Impact of Disturbance on Habitat Recovery in Habitat Management Areas on the Northern Edge of Georges Bank: Ecosystem Perturbation Experiment

Woods Hole Oceanographic Institution

Scott Gallager, Steve Lerner, Cameron Fairclough, Mike Saminski

Fishing Community
Lund's Fisheries: Wayne Reichle, Jeff Kaelin,
Captain Brady of the F/V Jersey Cape

Annotators: Jinshi Chen, Phil Alatalo, Mary Carman, Patti Keating

2016 Scallop Research Set-Aside

NOAA-NMFS-NEFSC-2016-2004548

Summary

- A BACI whole ecosystem experiment was started in 2016 in Closed Area II, HAPC for the purpose of examining what level of impact from scallop dredges would cause irreparable damage in an area that is considered essential fish habitat for Gadids and other commercially important species.
- The Closed Area II HAPC has been closed to bottom tending gear since 1994 after being fished intensively for many years.
- In the HAPC, six sites representing two distinct habitats (epifauna/mussels; sand/gravel) were chosen and surveyed twice before and three times after impact by scraping with a commercial scallop dredge to base sediment.
- A Before After, Control Impact (BACI) experiment was designed and analyzed using a 3-way ANOVA to inspect a mixed effect model of fixed and random effects
- Percentage change in either numerical abundance or percent cover two years after impact was examined using multi-way ANOVA with p value of 0.05
- Both Biodiversity and Species Richness decreased and remained <30% of control in complex epifaunal sites while no significant change in Species Richness was detected in sand/gravel sites.
- Epifauna (sponge, bryozoa, Hydrozoa, Lacy Tube worm, anemone, stalked tunicate) and infauna (Myxicola) in Sites 1-3 significantly decreased on impact and remained <50% than control after two years of recovery.

Conclusions

- There were significant high order effects (Habitat X Control X Impact) in five out of 10 faunal classes indicating that the impact made by scallop dredging is strongly influenced by habitat with complex epifaunal habitat being significantly more susceptible to mechanical impact than sand/gravel habitats.
- There was strong suggestion that some fish species (e.g., Monkfish) increased in impacted Sites 1-3 by more than 80% of control immediately following impact and remained elevated for two years.

- It is clear that two years is not sufficient for complex habitat to recover to 100% of control It may be possible to target specific homogenous habitats for opening a limited fishery where scallop abundance is high while maintaining no-take zones in complex epifaunal habitat with a defined boundary of at least several 100 meters.

This overview of the BACI experiment in the CLAII HAPC is coordinated with a slide deck named RSA_HAPC_BACI_Exp_09-16-21-a.pdf. The original slide deck released on April 4, 2021 had an error in the calculations and units for the fauna removed from the sites by dredging: the original units were in $\#/m^2$, this has been corrected to $\#/km^2$.

Background

Georges Bank Closed Areas I and II, and Nantucket Lightship Closed Area were closed in December 1994 to fishing for groundfish in order to help rebuild these stocks. After these closures, scallop biomass rapidly increased (Murawski et al. 2000, Hart and Rago 2006), but the effects on groundfish were mixed. For example, yellowtail flounder and haddock increased within the closures, but cod did not (Murawski et al. 2005). Portions of each of the three closures have been reopened to scallop fishing for short periods (typically June 15 through January 31 of the following year), with quotas set both for scallop and yellowtail flounder catch. Some short-term fishing for groundfish has also been allowed in these areas, most prominently, the special access program (SAP) for yellowtail flounder in 2004. A detailed historical review of each RCA may be found on the NEFC website, however, in this discussion we are only concerned with CLAII and the HAPC. The intent is to apply the information obtained from this area to others representing different habitats. These RCAs provide a wide range of habitats and temporal sequencing of closures and provide a "natural" experiment in disturbance of benthic community structure by bottom fishing.

Impact of bottom fishing on community structure. Many studies have documented a variety of impacts on benthic community structure resulting from bottom fishing (e.g., Aronson 1990; Messieh et al 1991; Jones 1992; Whitman and Sebens 1992; Thrush et al 1995; Dayton et al 1995; Auster and Langton 1999; Kaiser et al. 2002; Collie et al. 2000; Ragnarsson and Lindegarth 2009). In particular, Ragnarsson and Lindegarth (2009) succeeded in providing unequivocal projections of ecosystem recovery trajectories based on quantitative analysis of large scale responses of habitats to fishing disturbance. Studies designed to test the effects of different fishing gear on benthic communities often provide inconsistent results due to the wide variety of methods used in fishing, lack of replication and control sites, and a large variation of site-specific substrate and hydrographic conditions. The success of the Ragnarsson and Lindegarth (2009) study is due to, we believe, attention to statistically sound time series measurements and experimental design. The authors manipulated four sites and maintained four sites as controls. Benthic surveys were conducted immediately following dredging of areas previously closed to fishing and two and seven months later. A total of 160 taxa were observed in grab samples of the areas which were dominated by polychaetes and bivalves. No significant differences were detected in taxa abundance or multivariate structure after seven months, but strong effects of dredging were evident in diversity and species richness. There is consensus in the literature that in order to quantify the direct effect of disturbance on benthic community structure an experimental approach must be used which compares impacted against unimpacted areas (Van Dolah et al. 1987; Riemann and Hoffman 1991) using Before-After-Control-Interaction (BACI) experimental models. There are examples of successful plot disturbance studies in the terrestrial world (Plotkin et al 2013; Carlton and Bazzaz 1998). For example, an experimental site in the Harvard Forest was subjected to a simulated hurricane in a disturbance/resilience study (Plotkin et al 2013). Translating this disturbance methodology to the oceanic environment would yield a better understanding of ecosystem resilience.

At their June 2015 meeting, the New England Fisheries Management Council (Council) approved two Habitat Management Areas (HMAs), both located on the northern edge of Georges Bank within the confines of Closed Area II HAPC (slide 2). Our overall goal of this project is to provide the Council with information on what temporal and spatial scales that scallop fishing could be allowed on a limited basis in the HMAs that would minimize impact to habitat and avoid disturbance to ground fish nursery and spawning areas. In order to accomplish this goal, we need to understand ecosystem resiliency, impact of scalloping at specific temporal and spatial scales on habitat, and to survey the location and boundaries of high density scallops and their habitat in the HMAs.

Goals and Objectives

Our overall goal of this project was to provide Council with information on what temporal and spatial scales scallop fishing could be allowed that would minimize impact to habitat. In order to accomplish this goal, we need to understand ecosystem resiliency, impact of scalloping at specific temporal and spatial scales on habitat, and the location and boundaries of high density scallops and their habitat in the HMAs.

Our study had three objectives:

1) To determine the persistence of mechanical impacts of scallop dredging and long-term ecosystem resiliency as a function of substrate type (e.g., sand, sand/gravel, gravel/cobble) measured by both acoustics and optics in the HMAs and surrounding regions where VIMs and NOAA have previously conducted survey tows,

2) To complete a series of high resolution Before-After Control-Impact (BACI) habitat characterizations in three habitat types (sand, sand/gravel/shell, gravel/epifauna) to evaluate ecosystem and habitat resiliency. Metrics for Recovery Rate that relate Impact Intensity and Habitat Type over time allowed for a direct, statistical description of where, at what scale, and how often HMAs could be opened to target high density scallops with minimum impact on sensitive habitat. And

3) To complete high resolution surveys of scallop abundance in the CLA II HMAs to provide information to the Council as to where targeted scallop fishing might be allowed on a limited basis while concurrently mitigating impact on habitat.

We used both HabCamV4 and V5 with very high resolution (mm scale) stereo imagery and a sidescan unit (cm to 100m scale) for the fine scale BACI habitat studies and to collect fine scale distributional data on scallops in the entire Northern part of CLAII and surrounding regions.

Some of the important questions that needed to be addressed before the proposed Habitat Management Areas were enacted include the following: 1) What is the current fine scale (m) distribution of habitat types in the HAPC? 2) What would the impact be on the current communities (epifauna, scallops, groundfish) and habitat if regions of the HAPC were to have Partial Access? 3) How long do the mechanical impacts of scallop dredging persist as a function of substrate type (sand, sand/gravel, gravel/cobble) measured by both acoustics and optics? (e.g., slide 3), 4) How resilient are the different communities? (i.e., if allowed to rebound following episodes of dredging, how long would it take various communities to return to pre-impact condition)? 5) What is the distribution of the invasive tunicate species *Didemnum vexillum* in the HAPC (closed to ground fishing) and how would providing Partial Access impact that distribution?

Methods

Surveys

HabCamV5 (slide 4) was used to conduct a high resolution grid survey of the HAPC at 0.5 nm spacing in the northern Northeast Reduced Impact Habitat Management Area (NERIA) and at a resolution of 1 nm in the southern part of NERIA, the Eastern Georges Shoals and Northeast Habitat Management Area (slide 5) in June 2012 and July 2016. This was followed by a third survey of the same area in October 2016, the initiation of the BACI impact experiment and a fourth survey of the impact sites. Fifth and sixth surveys were conducted in July 2017 and in June-July 2018.

Following the second survey in July 2016, six sites were chosen in the HAPC that represented habitats of complex epifauna/mussels, sand/gravel/patchy epifauna, sand/gravel, and compact mud and dark sand (slides 6 and 7). A 1 nm strip was established in each site representing each of the habitat types. The impact part of the study was conducted in October 2016 using a commercial 15' New Bedford scallop dredge. Between 9 and 11 passes with the dredge were made in each 1 nm strip at a ship speed of 2 kts. Following each dredge pass, the contents were emptied on the deck and analyzed by counting and sizing a subset of scallops and all finfish. Epifauna type, mussels and total scallops were estimated by the number of bushels collected of each type. The contents on the deck were then dumped downstream to the east at least 2 nm away from a particular study site.

Following each dredge pass, the HabCamV5 was deployed and an imaging pass was made to assess impact by the dredge. The sidescan imaging system clearly delineated the dredge tracks and allowed precise co-location of imaging and dredging. Each imaging pass was conducted to provide images within the dredged strip (impact) and outside the strip (control) by weaving in and out of the strip as the ship steamed forward (slide 8). Between 40,000 and 57,000 images were taken inside each strip and more than 180,000 images outside the strip as controls (slide 7). A 1 nm square buffer was established around each strip where initial survey data could also be used as control information (slide 9). The decrease in the number of bushels of scallops from each subsequent pass provided evidence of depletion.

BACI analysis. For each survey that was conducted at an impact site, the following metrics were calculated for every image: Substrate percentage composition (mud, sand, gravel, cobble, shell hash, any combination thereof), bathymetry, rugosity, slope, gradient (from optics and acoustics), epifauna (e.g., lacy tube worm, bryozoa, mussels, encrusting sponge, globular sponge, *Didemnum*, stalked tunicate, etc.), scallop abundance and size frequencies, and all of the potential fish targets provided in slides 10 and 11. Data on the these variables within and between impact sites and within and between control sites provided data for both 3-way ANOVA analysis to examine the difference between impact sites and control sites relative to ecosystem recovery over time. This tested the null hypothesis that there are no differences between biological communities among controls and different times, before and after impacts (slide 12).

Significance testing on selected individual abiotic and biotic variables was conducted using 1-way Analysis of Variance (ANOVA). Important elements of experimental design such as replication, randomization and blocking were integrated and incorporated in this repeated measures study.

Image Processing
Every 10th image was annotated by humans and every single image was annotated automatically by the Convolutional Deep Learning Neural Network described in Gallager et al. (2020). Automated classification of substrate and individual targets was possible based on our current research allowing rapid turn-around of data products. However, manual annotation, and particularly scallop assessment was conducted to test the automated analyses as a defined quality control step in the data product workflow.

The main indices of impact and recovery was biodiversity and species richness (slide 13). A diversity index is a quantitative measure that reflects how many different types (such as species) there are in a dataset, and simultaneously takes into account how evenly the basic entities (such as individuals) are distributed among those types. Alpha-diversity, beta-diversity, species richness, the Shannon Index, and the Simpson Index were calculated to examine how the BACI sites were changing over time. With these diversity indices as our metrics for impact, we evaluated Recovery (R) as a function of time at each site as a function of habitat type.

Results
Habitat Type and Scallops
Slides 14-16 show the fine scale delineation of habitat type along with bathymetery in the HAPC. In these figures, the color scale is depth and the black contours are sand, gravel and epifauna, respectively. Slide 16 shows the region of high epifauna that was originally described by Page Valentine in a 2008 cruise report as the “pristine area”. The use of the term pristine has since been discontinued since the entire HAPC was heavily fished prior to 1996 so this area could hardly be considered pristine. We prefer to use the term complex epifauna to describe this region. Slide 17 shows the combination of all substrate types as contours and the abundance of exploitable scallops as the color scale. The important point to note is that within the area of high epifauna denoted by the black contour lines, the abundance of exploitable scallops is very low. The highest concentration of scallops is to the northwest and south east of the region of high epifauna. Slide 18 shows the abundance of exploitable, medium sized (40-80 mm), and small (<40 mm) scallops in numbers per m^2.

Automated Classification
The Convolutional Deep Neural Network algorithm used was from Darknet, YOLO3. This allowed the detection of single targets by blob detection and classification all in one process (slides 19 and 20). The holistic classification of substrate was also part of the training set so that the substrate type in every image could be evaluated. About eight images per second could be classified with an accuracy between 90-97%. Demersal and epifaunal finfish were classified as just fish and then a human taxonomist went back and reclassified the target to species.

Impact dredging and Organism Depletion

Slides 21-23 show the types of organisms removed during the impact dredging in each of the habitat sites. Sites 1-3 (slide 21) consisted of hyrozoans and bryozoans, stalked tunicates, sponges and mussels on a sand/shell hash substrate. A relatively small number of scallops (6.5 bushels) were removed form Site 1 (slide 24) compared with Sites 2 (422 bushels) and Site 3 (470 bushels) and Site 5 (327 bushels). All sites showed strong depletion of scallops following the 9 to 11 passes with the dredge.

Slide 25 shows the abundance of organisms removed from each site. At Site 1, 380 bushels of mussels and epifauna were removed and a relatively small number of sea raven, cod, haddock and lobsters were removed. Note that mussels/epifauna, scallop and surf clams are in bushels while the remainder of organisms such as skate, yellow tail, monkfish and hake were recorded as individuals per km^2. Shell length of a subset of scallops and body length of all of the finfish were recorded.

Statistics

The 3-way ANOVA conducted on the BACI data included Time (T) as two years of survey data before impact (2012 and 2016) and three years of post-impact surveys (2016, 1017 and 2018) (slide 26). Habitat (H) was split into two categories (epifauna/sand and sand/gravel). Sites (S) consisted of the six habitat sites. Impact (I) was represented as before and after. Interactions between variables included HxT, IxT and HxI with fixed (HxIxT) and random (TxS(HxT)) effects. The between and within site variance was calculated. The mixed effects model was characterized by F-test for main and interaction effects. Linear contrasts among specific combinations of means were made using a 1-way ANOVA.

Species Richness for each site along with the statistical results for comparing control to impact over time are shown in slide 27. Note that the vertical dashed line represents the time of impact in each plot. All sites showed a significant difference between control and immediately following impact. Recovery from impact of Species Richness depended on habitat type with Sites 1, 2, 3, and 4 showing minimal recovery after two years and Sites 5 and 6 showing nearly full recovery after two years. The multimeasure plot in the bottom right corner shows the marginal means of Species Richness for the two habitats (epifauna/mussel and sand/gravel) both before and two years after impact. There is a significant difference for habitat 1 but not for habitat 2 suggesting that the sand/gravel habitat was not as impacted as the epifauna/mussel habitat.

A similar result was found for biodiversity H' between habitats (slide 28). Both habitat types were strongly impacted initially but only the sand habitat in Site 4 fully recovered after two years. There was a strong effect of habitat on recovery ($p=0.0067$) with Sites 1-3 not significantly recovering over time.

The density (#/m^2) of individual representative species in each site showed highly variable results. The sponge *Iophon* is sensitive to mechanical disturbance and showed little recovery over two years (slide 29). Changes in the bryozoan/mussel habitat remained strong in Sites 1 and 3 following two years but not in Site 2 where it apparently fully recovered. Lacy Tube Worm *Filograna implexa* is another sensitive indicator species and was hard hit initially and remained low after two years (slide 31). There was no significant impact on the red sea anemone *Actina* *tenebrasa* (p=0.379) (slide 32). The stalked tunicate *Boltenia olvifera* was significantly impacted but there was a strong habitat mixed effect (p=0.009) suggesting that its impact was habitat specific with recovery lowest in Site 3. All epifauna taken together were significantly impacted (p=0.025) and have not recovered in any site, although Site 4 had the least amount of epifauna of the six sites (slide 34). Monkfish abundance was interesting since it significantly increased in all sites and remained relatively high throughout the two-year recovery period (slide 35). This is probably because of its highly mobile and exploitive behavior moving into the impacted sites. There was little impact on all finfish taken together in any of the sites with the exception of an increase in Site 1 dominated by Monkfish (slide 36).

The table in slide 37 shows the main and interaction effects of time and habitat for combinations of similar type organisms and individual species. A significant change at $p<0.05$ is indicated by the asterisks. The last two columns give the percentage change between controls and after two years' recovery for the two habitat types. Note that biodiversity and species richness were both significantly impacted in habitat 1 but not necessarily in habitat 2. This reflects the substrate type being harder and less disrupted by the scallop dredge in habitat 2. Large losses in organisms such a *Myxicola*, Lacy Tube Worm, *Styela*, *Iophon* and bryozoan in habitat 1 reflect the sensitive nature of these soft bodied organisms, static lifestyle and relative slow rate of reproduction. The large increase in *Didemnum vexillum* in habitat 2 reflects the opportunistic nature of this colonial tunicate when substrate is disturbed.

Summary and Conclusions

Both biodiversity and species richness decreased and remained <30% of control in complex epifaunal sites while no significant change in species richness was detected in sand/gravel sites. Epifauna (sponge, bryozoa, Hydrozoa, Lacy Tube worm, anemone, stalked tunicate) and infauna (*Myxicola*) in Sites 1-3 significantly decreased on impact and remained <50% than control after two years of recovery. It is clear that the softer substrate in Sites 1-3 were considerably more impacted than the sand, sand/gravel sites in Sites 4-6. There were significant high order effects (Habitat X Control X Impact) in five out of 10 faunal classes indicating that the impact made by scallop dredging is strongly influenced by habitat with complex epifaunal habitat being significantly more susceptible to mechanical impact than sand/gravel habitats. There was strong suggestion that some fish species (e.g., Monkfish) increased in impacted Sites 1-3 by more than 80% of control immediately following impact and remained elevated for two years. This reflects the mobile and opportunistic behavior of these species.

It is clear that two years is not sufficient for complex habitat to recover to 100% of control. Additional surveys are needed to evaluate recovery after five or more years has passed. It may be possible to target specific harder homogenous habitats for opening a limited fishery where scallop abundance is high while maintaining no-take zones in complex epifaunal habitat with a defined boundary of at least several 100 meters.

Literature Cited

Aronson, R.B. 1990. Onshore-offshore patterns of human fishing activity. Palaios 5: 88–93.

Auster, P.J., Langton, R.W. 1999. The effects of fishing on fish habitat. In: Benaka, L. (ed) Fish habitat: essential fish habitat and restoration. Symposium 22. American Fisheries Society, Bethesda, MD, p 150–187.

Carlton, G. C., Bazzaz, F. A. 1998. Resource Congruence and Forest Regeneration Following an Experimental Hurricane Blowdown. Ecology 79: 1305-1319.

Collie J.S., Hall S.J., Kaiser, M.J., Poiner I.R. 2000. A quantitative analysis of fishing impacts on shelf-sea benthos. J AnimEcol 69: 785–799.

Dayton P.K., Thrush S.F., Agardy, M.T., Hofman R.J. 1995) Environmental effects of marine fishing. AquatConserv 5: 205–232.

Gallager, SM, S Lerner, and C Fairclough. 2020. AI for classification, sensor fusion and habitat modeling. RSA Deep Learning Meeting, May 7 2020.

Jones, J.B. 1992. Environmental impact of trawling on the seabed: a review. NZ J Mar Freshwat Res 26: 59-67.

Kaiser, M.J., Collie, J.S., Hall, S.J., Jennings, S., Poiner, I.R. 2002. Modification of marine habitats by trawling activities: prognosis and solutions. Fish Fish 3:114–136.

Messieh, S.N., Rowell, T.W., Peer, D.L., Cranford, P.J. 1991. The effects of trawling, dredging, and ocean dumping on the Eastern Canadian Continental Shelf seabed. Cont Shelf Res 11: 1237–1263

Murawski, S.A., Brown, R., Lai, H.-L., Rago, P.J., Hendrickson, L. 2000. Large-scale closed areas as a fishery management tool in temperate marine systems: the Georges Bank experience. Bulletin of Marine Science 66: 775–798.

Murawski, S.A., Wigley, S.E., Fogarty, M.J., Rago P.J., Mountain, D.G. 2005. Effort distribution and catch patterns adjacent to temperate MPAs. ICES Journal of Marine Science 62(6): 1150–1167.

Plotkin, A., Foster, D. R., Carlson, J, Magill, A. H. 2013. Survivors, not invaders, control forest development following simulated hurricane. Ecology 94: 414-423.

Ragnarsson, S.Á., Lindegarth, M. 2009. Testing hypotheses about temporary and persistent effects of otter trawling on infauna: changes in diversity rather than abundance. Mar EcolProgSer 85:51–64

Riemann, B., Hoffman, E. 1991. Ecological consequences of dredging and bottom trawling in the Limfjord, Denmark. Marine Ecology Progress Series 69: 171–178.

Thrush, S. F., Hewitt, J. E., Cummings, V. J., Dayton, P. K. 1995. The impact of habitat disturbance by scallop dredging on marine benthic communities – what can be predicted from the results of experiments? Marine Ecology Progress Series 129: 141–150.

Van Dolah, R,F., Wendt, P.H., Nicholson, N. 1987. Effects of a research trawl on a hard-bottom assemblage of sponges and corals. Fisheries Research 5: 39–54.

Whitman J.D., Sebens, K.P. 1992. Regional variation in fish predation intensity: a historical perspective in the Gulf of Maine. Oecologia 90: 305–315.