.33	5.76	6.09	9.96
Hake	0.00	0.45	0.51	0.30
Flounder	0.20	0.15	0.03	0.20
Skate	0.36	0.07	1.70	1.81
Haddock	0.63	0.19	0.16	0.00
Cod	0.07	0.22	0.06	0.00
OceanPout	0.03	0.00	0.19	0.00
Sculpin	0.46	0.19	0.25	0.05
Hagfish	0.00	0.00	0.00	0.00
Other fish	0.16	0.82	0.57	0.20
% Similarity	93.4		85.7	

Table 3. Comparison of mean number of individuals m^{-2} within each taxonomic category in Experiments Ia before (2004) and after (2005) fishery, using 1 way ANOVA; data are log(x+1)-transformed; all taxonomic categories were tested but only significant results are presented here. Power is beta, with alpha set at 0.05.

Categories		df	SS	MS	*F*	p	Power
Expt Ia - CAIIN / NLCA							
Control area (Jul 2004 vs. Oct 2005)							
Hermit crabs	Between groups	1	0.016	0.016	26.649	<0.001	1.000
	Residual	317	0.190	0.001			
Sponges	Between groups	1	0.006	0.006	7.429	0.007	0.723
	Residual	317	0.271	0.001			
Hake	Between groups	1	0.000	0.000	6.666	0.010	0.663
	Residual	317	0.009	0.000			
Skate	Between groups	1	0.000	0.000	4.918	0.027	0.495
	Residual	317	0.009	0.000			
Haddock	Between groups	1	0.000	0.000	4.069	0.045	0.400
	Residual	317	0.022	0.000			
Sculpins	Between groups	1	0.000	0.000	4.049	0.045	0.398
	Residual	317	0.011	0.000			
Other fish	Between groups	1	0.000	0.000	9.074	0.003	0.824
	Residual	317	0.017	0.000			
Impact area (May 2004 vs. Oct 2005)							
Sea scallop	Between Groups	1	0.222	0.222	30.272	<0.001	1.000
	Residual	405	2.965	0.007			
Hermit crabs	Between Groups	1	0.009	0.009	37.311	<0.001	1.000
	Residual	405	0.099	0.000			
Hake	Between Groups	1	0.000	0.000	5.337	0.021	0.539
	Residual	405	0.011	0.000			
Oceanpout	Between Groups	1	0.000	0.000	4.556	0.033	0.456
	Residual	405	0.004	0.000			
Sculpins	Between Groups	1	0.000	0.000	5.541	0.019	0.560
	Residual	405	0.005	0.000			

Table 4. Comparison of mean number of individuals m^{-2} within each taxonomic category in Experiments Ib before (2005) and after (2006) fishery, using 1 way ANOVA; data are log(x+1)-transformed; all taxonomic categories were tested but only significant results are presented here. Power is beta, with alpha set at 0.05.

Categories		df	SS	MS	*F*	p	Power
Expt Ib - CAIIN / NLCA							
Control area (Oct 2005 vs. Aug 2006)							
Sea scallop	Between Groups	1	0.092	0.092	6.349	0.012	0.635
	Residual	318	4.613	0.015			
Sea stars	Between Groups	1	0.298	0.298	83.889	<0.001	1.000
	Residual	318	1.130	0.004			
Sand dollars	Between Groups	1	0.001	0.001	8.289	0.004	0.780
	Residual	318	0.042	0.000			
Bryozoans/hydrozoans	Between Groups	1	0.009	0.009	7.876	0.005	0.754
	Residual	318	0.348	0.001			
Skate	Between Groups	1	0.000	0.000	13.064	<0.001	0.951
	Residual	318	0.010	0.000			
Haddock	Between Groups	1	0.000	0.000	5.195	0.023	0.524
	Residual	318	0.003	0.000			
Oceanpout	Between Groups	1	0.000	0.000	4.516	0.034	0.451
	Residual	318	0.002	0.000			
Sculpins	Between Groups	1	0.000	0.000	2.492	0.115	0.214
	Residual	318	0.009	0.000			
Other fish	Between Groups	1	0.000	0.000	7.111	0.008	0.699
	Residual	318	0.019	0.000			
Impact area (Oct 2005 vs. Aug 2006)							
Sea scallop	Between Groups	1	0.061	0.061	8.805	0.003	0.811
	Residual	405	2.794	0.007			
Sea stars	Between Groups	1	0.510	0.510	115.234	<0.001	1.000
	Residual	405	1.791	0.004			
Sponges	Between Groups	1	0.003	0.003	7.038	0.008	0.694
	Residual	405	0.184	0.000			
Sand dollars	Between Groups	1	0.012	0.012	17.257	<0.001	0.990
	Residual	405	0.275	0.001			
Bryozoans/hydrozoans	Between Groups	1	0.004	0.004	4.713	0.031	0.473
	Residual	405	0.319	0.001			
Hake	Between Groups	1	0.001	0.001	11.601	<0.001	0.920
	Residual	405	0.027	0.000			
Flounder	Between Groups	1	0.000	0.000	9.809	0.002	0.859
	Residual	405	0.016	0.000			
Oceanpout	Between Groups	1	0.000	0.000	5.075	0.025	0.512
	Residual	405	0.003	0.000			
Sculpin	Between Groups	1	0.000	0.000	7.315	0.007	0.715
	Residual	405	0.009	0.000			

Table 5. Comparison of mean number of individuals m^{-2} within each taxonomic category in Experiments II before (2004) and after (2006) fishery, using 1 way ANOVA; data are log(x+1)-transformed; all taxonomic categories were tested but only significant results are presented here. Power is beta, with alpha set at 0.05.

Categories		df	SS	MS	*F*	p	Power
Expt II - CAI							
Control area (Aug 2004 vs. Jun 2006)							
Hermit crabs	Between Groups	1	0.014	0.014	30.452	<0.001	1.000
	Residual	223	0.103	0.000			
Bryozoans/hydrozoans	Between Groups	1	0.023	0.023	45.324	<0.001	1.000
	Residual	223	0.112	0.001			
Hake	Between Groups	1	0.001	0.001	4.543	0.034	0.453
	Residual	223	0.071	0.000			
Other fish	Between Groups	1	0.000	0.000	12.996	<0.001	0.949
	Residual	223	0.007	0.000			
Impact area (Aug 2004 vs. Jun 2006)							
Hermit crabs	Between Groups	1	0.000	0.000	1.965	0.161	1.000
	Residual	628	0.034	0.000			
Sponges	Between Groups	1	0.073	0.073	92.041	<0.001	0.452
	Residual	628	0.495	0.001			
Bryozoans/hydrozoans	Between Groups	1	0.000	0.000	0.193	0.660	1.000
	Residual	628	0.420	0.001			
Hake	Between Groups	1	0.138	0.138	181.371	<0.001	0.503
	Residual	628	0.478	0.001			
Skate	Between Groups	1	0.000	0.000	1.276	0.259	0.767
	Residual	628	0.016	0.000			
Haddock	Between Groups	1	0.003	0.003	8.049	0.005	0.906
	Residual	628	0.254	0.000			
Sculpins	Between Groups	1	0.000	0.000	6.129	0.014	0.617
	Residual	628	0.011	0.000			
Other fish	Between Groups	1	0.000	0.000	8.347	0.004	0.785
	Residual	628	0.013	0.000			

Table 6. Comparison of mean number of individuals m^{-2} indicating temporal variations within epibenthic communities each taxonomic category in Experiments Ib; data are log(x+1)-transformed. The 1-way ANOVA's were performed on surveys chronologically; all taxonomic categories were tested but only significant results are presented here. Power is beta, with alpha set at 0.05.

Categories		df	SS	MS	*F*	p	Power
Expt Ib - CAIIN / NLCA							
Before vs. before: impact area (Oct 2005 vs. Jun 2006)							
Bryozoans/hydrozoans	Between Groups	1	0.045	0.045	43.231	<0.001	1.000
	Residual	405	0.419	0.001			
Hake	Between Groups	1	0.001	0.001	11.962	<0.001	0.929
	Residual	405	0.023	0.000			
Haddock	Between Groups	1	0.000	0.000	4.080	0.044	0.402
	Residual	405	0.002	0.000			
Oceanpout	Between Groups	1	0.000	0.000	5.594	0.018	0.565
	Residual	405	0.005	0.000			
Sculpins	Between Groups	1	0.000	0.000	15.974	<0.001	0.983
	Residual	405	0.011	0.000			
Before vs. after: impact area (Jun 2006 vs. Aug 2006)							
Sea stars	Between Groups	1	0.440	0.440	100.229	<0.001	1.000
	Residual	406	1.782	0.004			
Crabs	Between Groups	1	0.000	0.000	6.627	0.010	0.660
	Residual	406	0.005	0.000			
Hermit crabs	Between Groups	1	0.003	0.003	8.837	0.003	0.813
	Residual	406	0.154	0.000			
Sand dollars	Between Groups	1	0.006	0.006	7.212	0.008	0.707
	Residual	406	0.321	0.001			
Bryozoans/hydrozoans	Between Groups	1	0.023	0.023	20.823	<0.001	0.998
	Residual	406	0.443	0.001			
Flounder	Between Groups	1	0.000	0.000	9.976	0.002	0.866
	Residual	406	0.016	0.000			

Table 7. Percent similarity index for epibenthic community observed in Experiment Ib on Georges Bank. Lines indicate survey years used to calculate % similarity index. J: June; A: August

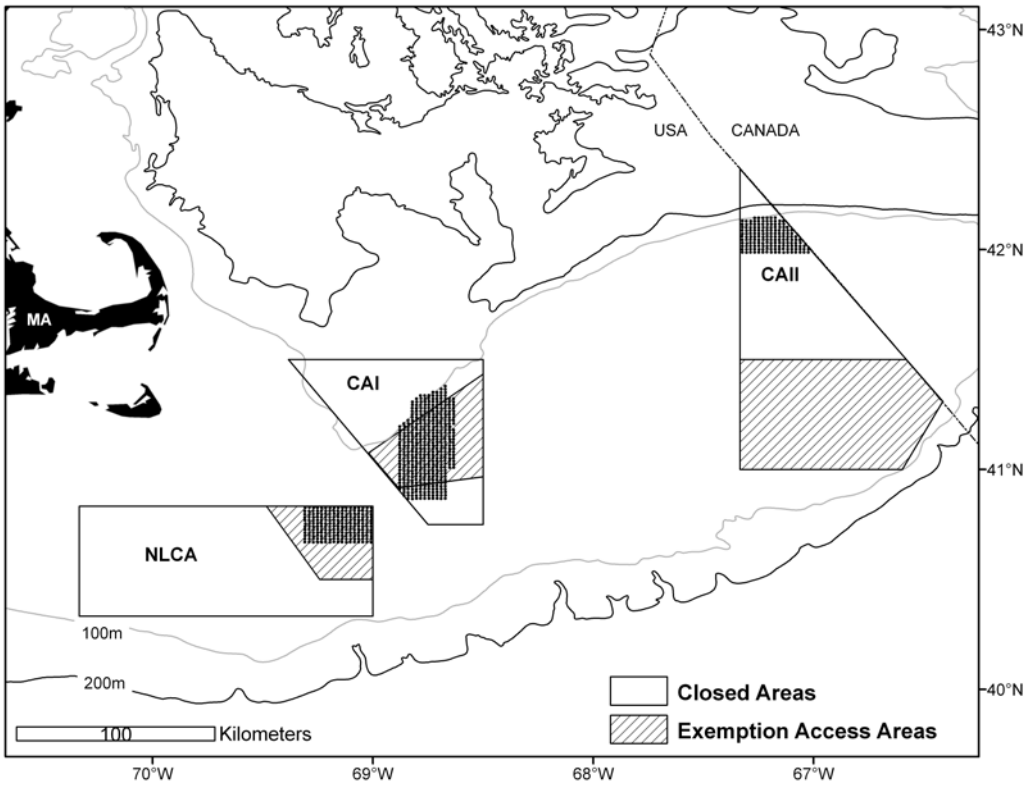
Categories	Control Area		Impact Area		
	Before 2005	After 2006	Before 2005	Before 2006 (J)	After 2006 (A)
Scallops	77.08	66.19	50.50	48.25	37.33
SeaStars	4.49	21.22	25.00	21.01	42.90
Crabs	0.04	0.11	0.20	0.04	0.22
HermitCrab	6.80	2.92	5.63	3.79	3.51
Sponges	3.53	2.92	3.12	3.47	2.71
Sand Dollars	0.22	0.66	3.02	3.59	3.75
Bryozoans / Hydrozoans	5.76	4.82	9.96	15.39	6.17
Hake	0.45	0.07	0.30	1.16	0.72
Flounder	0.15	0.11	0.20	0.16	0.50
Skate	0.07	0.40	1.81	1.67	1.42
Haddock	0.19	0.00	0.00	0.16	0.05
Cod	0.22	0.07	0.00	0.04	0.07
OceanPout	0.00	0.09	0.00	0.28	0.12
Sculpin	0.19	0.24	0.05	0.76	0.29
Hagfish	0.00	0.00	0.00	0.00	0.00
Other fish	0.82	0.18	0.20	0.24	0.24
% Similarity	82.3		91.6		
% Similarity				75.9	
% Similarity			80.1		

Table 8. Percent similarity index for epibenthic community observed in Experiment II on Georges Bank. Lines indicate survey years used to calculate % similarity index.

Categories	Control Area		Impact Area	
	Before 2004	After 2006	Before 2004	After 2006
Scallops	40.63	27.96	61.62	42.17
SeaStars	16.21	11.34	12.12	10.99
Crabs	1.68	0.48	0.76	0.41
HermitCrab	4.63	17.57	3.68	16.35
Sponges	2.53	3.67	1.28	2.04
Sand Dollars	13.26	11.82	5.76	5.57
Bryozoans / Hydrozoans	4.42	18.85	3.84	17.28
Hake	8.21	2.40	2.44	1.18
Flounder	0.84	0.96	0.48	0.66
Skate	4.00	3.67	6.08	2.63
Haddock	0.42	0.16	1.04	0.10
Cod	0.00	0.00	0.08	0.03
OceanPout	0.00	0.16	0.00	0.00
Sculpin	0.21	0.64	0.16	0.52
Hagfish	0.00	0.16	0.00	0.00
Other fish	2.95	0.16	0.68	0.07
% Similarity	70.6		72.6	

Figure 1. SMAST video stations surveyed between 8 June to 20 August 2006.

A



B

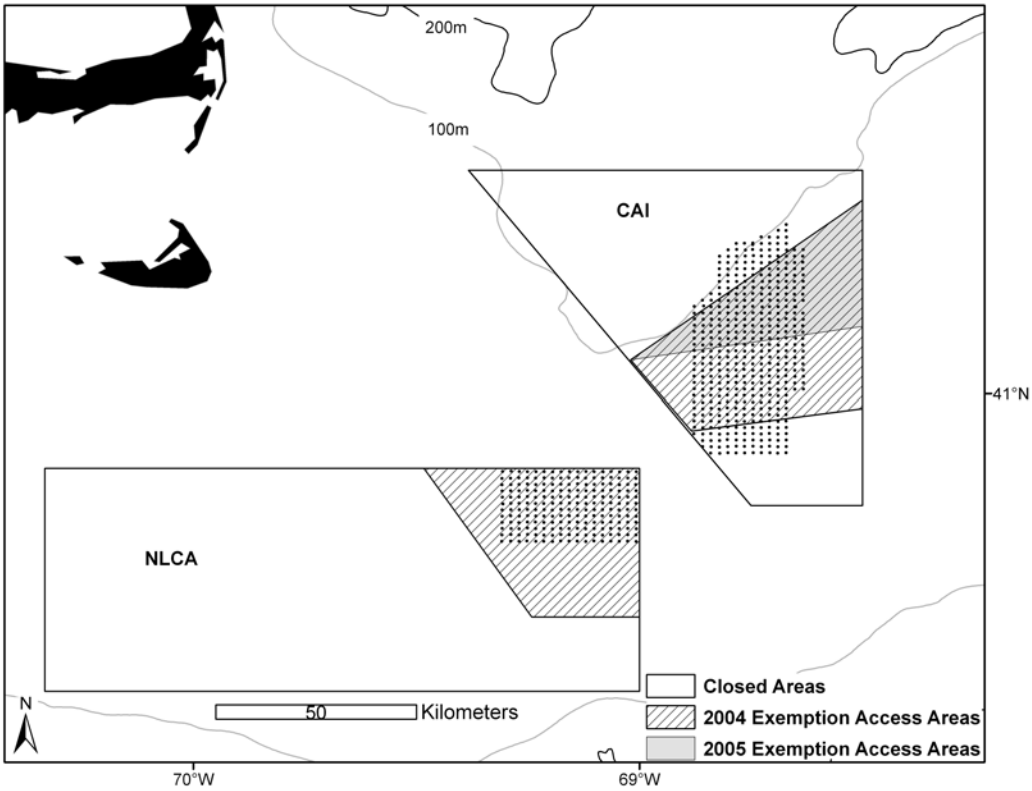


Figure 2. Mean (±SE) individuals m^{-2} for taxonomic categories observed (A) before and (B) after sea scallop exemption fishery in Experiment Ia on Georges Bank. Thicker portions of axes indicate portions of axes that have been enlarged in insets.

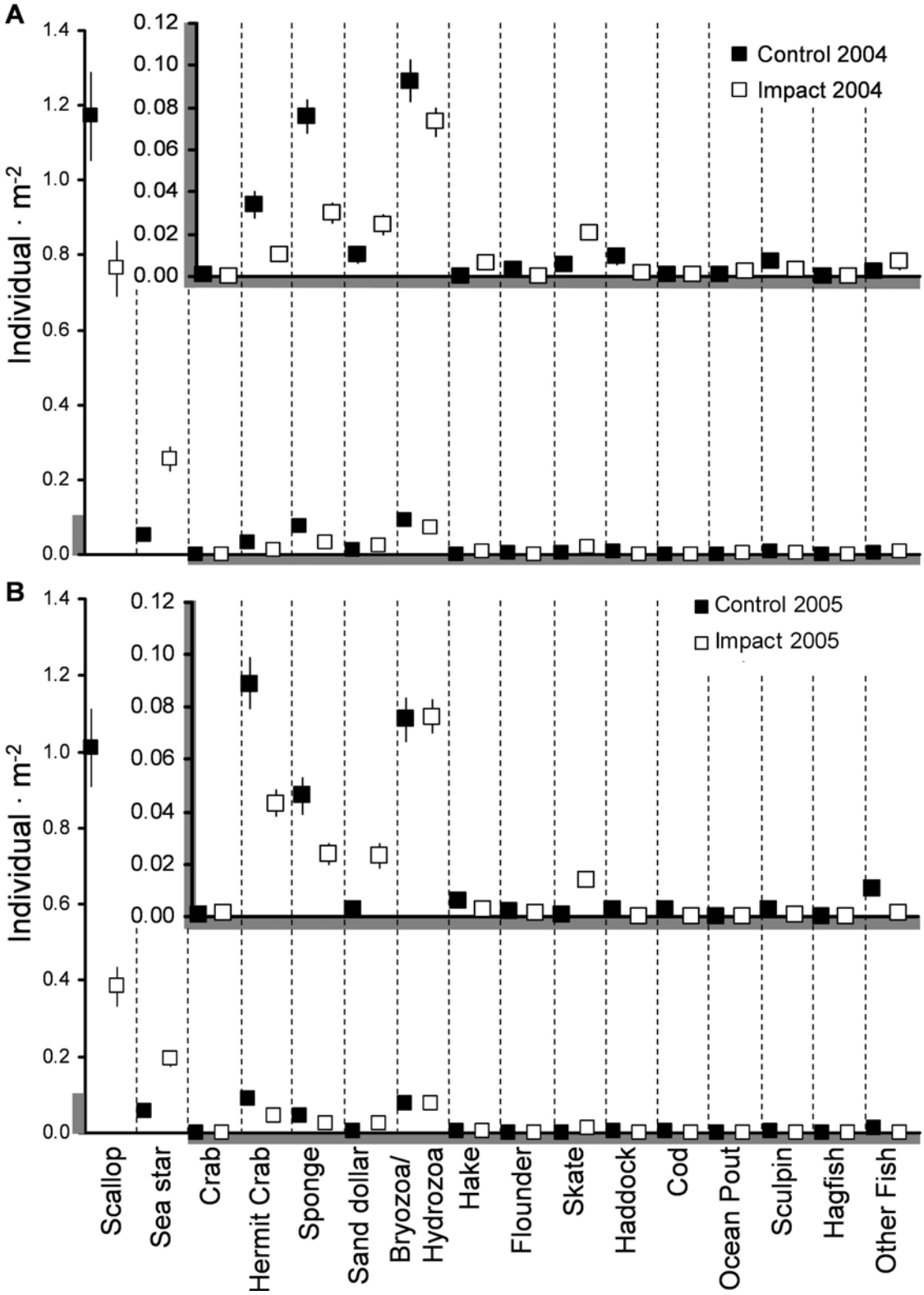


Figure 3. Difference in mean densities for taxonomic categories observed in Experiment Ia control (CAIIN) and in impact (NLCA) areas before (2004) and after (2005) the limited fishing event; data are log(x+1)-transformed. *Significant difference at p = 0.05

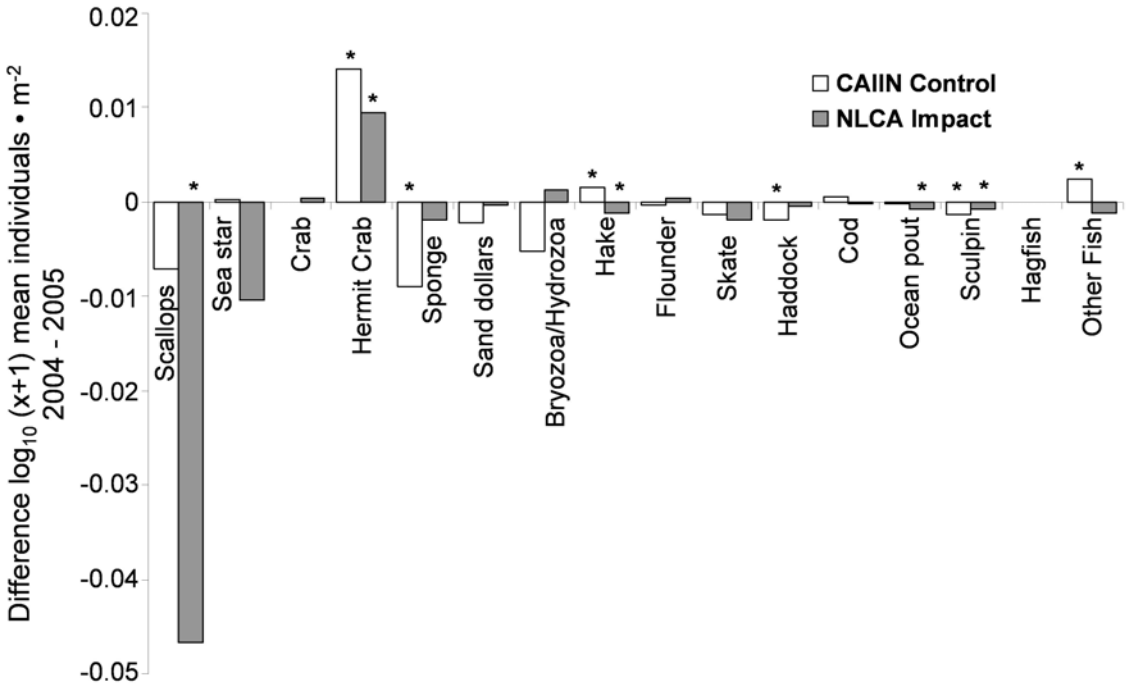


Figure 4. Sediment composition in control and impact areas in Experiment Ia observed in 2004 and 2005. Sand = 0.0625 to 2.0 mm, granule/pebble = 2.0 to 64.0 mm, cobble = 64.0 to 256.0 mm and boulders >256.0 mm particle diameter.

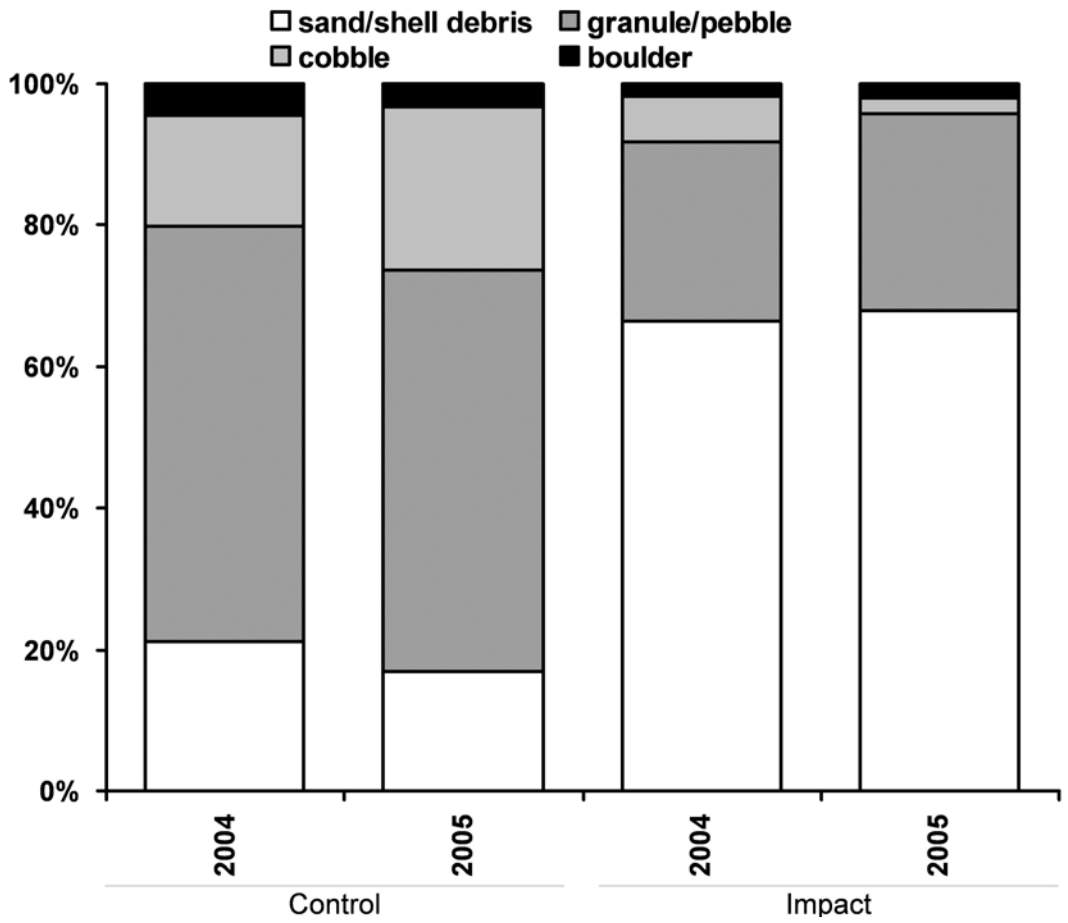


Figure 5. Mean (±SE) individuals m^{-2} for taxonomic categories observed (A) before and (B) after sea scallop exemption fishery in Experiment Ib on Georges Bank. Thicker portions of axes indicate portions of axes that have been enlarged in insets.

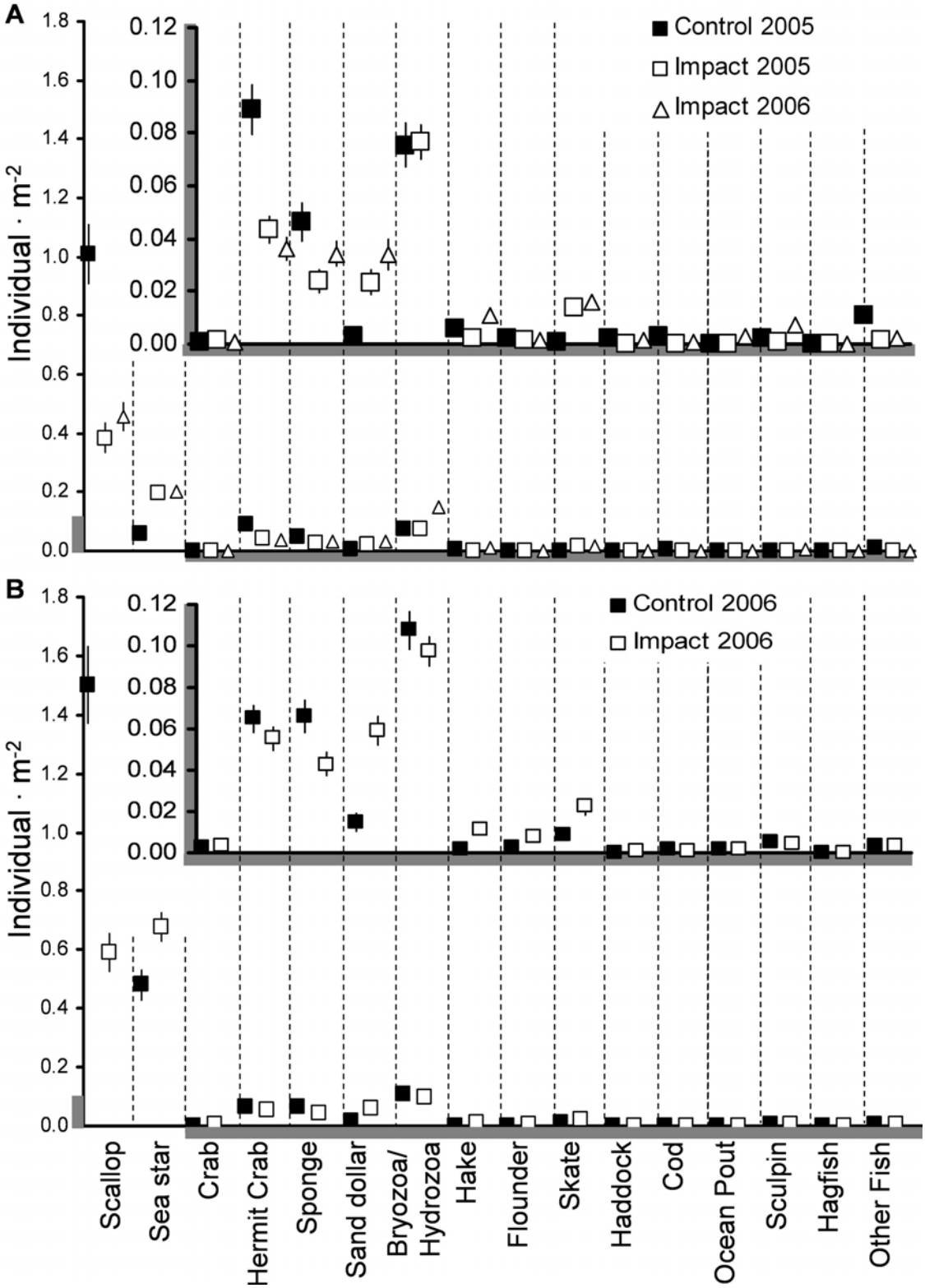


Figure 6. Difference in mean densities for taxonomic categories observed in Experiment Ib control (CAIIN) and in impact (NLCA) areas before (2005) and after (2006) the limited fishing event; data are log(x+1)-transformed. *Significant difference at p = 0.05

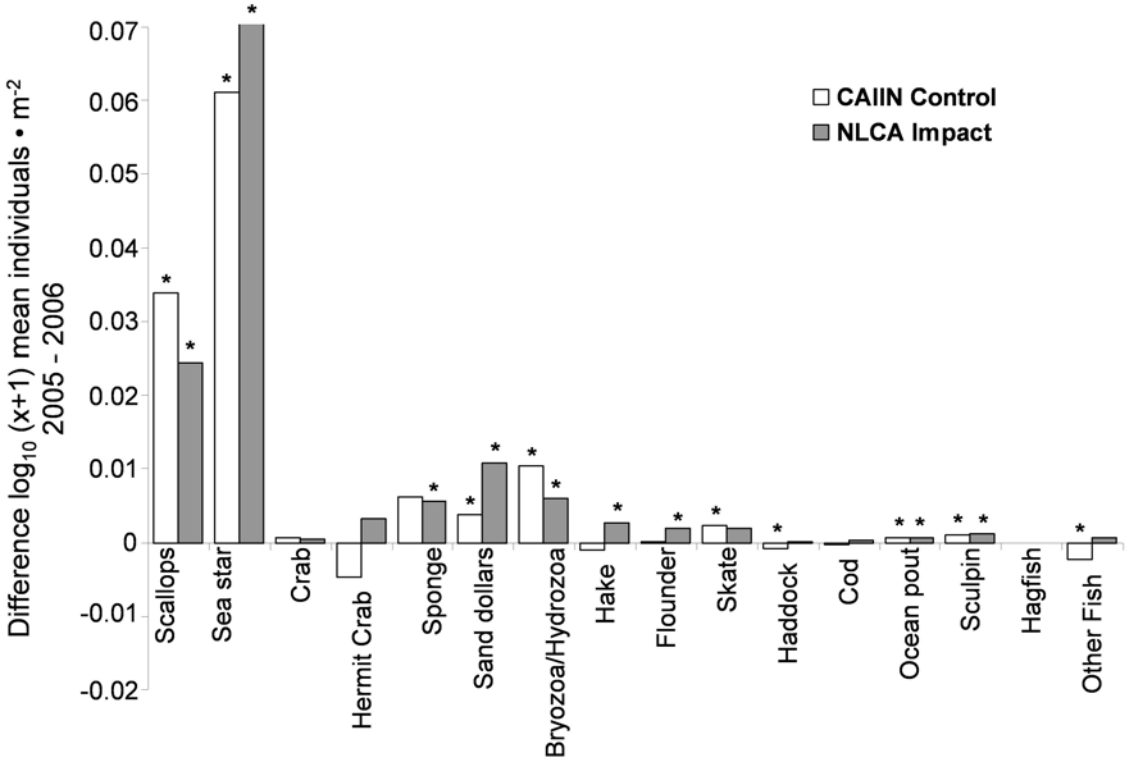


Figure 7. Sediment composition in control and impact areas in Experiment Ib observed in 2005 and 2006. Sand = 0.0625 to 2.0 mm, granule/pebble = 2.0 to 64.0 mm, cobble = 64.0 to 256.0 mm and boulders >256.0 mm particle diameter. J: June; A: August

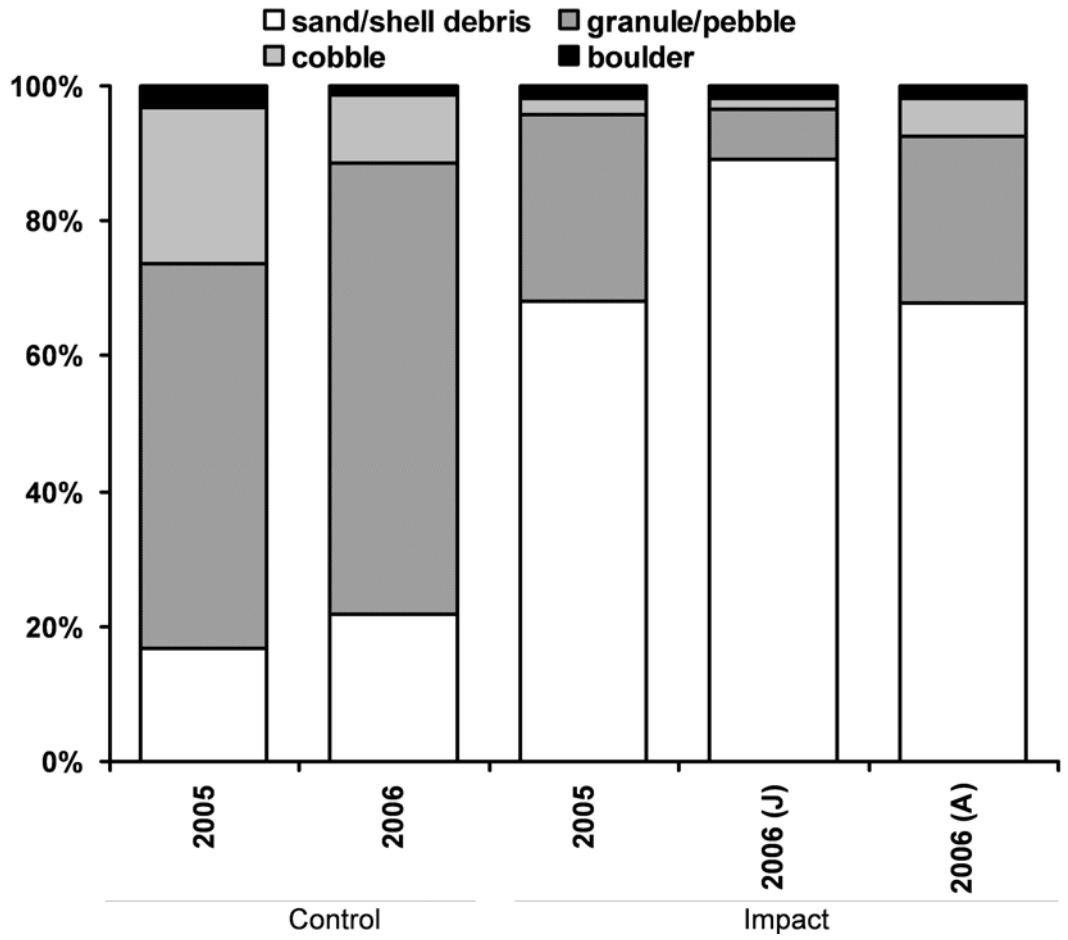


Figure 8. Difference in mean densities for taxonomic categories observed in Experiment Ib impact area (NLCA) from October 2005 to June 2006 (undisturbed) and June 2006 to August 2006 (the fishing event occurred between these 2 surveys); data are log(x+1)-transformed. *Significant difference at p = 0.05

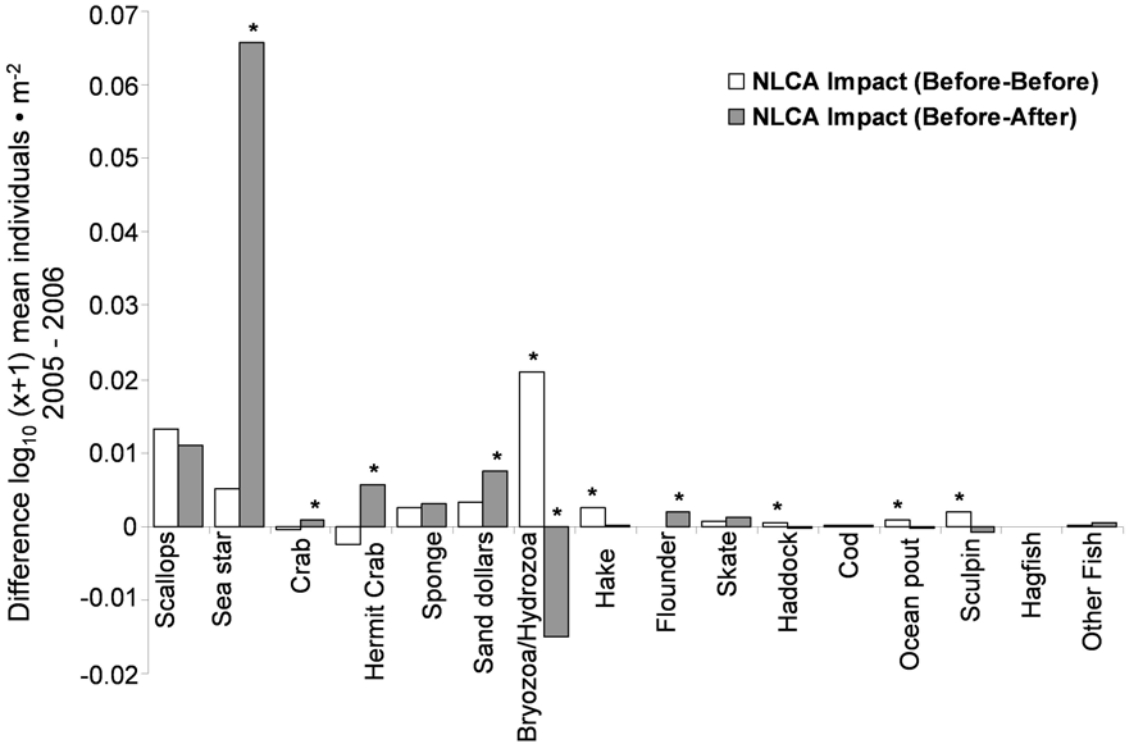


Figure 9. Mean (±SE) individuals m^{-2} for taxonomic categories observed (A) before and (B) after sea scallop exemption fishery in Experiment II on Georges Bank. Thicker portions of axes indicate portions of axes that have been enlarged in insets.

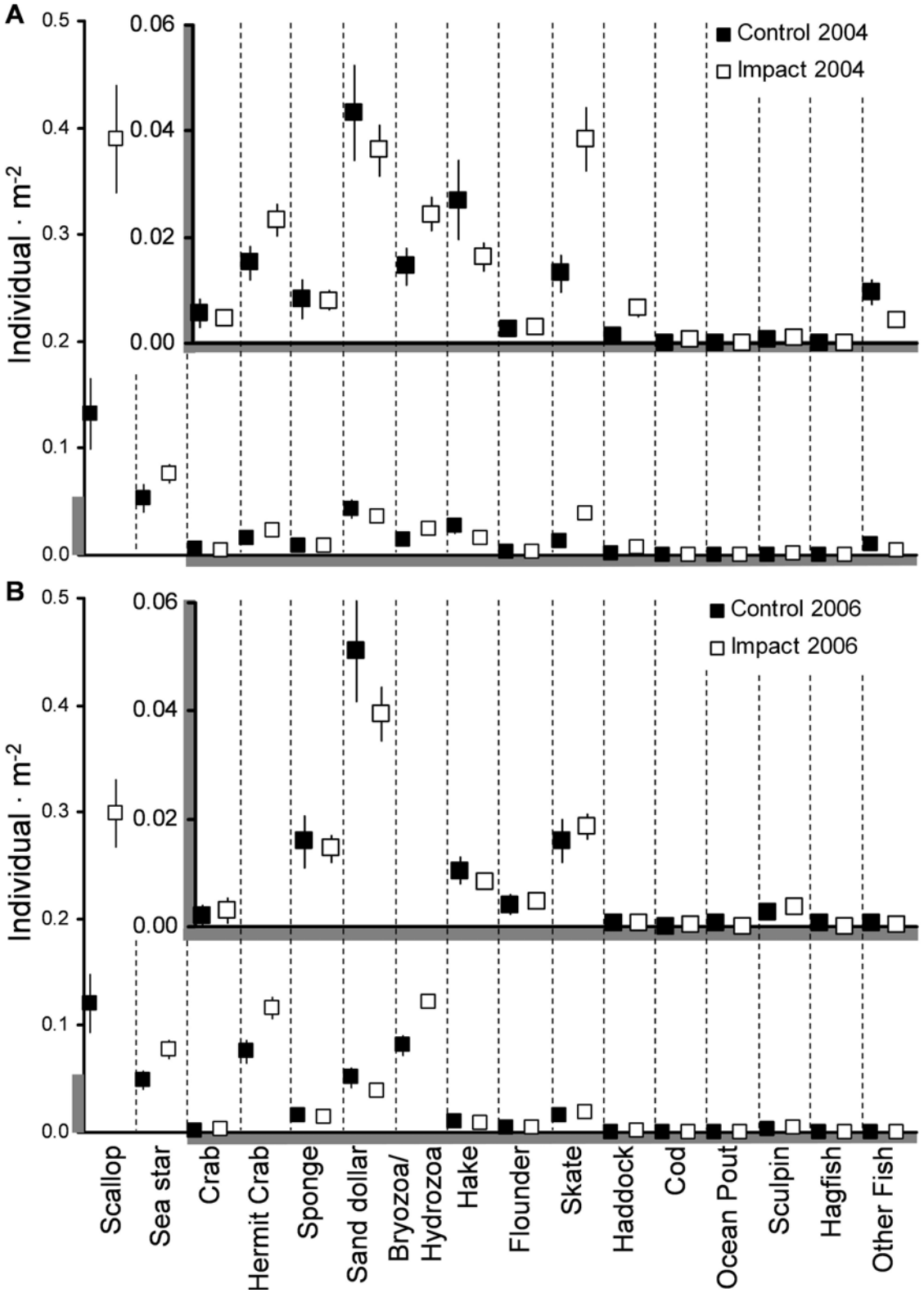


Figure 10. Difference in mean densities for taxonomic categories observed in Experiment Ia control (CAIS) and in impact (CAIN) areas before (2004) and after (2006) the limited fishing event; data are log(x+1)-transformed. *Significant difference at p = 0.05

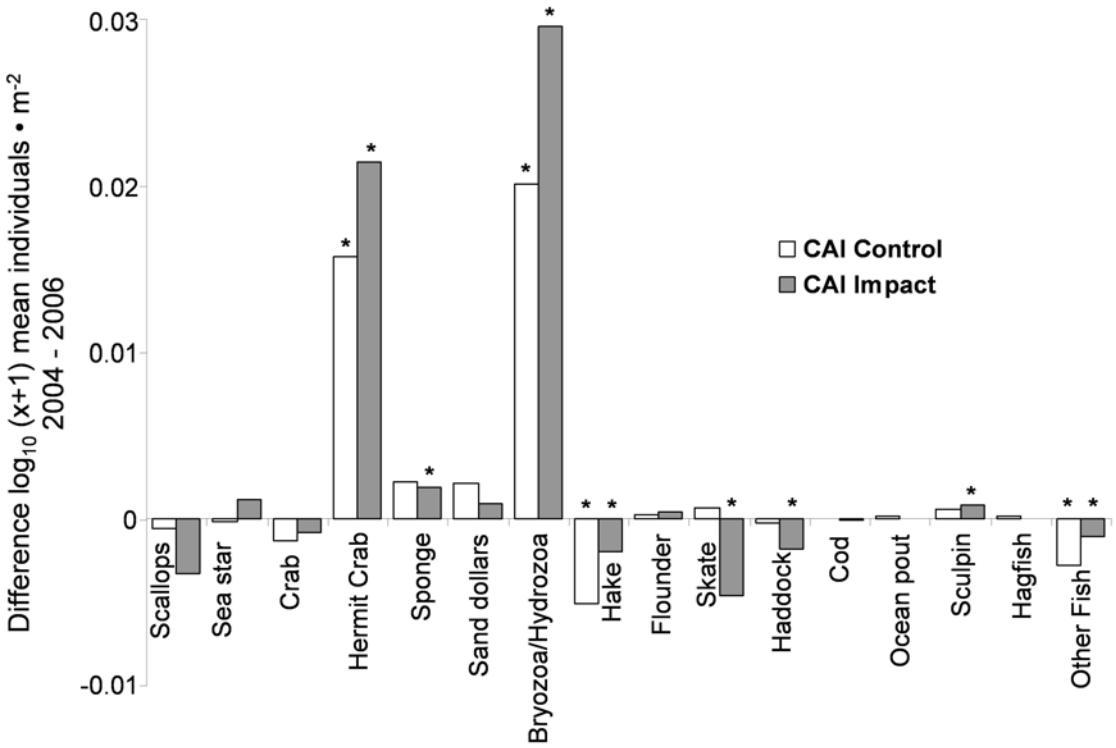
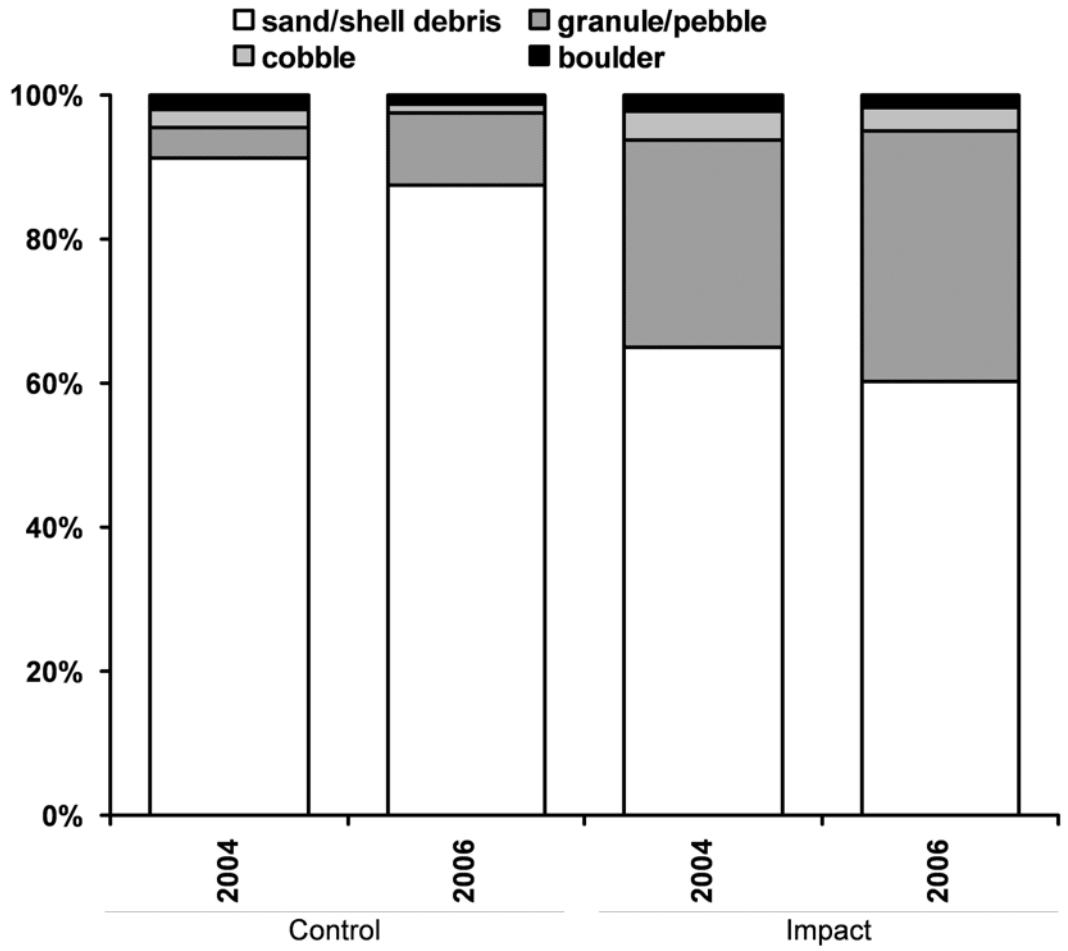



Figure 11. Sediment composition in control and impact areas in Experiment Ia observed in 2004 and 2005. Sand = 0.0625 to 2.0 mm, granule/pebble = 2.0 to 64.0 mm, cobble = 64.0 to 256.0 mm and boulders >256.0 mm particle diameter.