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Recovery in a High Arctic Kelp Community

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Abstract

High arctic kelp communities in Prudhoe Bay are considered sensitive habitats and have the potential of being impacted by factors such as oil and gas activities, sedimentation, and ice scour. Impacts can result in the removal or scouring of sessile organisms leaving open space for new recruitment or damaged organisms needing to recover. The over-arching goal of this project was to acquire a better understanding of how sessile communities recover after disturbances in the Boulder Patch, a high arctic kelp community in Prudhoe Bay. Specifically this research determined 1) timing of natural recruitment of sessile organisms onto hard substrates, 2) effect of grazers on recruitment success, 3) effect of sedimentation on recruitment success, and 4) rate of vegetative regrowth of various sessile organism groups. This project determined the timing of natural recruitment over a seven year time period by annually monitoring new settlement on rocks that were cleared in 2002. To determine grazer impacts, cleared rocks placed into grazer exclusion cages in 2002 were monitored for seven years. Sedimentation impacts on initial recruitment were determined by comparing new recruits that settled on the tops (where sediment accumulates) and undersides (where no sediment accumulates) of settling plates that were placed into the field for two years. To determine the rate of vegetative regrowth, partial clearings established in 2007 were monitored for regrowth of specific sessile organism groups for four years. This study found that initial recruitment of sessile organisms onto the cleared rocks started after three years but at less than 1% cover of recruited individuals. Less than 10% of the boulder surfaces were colonized after seven years. Recruitment was so slow that it was difficult to ascertain grazer impacts. After seven years, approximately 12% of the boulders excluded from grazers were covered with recruits. In contrast to grazers, sedimentation appeared to influence recruitment. After just two years, an average of 30 new individual recruits colonized the underside of the experimental settlement plates where sediments were excluded compared to less than three individuals on the tops. Lastly, this study showed that vegetative re-growth of sponges and encrusting coralline red algae was fast, especially when compared to recruitment. Sponges averaged 100% regrowth after two years and corallines averaged 40% after four years. Coralline regrowth was much slower at a site with higher sedimentation. Overall this study has shown that recovery of sessile communities from disturbances is very slow in the Beaufort Sea, especially if entire organisms are removed or killed. However, if some part of either sponges or corallines remain on the substrate after the disturbance, recovery can be quicker for these organisms, particularly in low sediment areas. Still, even with the faster recovery from regrowth, complete community recovery in this system after a disturbance may take a decade or more. Sedimentation was the one driver that appeared to influence recruitment and may also impact recovery rates.

Introduction

Disturbance has been defined as any process that removes biomass from the community (Grime 1977) and has long been recognized as influencing species coexistence and the maintenance of community structure (Connell 1978, Huston 1979). As a result, there has been much research examining disturbance effects. Early pioneering work demonstrated that disturbance can be important in maintaining diversity and structure because it opens up space, which re-sets the community so that succession and recovery can start anew (Sousa 1979). Typically, early colonists have rapid dispersal and can recruit into new open space quickly. After the early colonists, the later successional species, which are better competitors, start to outcompete the early recruits. This intermediate state is when diversity is the highest. As these communities mature, more competition occurs, resources may become limiting and late successional organisms dominate (Sousa 1979). Disturbances that cause these successional states are common in shallow water boulder fields where wave action can have large impacts by overturning boulders and damaging sessile organisms (Sousa 1979, 1980, vanTamelen 1987). In arctic systems, disturbances can occur because of ice grounding into the seafloor, wave action, and sediment accumulation from river drainages, oil and gas activities (Konar 2007, Gutt 2011). In particular, oil spills have been shown to cause extensive damage to cobble/boulder habitats and their residents (Michel et al. 1978, Peterson et al. 2003, Olsen et al. 2011).

Disturbance in a shallow water boulder field, e.g., when a boulder is overturned, can kill the sessile community in whole or part by a combination of anoxia, low light levels, or mechanical damage caused by crushing or abrasion (Sousa 1980). Recovery from these disturbances on space-limited boulders can be very quick in temperate systems, where algal communities have been shown to recover to pre-disturbance densities within one year of denuding (Bertness et al. 2004, Milazzo et al. 2004). Also, although coralline algal recruitment and growth is slow, they will settle and grow to a visible size in a few months in temperate waters (Matsuda 1989, Konar and Foster 1992).

In contrast to these quickly recovering temperate systems, recruitment in high arctic systems can be slow, even for the encrusting corallines that dominate the substrate (Dunton et al. 1982, Konar 2007). Two previous recolonization experiments in the Beaufort Sea demonstrated that recovery of denuded rocky substrates is slow, with one experiment resulting in 50% of the substrate still being bare three years after an initial disturbance (Dunton et al. 1982), and the other showing less than 5% recovery after four years (Konar 2007). The reasons for the slow recruitment in arctic boulder fields remain unknown.

Whether temperate or polar, community recovery varies in space and time, as well as by recolonization mechanism. After disturbances, recovery can occur through recruitment of propagules (spores or gametes, recruiting larvae) or through vegetative re-growth (Sousa 1979), with the relative importance of each mechanism in maintaining communities highly variable (DeWreede and Klinger 1988, Santelices 1990, Poore and Fagerström 2001). For example, in kelps, spores can be viable immediately upon release and dispersal can be limited with settlement occurring on the seafloor within minutes (Santelices 1990). In contrast, most invertebrate species recruit as larvae after variable times in the plankton for dispersal and preparing for metamorphosis (Todd 1998). Algal and invertebrate recruitment can be influenced by the timing and location of the initial disturbance, the availability of bare rock and viable propagules/larvae, and environmental conditions (Airoldi 2000). In contrast to recruitment, often times substrates are first colonized by species with rhizoidal, stoloniferous, or runner-like morphology using vegetative regrowth, commonly seen in some brown algae, encrusting sponges, etc (Markham 1968, Jackson 1979). In some algal species, vegetative regrowth can occur from minute amounts of holdfast tissue (Gomez and Westermeier 1991, McCook and Chapman 1992, Sussmann and DeWreede 2007). In invertebrates such as sponges and colonial tunicates, regrowth can be quick resulting in these organisms outcompeting others for open space (Keough 1984).

One factor that may influence the rates of both propagule recruitment and vegetative regrowth is grazing, which can easily remove spores and new recruits, and damaged adult organisms that are trying to regrow. Grazers may directly feed on these life stages or they may indirectly impact spores and gametes through bulldozing them off rock surfaces. The importance of grazing on community recovery after disturbance has been shown repeatedly in temperate rocky communities (Konar 2000, Konar and Estes 2003, Aguilera and Navarrete 2007, Mumby et al. 2007) but its importance in high arctic systems is unknown.

Another factor that may be important in recruitment and regrowth processes is sedimentation. This driver can have significant control on marine communities, influencing algal and invertebrate assemblages in a variety of ways including scouring the substrate, smothering propagules, and reducing light (Rogers 1990, Konar and Roberts 1996, Airoldi and Cinelli 1997, Airoldi, 2003, Schiel et al. 2006). For example, in some Alaskan kelps, spore attachment was significantly and similarly affected by suspended particles, settled sediments covering the substratum, and by the smothering effects of settling sediments (Deiman 2010). In that study, spore attachment decreased by approximately 90% at the highest sediment loads, suggesting that increases in sedimentation may constrain the success of kelp spore development and thus kelp abundance and distribution within Alaska’s coastal waters. Data from tropical and temperate communities indicate this is a problem that can have ecosystem-level consequences (Rogers 1990, Konar and Roberts 1996, Vaselli et al. 2008).

The over-arching goal of this study was to determine how sessile communities recover after disturbances in the Boulder Patch, a high arctic kelp community in Prudhoe Bay. Specifically, this research determined the 1) timing of natural recruitment of sessile organisms onto hard substrates, 2) effect of grazers on recruitment success, 3) effect of sedimentation on recruitment success, and 4) rate of vegetative regrowth of various sessile organism groups.

Objectives/Hypotheses

To further our understanding of recruitment and recovery in arctic boulder fields, the following objectives and hypotheses were examined:

Objective 1: *Determine the timing of natural recruitment onto hard substrates.*
H1) Recruitment is slow and episodic.

Objective 2: *Determine the effect of grazers on recruitment success.*
H2) Grazers slow the initial recolonization of sessile organisms.

Objective 3: Determine the effect of sedimentation on recruitment success.
H3) Sedimentation slows initial recolonization of sessile organisms.

Objective 4: What is the rate of vegetative regrowth of various sessile organism groups?
H4) Vegetative regrowth is relatively quick for damaged, sessile organisms.

Study Area

Alaska's Beaufort Sea shelf is typically characterized by silty sands and mud and by an absence of macroalgal beds and associated organisms (Barnes and Reimnitz 1974). However boulder fields exist throughout this area, including at Konganevik Point (Konar and Iken unpub data) and in Stefansson Sound (Dunton et al. 1982, Dunton and Schonberg 2000). The Stefansson Sound boulder field, was discovered in 1971, and named the Boulder Patch. The Boulder Patch contains large numbers of cobbles and boulders that provide a substrate for attachment for a diverse assortment of invertebrates and several species of red and brown algae. The kelp, *Laminaria solidungula*, dominates the brown algal biomass by 90% (Dunton et al. 1982). This alga is an important food source to many benthic and epibenthic organisms (Dunton and Schell 1986, Debenham 2005). Approximately 148 animal taxa and 10 algal species cover nearly all exposed hard substrate at densities approaching 18,441 individuals/m^2 with an average biomass of 283 g/m^2 (Dunton and Schonberg 2000). Differences in infaunal abundance and biomass between the Boulder Patch and peripheral sediment areas demonstrate the importance of this unique habitat for biodiversity (Dunton and Schonberg 2000).

This study was primarily conducted in the area of DS-11 of the Boulder Patch (Figure 1). DS-11 was the primary site for the initial Boulder Patch biological work conducted in the 1980s (Dunton and Schell 1986). A satellite area (L1), 4 km away, visually had a higher occurrence of sedimentation than DS-11 and was established to examine vegetative re-growth of encrusting coralline algae under a different sedimentation condition. This site was also used in the historic Boulder Patch studies (Aumack et al. 2007). Although no sedimentation measurements were taken at either site, compared to DS-11, L1 always had a thicker layer of sediments coating the substrate and the tops of sessile organisms. Both study areas were in 6-7 m water depth. In 2004, a survey was completed at DS-11 to determine community structure (percent cover of sessile organisms and counts of mobile organisms from 15 haphazardly place 1 m^2 quadrats). This survey found that the substrate was covered by approximately 60% encrusting coralline algae, 27% foliose algae, 3% sponges, and 2% or less of a combination of bryozoans, hydroids, and soft corals. The primary herbivores encountered were the chitons *Amicula* spp. (6.4±2.1 s.e. per m^2) and *Ischnochiton* sp. (12.8± 2.09 s.e. per m^2). Seastars and the gastropod *Margarites* sp. were also occasionally seen at the study sites. The algal community was largely dominated by the brown alga, *Laminaria solidungula* and the encrusting red coralline *Phymatolithon spp.*. Along with these, there were a few foliose reds, the most numerous of which included *Dilsea integra*, *Odonthalia dentata*, *Phycodrys rubens*, and *Rhodomela confervoides* (Konar 2007).

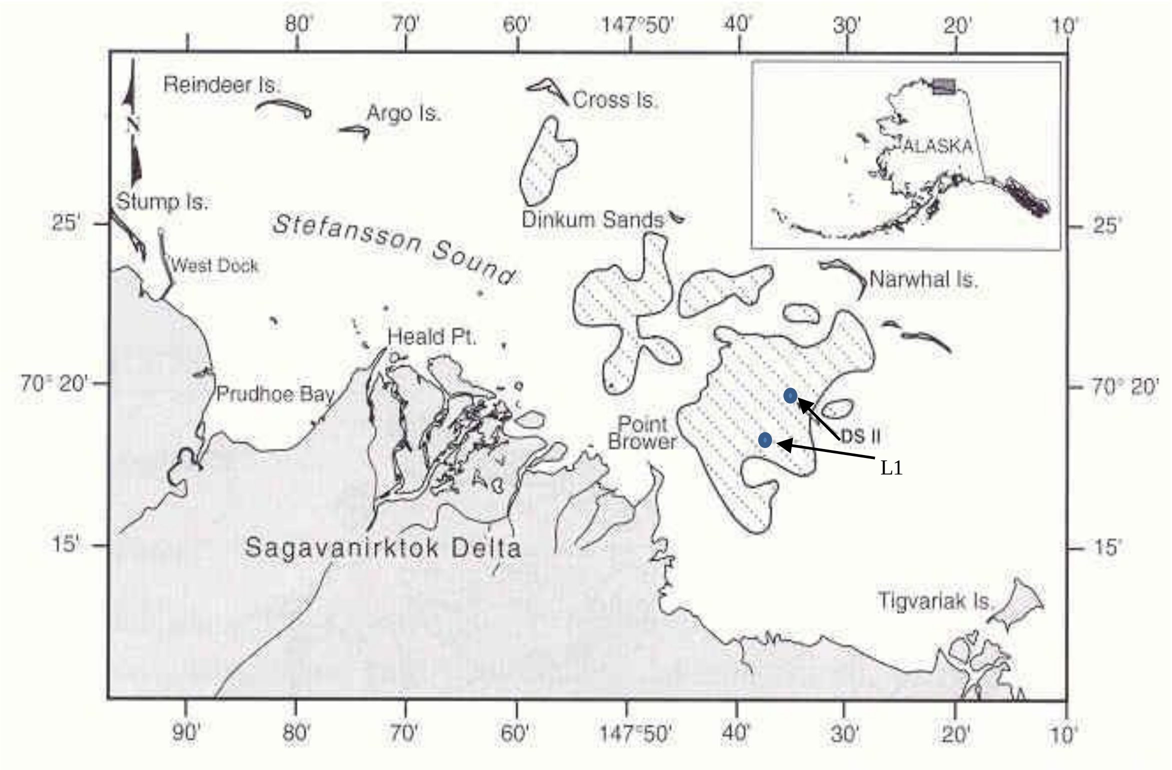

Figure 1. Chart of Boulder Patch showing study areas within Stefansson Sound. Hatched polygons are areas with high boulder/cobble density. From Dunton and Schonberg 2000.

Methods

Objective 1: Determine the timing of natural recruitment on to hard substrates.

To address this objective, 18 boulders (approximately 30-40 cm in diameter and 10-20 cm tall) from DS-11 were brought to the surface and cleared of all sessile organisms using metal scrapers and wire brushes. Boulders were left in the air for five days to kill any remaining seed bank and then replaced into one of three areas within DS-11. These areas were haphazardly chosen and were approximately 30 m apart from one another. Six uncleared boulders also were marked in each of the three areas within DS-11 to monitor natural changes in the community composition and natural recruitment over time. These cleared and uncleared boulders were monitored using visual percent cover estimates yearly between August 2002 and August 2009. The number of replicates resampled each year varied depending on how many replicates were relocated (Table 1; cleared boulders resampled in 2003 and 2004 = 18, 2005 and 2006 = 15, 2007 = 9, and 2008 =2, and 2009 = 1; uncleared boulders resampled in 2002 and 2003 = 18, 2004 and 2005 = 15, 2006 = 14, 2007 = 11, 2008 = 6, and 2009 = 5).

Table 1. Recovery data from recruitment and regrowth experiments. Show for each taxon by treatment and year. Mean (+/- 1 s.d.) and the replicate number are given.

Recruitment Experiment at DS-11

SAMPLE YEAR	2003	2004	2005	2006	2007	2008	2009
cleared boulders	n=18	n=18	n=15	n=15	n=9	n=2	n=1
bryozoan	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
hydroid	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
spirorbids	0 (0)	0 (0)	0.5 (0.5)	0.4 (0.5)	0.6 (0.2)	0 (0)	4 (0)
barnacles	0 (0)	0 (0)	0.1 (0.3)	0.2 (0.4)	0 (0)	0 (0)	2 (0)
sponge	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
cage boulders	n=18	n=18	n=15	n=13	n=11	n=3	n=3
bryozoan	0 (0)	0 (0)	0 (0)	0.4 (0.6)	0 (0)	0 (0)	10 (0)
hydroid	0 (0)	0 (0)	0 (0)	0.5 (1.3)	0 (0)	0 (0)	3 (2.8)
spirorbids	0 (0)	0 (0)	0 (0)	0 (0)	0.2 (0.2)	0 (0)	5 (0)
barnacles	0 (0)	0 (0)	0 (0)	0.2 (0.4)	0 (0)	0 (0)	0 (0)
sponge	0 (0)	0 (0)	0 (0)	0.1 (0.5)	0 (0)	0 (0)	5 (0)
cage control boulders	n=18	n=18	n=15	n=15	n=9	n=3	n=3
bryozoan	0 (0)	0 (0)	0.1 (0.3)	0.1 (0.3)	0 (0)	0 (0)	2.0 (0)
hydroid	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
spirorbids	0 (0)	0 (0)	0.5 (0.7)	0.2 (0.4)	0 (0)	0 (0)	4.0 (1.4)
barnacles	0 (0)	0 (0)	0.3 (0.5)	0.5 (1.1)	0 (0)	0 (0)	2.5 (0.7)
sponge	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Regrowth Experiment

SAMPLE YEAR	2008	2009	2010	2011
sponge at DS-11	n=4	n=5	n=4	n=1
	24.8 (7.8)	93.2 (9.3)	96.7 (6.7)	100 (0)
coralline at DS-11	n=3	n=5	n=5	n=5
	12.5 (7.7)	26.0 (10.1)	33.4 (7.4)	40.9 (9.2)
coralline at L1	n/d	n=5	n=5	n=3
All these were weight loss:		2.9 (2.7)	54.9 (72.3)	12.3 (12.3)

Objective 2: Determine the effect of grazers on recruitment success.

For this objective, 36 boulders from DS-11 were brought to the surface and cleared of all sessile organisms as described above. These boulders were also left in air for five days to kill any remaining seed bank and then assigned to one of two treatments: 1) caged, and 2) cage controls. Cages were 45 cm on a side, 30 cm tall, with a 1 cm mesh size and constructed of stainless steel mesh coated with a non-toxic antifouling compound (copper paint) to inhibit sessile invertebrate and algal growth (Figure 2). Cage controls (cages with holes cut into them so that grazers had access to the boulders) controlled for artifacts produced by the cages themselves such as decreased light, increased sedimentation, or change of currents (Figure 3). Light inside and outside of all cages was determined using a Li-Cor Model LI-185A Quantum Light Meter with a spherical sensor in 2004 on three separate days. These results showed a significant reduction in light due to cages (ANOVA, $F_{2,6}$=12.924, p=0.0067); however, there was no significant light difference between cages and cage controls. This suggests that differences found between results occurring within caged boulders and cage control boulders were not due to a light effect. Six replicates of each treatment were randomly placed *in situ* at each of the three areas previously described within DS-11 in August 2002 and were monitored using visual percent cover estimates yearly until August 2009. The number of replicates resampled each year varied depending on how many replicates were relocated (Table 1; caged boulders resampled in 2003 and 2004 = 18, 2005 = 15, 2006 = 13, 2007 = 11, and 2008 and 2009 = 3; cage control boulders resampled in 2003 and 2004 = 18, 2005 and 2006 = 15, 2007 = 9, and 2008 and 2009 = 3).

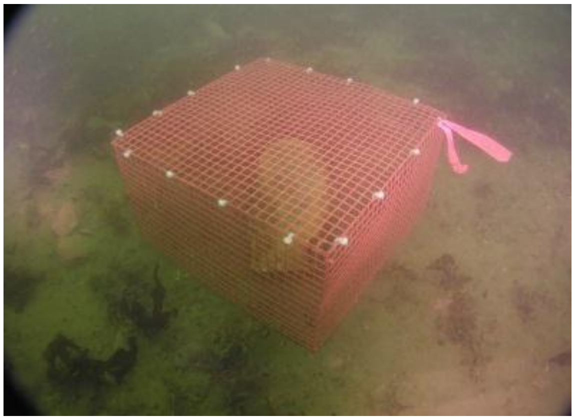

Figure 2. Caged rock *in situ.*

Figure 3. Cage control *in situ.*

Objective 3: Determine the effect of sedimentation on recruitment success.

For this objective, six settlement plates were placed in each of the three areas within DS-11, totaling 18 plates. Plates were made of plexiglass approximately 20 cm on each side, 3 mm thick, and were placed approximately 10 cm above the substrate (Figure 4). Both sides of the plates were roughened by scrubbing with sand paper to facilitate settlement. Plates were monitored by counting the number and types of newly recruited sessile individuals on the underside of the plates where no sediments accumulated and on the topside, where sediments do accumulate. This is a common technique used to ascertain recruitment while eliminating sedimentation effects (Irving and Connell 2002). This study was done from 2004 to 2006, with 11 plates being sampled in 2006. New plates were deployed in 2007 but these could not be surveyed in 2008 due to poor weather conditions and were not found in 2009 or later. The results from the 11 plates sampled in 2006 are presented in this study.

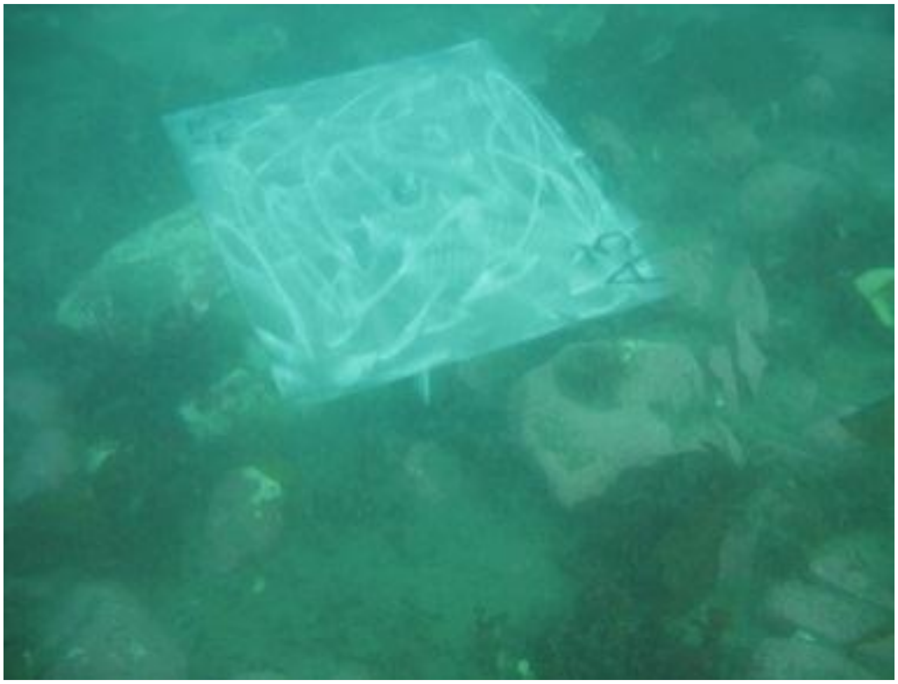

Figure 4. Settlement plate at DS-11.

Objective 4: What is the rate of vegetative re-growth of various sessile organism groups?

For this objective, 4 cm x 4 cm clearings were made on boulders using metal scrapers and wire brushes in the center of an encrusting organism patch at the three previously described areas where rocks were cleared and sediment plates were placed within DS-11 (Figure 5). In each area, eight boulders had clearings centered in a sponge (*Halichondria panacea*) patch, and six each were centered in encrusting coralline (*Phymatolithon spp.)* and foliose red algal (a mix of *Phyllophora truncata*, *Phycodrys riggii* and *Dilsea socialis*) patches. An additional six boulders with encrusting coralline patch clearings were placed at the site where sedimentation was visibly greater (L1). Each organism patch extended at least 2 cm beyond the cleared area to ensure some live material for re-growth. These cleared areas had vegetative re-growth calculated each year for four years using digital photography and SigmaScan. Regrowth was calculated as the percent area regrown from the previous year. The number of replicates resampled each year varied depending on how many replicates were relocated (Table 1; sponge at DS-11 resampled in 2008 = 4, 2009 = 5, 2010 = 4, and 2011 = 1; coralline at DS-11 resampled in 2008 = 3, and 2009, 2010, and 2011 = 5; coralline at L1 resampled in 2009 and 2010 = 5 and 2011 = 3). The replicate counts listed above at DS-11 do not include the one sponge and one coralline that were obviously dying as this may have been an experimental artifact (i.e. the organism was damaged in a way that was not controlled for in this experiment while it was bring cleared).

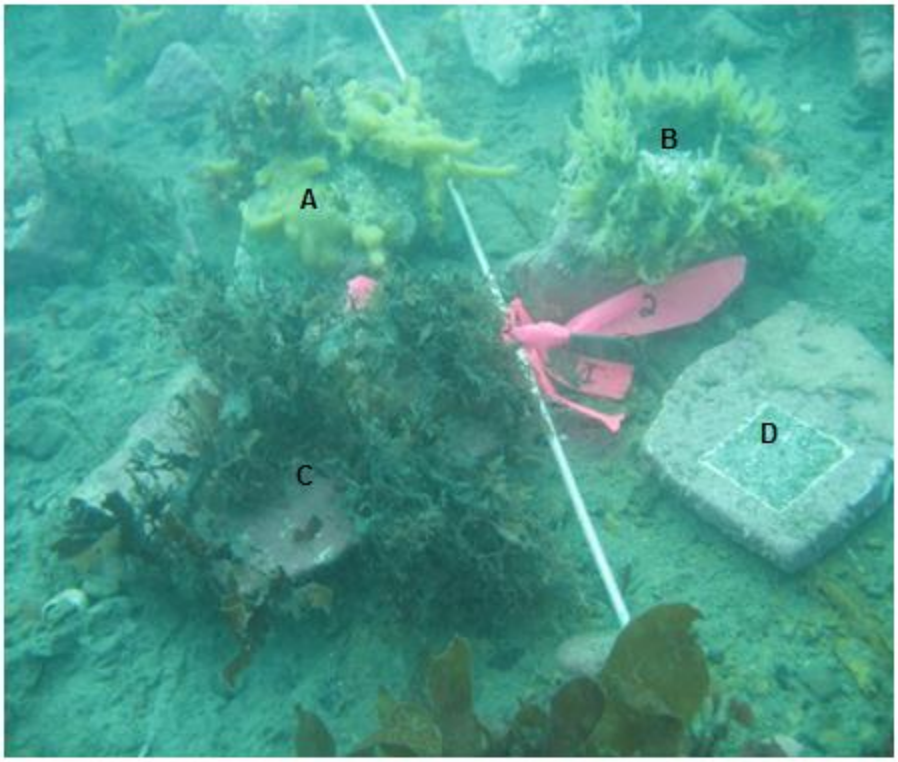

Figure 5. A set of cleared rocks at DS-11. A and B are sponge clearings, C is within a red algal patch and D is within an encrusting coralline patch.

Results

Objective 1: Determine the timing of natural recruitment on to hard substrates.

Uncleared rocks that were monitored for community changes showed that the epilithic community on undisturbed (control) boulders did not change significantly over time (repeated-measures ANOVA, $F_{6,108}=1.912$, p=0.6, Figure 6). Also, few to no newly recruited individuals were ever found on these undisturbed boulders. In 2007, ice removed and destroyed two of the experimental site set ups within DS-11 so the sample size decreased dramatically at that time. In 2008, only six rocks were relocated. Overall, percent cover of bare rock and total invertebrates was low in all years. The primary space occupier was algae, with encrusting corallines occupying the most space followed by total foliose algae. Total foliose algae were primarily reds but also occasionally included the kelps.

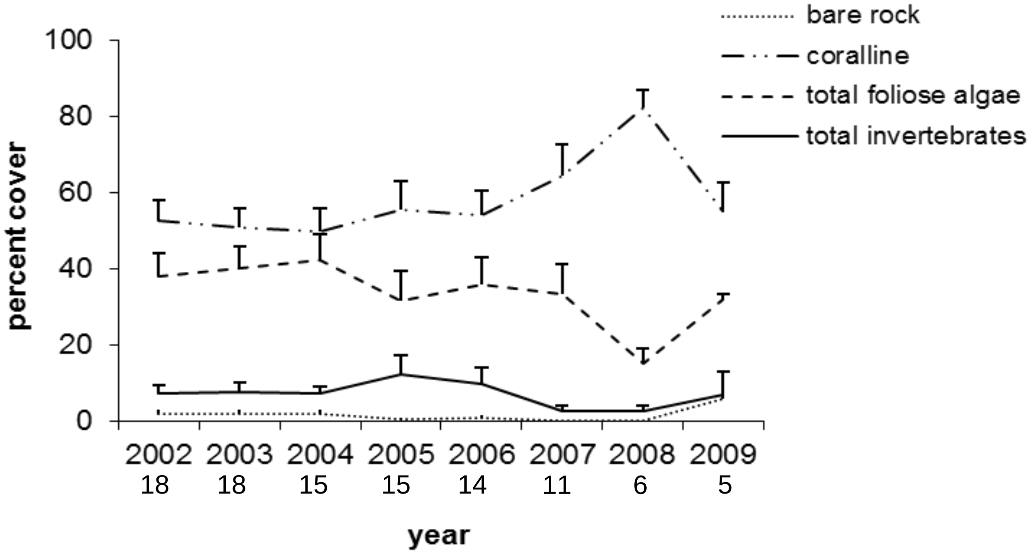

Figure 6. Mean percent cover (±1 s.e.) of bare rock, corallines, total foliose algae, and total invertebrates on uncleared control boulders from 2002 to 2009. The number below the year corresponds to the number of boulders surveyed.

Boulders that were cleared and replaced into the field showed little recruitment over the seven years. In fact, it was not until 2005 that the very first invertebrate recruits were seen, although they covered less than 1% area (Table 1, Figure 7). These invertebrates were barnacles and spirorbids; organisms not typically found in the mature community. In 2009, after seven years, the surface of the boulders showed 6% cover of spirorbids and barnacles. No corallines or foliose algae were seen on these cleared boulders. It should be noted that only two replicates were found in 2008 and only one in 2009, as explained above.

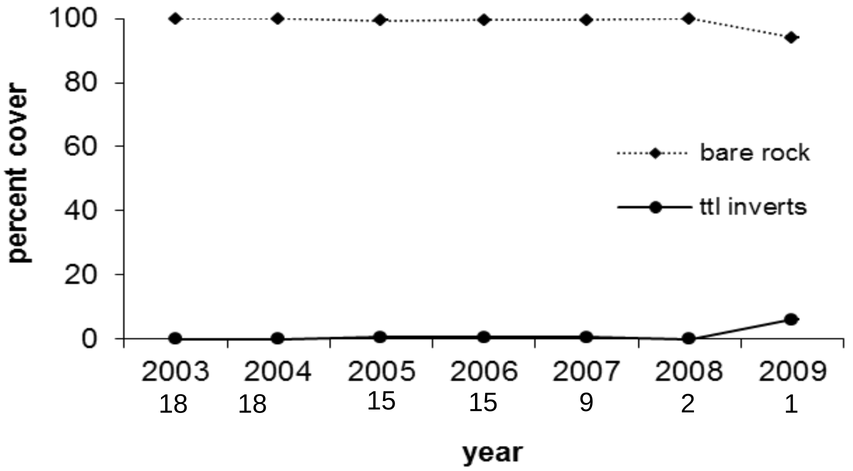

Figure 7. Mean percent cover (±1 s.e.) of bare rock and total invertebrates on cleared boulders from 2002 to 2009. The number below the year corresponds to the number of boulders surveyed.

Objective 2: Determine the effect that grazers have on recruitment success.

Caged boulders showed little recruitment over the seven year period that they were monitored (Figure 8A). Similar to the uncaged cleared boulders, after three years, some invertebrate recruits were found, primarily barnacles and spirorbids, although they covered generally less than 1% or the rock surface. After seven years, recruitment increased to 9% (primarily corallines and invertebrates); however, at this time, the sample size was extremely low (n=3) due to the removal of most cages by ice in 2007.

Cage control boulders showed similar trends to those seen in the cleared uncaged and cleared caged boulders (Figure 8B). After three years, barnacles and spirorbid recruits covered less than 1% of the rock surface. After seven years, the cover of recruits increased to approximately 11% of the rock (2.5% corallines, 3.5% foliose algae, and 5.7% invertebrates). Again, note the small sample size, n=3 in both 2008 and 2009. Although in 2006 there was slightly more recruitment in the caged versus uncaged rocks (ANOVA, $F_{2,41}=4.461$, p=0.02), overall recruitment in the final year was not significantly different among any of the caged or uncaged cleared rocks (ANOVA, $F_{2,10}=0.116$, p=0.9).

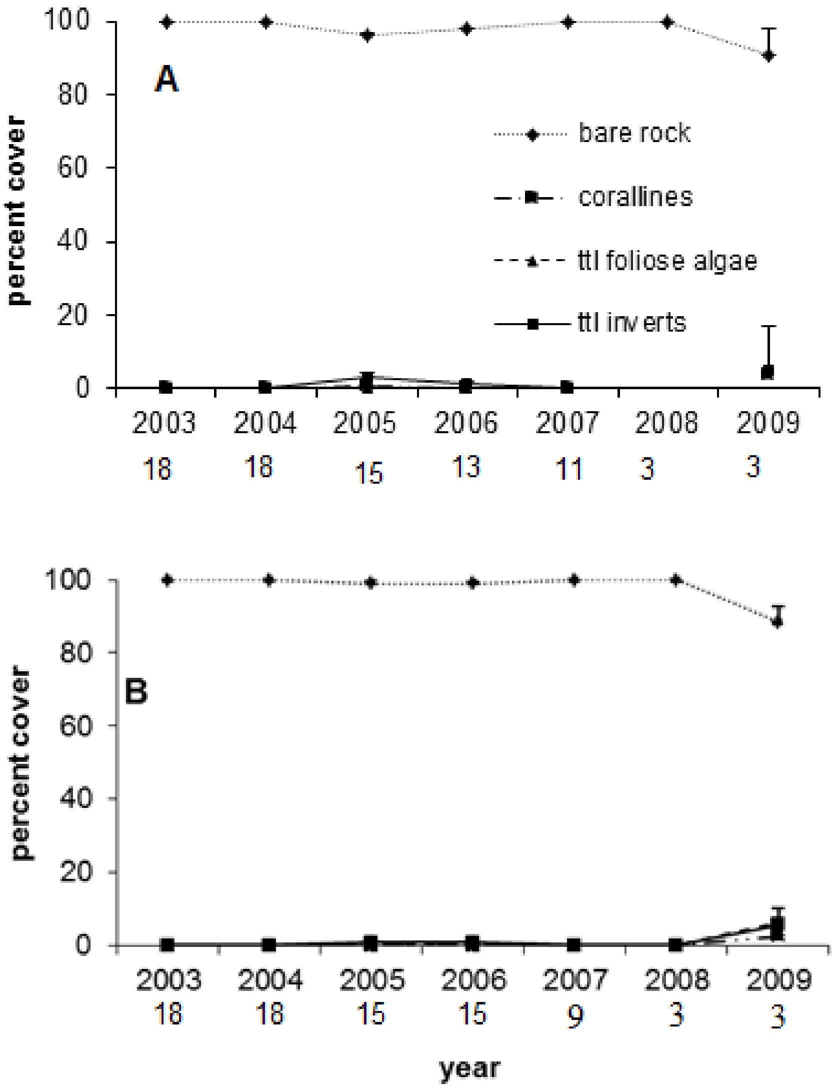

Figure 8. Mean percent cover (±1 s.e.) of bare rock, corallines, total foliose algae, and total invertebrates on caged boulders (A) and cage control boulders (B) from 2003 to 2009. The number below the year corresponds to the number of boulders surveyed.

Objective 3: Determine the effect of sedimentation on recruitment success.

Regrettably the settlement plates placed in the field in 2007 could not be found in subsequent years. However, the results of the 2004-2006 settlement plates suggest that sedimentation may be playing a key role in minimizing recruitment (Figure 9). The undersides of plates, which did not accumulate sediment, had significantly more recruits than the topsides (ANOVA, $F_{1,20}=15.415$, $p=0.0008$).The undersides recruited an average of 30 individuals per plate. These recruits included bryozoans, spirorbids and one individual sponge. The tops of plates, which did accumulate sediments, recruited less than three individuals per plate.

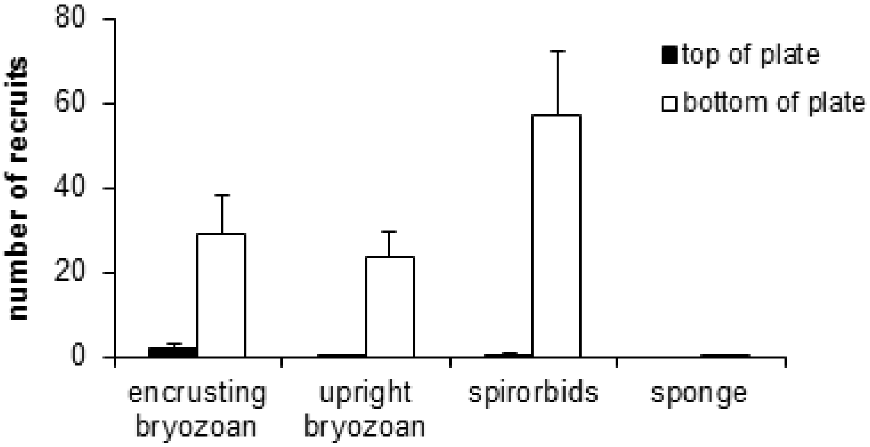

Figure 9. Number of sessile organism recruits (±1 s.e.) that settled onto plates after two years *in situ* (n=11).

Objective 4: What is the rate of vegetative re-growth of various sessile organism groups?

Of the various organisms that were partially cleared at DS-11, only the foliose red algae showed no visible regrowth. It was thought that perhaps holdfasts might grow outward and the upright portions would follow by vegetative growth; however, this was not seen in this study. In fact, no recovery by regrowth of any foliose algae was found in this study.

In 2008, regrowth of four partially cleared sponges was between 14 and 31% (Table 1, Figure 10, mean = 24.7 ± 3.9 s.e.). In 2009, 43% of the five sponge boulders that were relocated had completely recovered. In 2010, 71% had recovered (n=4). Only one sponge was found in 2011 and it had completely recovered. One sponge that was not found in 2008 was relocated in 2009 and it showed significant damage. A large portion of this sponge had died and sloughed off for unknown reasons. This sponge was not included in the recovery calculations because its damage may have been initiated by the actual clearing process. In 2011 and 2012, this sponge was showing marked recovery.

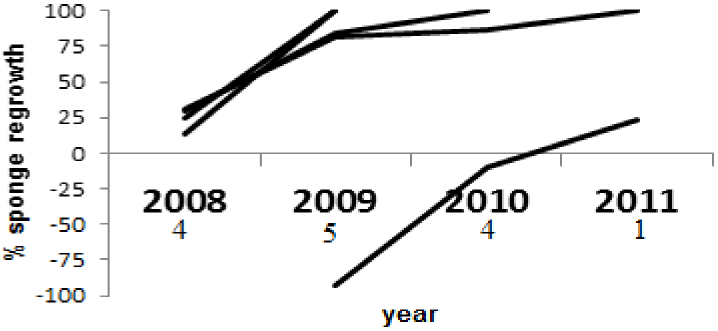

Figure 10. Percent regrowth of all DS-11 sponges. Each line represents one sponge colony. The number below the year corresponds to the number of boulders surveyed, not including the one that was highly damaged.

At DS-11, three of the corallines regrew between 10 to 20% in 2008 (Table 1, Figure 11, average =15.6 ± 4.4 s.e.). In 2011, 83% of the five coralline patches showed regrowth ranging from 30-51% (average =40.9 ± 4.1 s.e.). In 2008, one coralline showed injury (bleaching) and had a large decrease in total area (approximately -32%). This coralline was not included in the recovery calculations. It was not recovering at a rate comparable to the other corallines that were partially cleared in this study and in fact its area had further declined to -34% in 2011. Unlike the significantly damaged sponge at DS-11, this coralline showed no substantial recovery in 2010 and 2011. The reason for this mortality and lack of recovery is unknown.

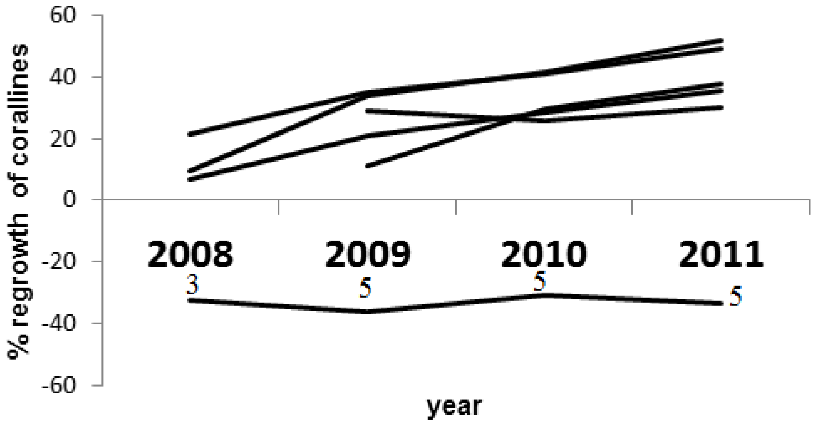

Figure 11. Percent regrowth of all DS-11 corallines. Each line represents one coralline individual. The number below the year corresponds to the number of boulders surveyed, not including the one that was highly damaged.

There was no measurable regrowth of corallines in the study area with the higher sediment load (Table 1, Figure 12). This area was not revisited in 2008 because of poor weather conditions but when it was surveyed in 2009, only decreased cover (negative growth) was seen. In 2011, between +0.1 and -24.5% growth was found on the partially cleared boulders. Similar to the organisms examined at DS-11, one partial coralline clearing at L1 showed extreme damage in 2010. Coralline cover on this rock decreased in area by -183%. Again, the reasons for this mortality are unknown.

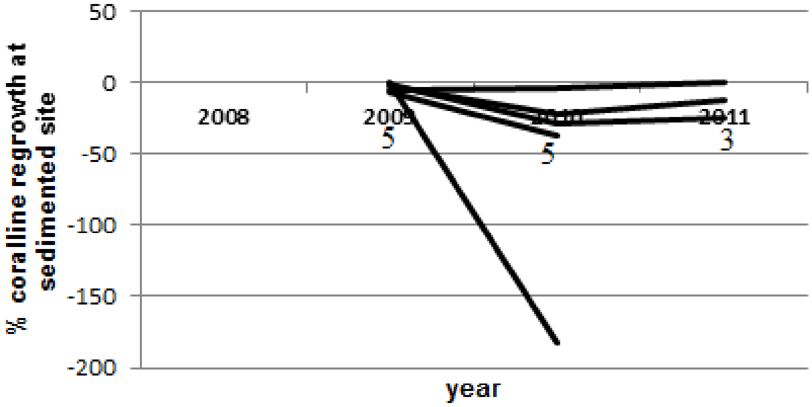

Figure 12. Percent regrowth of all L-1 corallines. Each line represents one coralline individual. The number below the year corresponds to the number of boulders surveyed.

Discussion and Conclusions

In coastal boulder communities, an array of disturbances can clear substrates or cause damage to existing organisms. Typically recovery from these disturbances can occur through recruitment of propagules (spores, gametes, larvae) or through vegetative regrowth of damaged individuals. In temperate systems, recovery can be quick, with full community recovery taking one year or less (Bertness et al. 2004, Milazzo et al. 2004). In contrast to this, high arctic systems have a much slower recovery (Dunton et al. 1982, Minchinton et al. 1997, Konar 2007). Different intertidal levels and communities in Canada recovered at different rates but were generally slower than the one year recovery seen in temperate waters (Minchinton et al. 1997). Similar to these previous arctic studies, the present study has confirmed the slow arctic recovery and it is concluded here that it may take a decade or more for arctic coastal boulder fields to recover if a major disturbance removes the sessile community.

In the Boulder Patch, almost 100% of all rock is covered with sessile organisms (Konar 2007), demonstrating that open space is limited in this system (Konar and Iken 2005). However, when space was cleared in this study, there was little to no recruitment even after seven years of observation. It could be that recruitment events are temporally rare and that seven years was not enough time to observe an event. This could also be confounded by the loss of replicates in all treatments due to ice scour. This slow initial recruitment contrasts to another arctic area in Nova Scotia where initial recruitment of ephemeral algae was almost immediate but succession to a more climax community was slow, at least six years for some sites (Minchinton et al. 1997). It could also be that spatially, recruitment is patchy in the Boulder Patch and that there was not enough open space offered for a recruitment event to be seen. This latter possibility seems unlikely because cleared and uncleared rocks that were monitored were spatially separated by at least 2 m within a site and 30 m between sites. Anecdotally very few small kelp recruits were seen in either of the study areas during the seven monitoring years. This lack of recruitment emphasizes the vulnerability of this community to disturbances, particularly those that kill all sessile organisms on the rock surfaces.

One biological driver that can impact community structure in other regions is grazing (Konar 2000, Konar and Estes 2003, Mumby et al. 2007). Grazers can directly feed on propagules or can indirectly remove recruits by bulldozing them off the surface. In this study, chitons were the main grazers and although they are fairly abundant in the Boulder Patch (Konar 2007), they did not have a significant impact on recruitment when they were excluded from boulders. This lack of impact contrasts to another study where chitons and other mollusks directly impacted succession in a temperate intertidal community (Aguilera and Navarrete 2007). It has also been suggested that grazers may counter negative effects of sediment burial by bulldozing sediments from hard substrates (Bertness 1984), although that was not seen in this study.

In other regions, sedimentation is a physical driver that can influence recruitment and community structure (Airoldi 2003, Schiel et al. 2006). Similarly, this study found that sediments influenced recruitment onto settling plates. Approximately ten times more recruits settled onto the bottom of plates where sediments were excluded than onto the tops of plates where sediments accumulated. One taxon that did not recruit onto the plates was the encrusting corallines. Typically when sediments are excluded from a substrate, encrusting corallines are among the first to recruit (Kendrick 1991). Why this was not seen in this study when encrusting corallines are so abundant in the developed community may best be explained by the spatial orientation of the plates (undersides) and the preference for encrusting corallines and most other algae to settle on up-facing surfaces (Baynes 1999, Irving and Connell 2002). While it is known that early post-settlement algal stages are vulnerable to sedimentation (Airoldi 2003, Deiman 2010), this study found that sedimentation likely also impacted vegetative regrowth. In this study, an area that visually had more sedimentation had much less regrowth of encrusting corallines compared to an area with seemingly less sedimentation.

The maintenance of communities through both sexual reproduction and vegetative regrowth is not uncommon in marine systems. In the field, vegetative regrowth can be the primary means of recovery from a disturbance with stoloniferous outgrowths forming new upright growth. In fact, in small patches, vegetative growth of adjacent organisms has been seen to overgrow newly settled larvae (Keough 1984). Other studies have suggested that while recruitment by sexual propagules can be highly variable through space and time, recovery by vegetative propagation can be more constant and highly predictable over a range of environmental conditions, and that vegetative regrowth is likely fundamental to spatial dominance in a variety of habitats (Airoldi 2000). The present study demonstrated the importance of vegetative regrowth over recruitment events for recovery in an arctic coastal boulder field. However, although vegetative regrowth was faster and more successful than recruitment events, this study also demonstrated that it may take a decade or more for complete community recovery after a disturbance, especially if no organism remnants remain thus limiting vegetative regrowth. Recovery time may be considerably longer in areas with higher sedimentation accumulation.

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Study Products (does not include annual reports)

Konar B (in prep) Recovery in a High Arctic Kelp Community. To be submitted to Marine Biology

Konar B (2012) Recovery of hard substrate benthic communities in the Beaufort Sea. Poster presentation at the Alaska Marine Science Symposium. 16-20 January 2012. Anchorage Alaska

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Appendix 1: Boulder Patch Fish Assemblages Project

Introduction

The discovery of petroleum on Alaska's North Slope in 1969 has triggered research on marine communities inhabiting the Beaufort Sea coastal waters in response to concerns about the potential impacts of oil development on indigenous species and their habitats (Jarvela and Thornsteinson 1998). Most of this work has taken place in the vicinity of Prudhoe Bay, the present center of production activities, and in adjacent waters in the coastal Arctic. Areas in Stefansson Sound have been central to much of this survey effort due to the occurrence of a unique nearshore habitat dominated by boulders, appropriately named the Boulder Patch (Figure 1 in main text). The Boulder Patch is a shallow (less than 10 m water depth) nearshore habitat, covering approximately 20 km^2 of seabed, and is characterized by cobbles and small boulders in an area otherwise dominated fine-grained sediments, silty sands, and/or mud. The boulders in the Boulder Patch provide a substrate for attachment for algae and sessile invertebrates and refuge habitat for fish.

Recent studies in this habitat have focused on macroalgal and invertebrate communities (starting with Dunton et al. 1982); however the epipelagic fish community has yet to be fully described. Epilithic sampling of rocks in the Boulder Patch has shown that fish do inhabit this area (*Liparis* sp., *Liparis herschelinus*, *Myoxocephalus scorpioides* and Stichaedae; Dunton and Schonberg 2000). Studies conducted in nearshore waters elsewhere in the Prudhoe Bay region (Tarbox and Moulton 1980; Craig et al. 1982; Craig 1984; Moulton and Tarbox 1987; Gallaway et al. 1991) also provide reference for species assemblage structure and habitat associations pertinent to this study and suggest that the fish community associated with the Boulder Patch is likely comprised of adult and larval fishes that commonly associate with rocky substrates and neritic riverine-influenced systems. The primary goal of this pilot study was to quantify fish diversity and abundance in the Boulder Patch by examining (1) fish community composition; (2) species' distributions, abundances, and visual estimation of individual fish length; and (3) species' relationships to habitat attributes such as benthic grain size and macroalgal distribution and abundance.

Study Area

Epipelagic fishes were surveyed in the Boulder Patch in Stefansson Sound (N 70° 19.336, W 147° 34.903), located 20 km northeast of Prudhoe Bay, Alaska, in the Beaufort Sea. Sites that were surveyed within the Boulder Patch were DS11, L1, and an area outside these patches by L1 (Figure 1 in previous section). As each transect had varying amounts of boulders, analyses will be completed by physical attributes and not by site.

Methods

This pilot study conducted two survey methods in three areas within the Boulder Patch (DS11, L1, and an area adjacent to L1). At DS11, three transects were completed at each of two sites (totaling 6 transects). At L1, three transects were conducted at each of two sties (totaling 6 transects). Three transects were also conducted an area adjacent to L1. The reason why different areas were chosen was to try to get a range of boulder densities and algal cover.

The first method utilized diver visual surveys conducted along randomly placed 50 m x 2 m x 2 m transects. Fish observed along these transects were identified to species and their length estimated to the nearest centimeter. Diver surveys consisted of an initial search that targeted mobile species within 2 m (vertical distance) of the substrate and species that were shown to move quickly through the survey area. A second search along the same transects targeted cryptic species associated with the substrate and perhaps hidden under the macroalgae. In the adjacent sandy areas, only the first search was done as there is no place for fish to hide in this habitat.

Along each transect, rugosity and kelp stipe counts were calculated. Rugosity is a measure of substrate topography and is a ratio of the topographical distance compared to a straight line distance. Rugosity was measured using a 1 m polyvinyl chloride (PVC) bar with a length of small mesh (5 mm diameter) chain attached to one end. At six points along each transect, the PVC bar was laid perpendicular to the transect, and the chain was placed in the same direction but allowed to drape and follow the substrate topography. At the end of the PVC bar, the chain was marked, straightened, and measured to provide the rugosity ratio. To determine the total number of kelp stipes along each transect, six 0.25m^2 quadrats were examined per transect. All understory kelps in each quadrat were counted.

The second method used consisted of observation stations baited with herring. These stations were under video surveillance without divers being present for a 30 minute timed survey period. These surveys were designed to better estimate biodiversity and abundance of small and/or cryptic fish. Two stations were videoed, one in DS11 and one in L1. The videos were completed to determine if this might be a feasible way to examine fish diversity between sites.

Results

All fish seen in the surveys conducted in this study were *Liparis* spp. (snailfish). Within DS-11, only one individual was found in the six transects that were conducted for a mean fish density of 0.0008 per m^3. At L1, three individuals were counted along the six transects for a mean fish density of 0.0025 per m^3. In the area outside of DS-11, four fish were found along the three transects that were conducted for a mean fish density for 0.0067 per m^3.

In Alaska, rugosity and kelp cover are known to influence fish assemblages (Hamilton and Konar 2007; Markis 2007) so correlations between these two factors were examined for the Boulder Patch fish assemblage. Interestingly, neither rugosity nor kelp cover seemed to influence the fish assemblage (Figures 1 and 2).

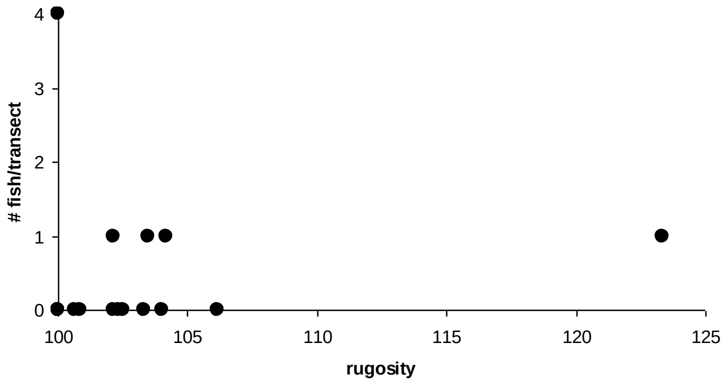

Figure A1. Total number of fish per transect related to average rugosity per transect.

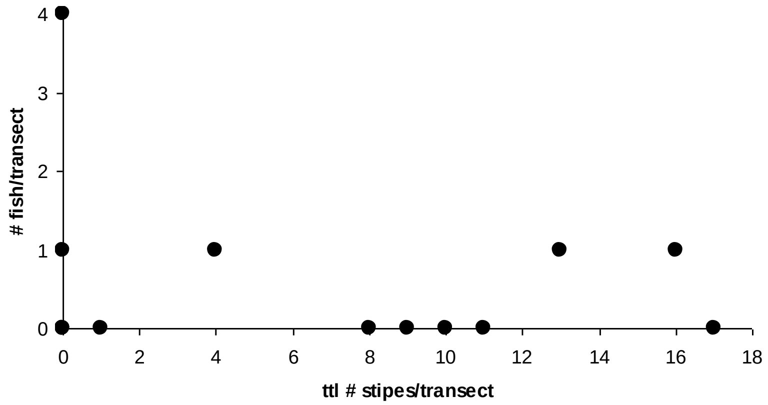

Figure A2. Total number of fish per transect related to total number of stipes per transect.

Video surveillance was not successful for examining fish diversity between sites. Although the cameras soaked for 30 minutes and were baited, no fish were observed on the video. The camera was working however as it did get images of various invertebrates moving through the stations.

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The Department of the Interior Mission

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