# ALGAL RECOLONIZATION OF FROG ISLAND, NOVA SCOTIA AFTER LARGE-SCALE REMOVAL OF ALGAL SPECIES THROUGH ANTHROPOGENIC ACTIVITY

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# Abstract

Macrophytic algae, which are at the base of intertidal food webs, provide food and shelter to organisms of higher trophic levels. Rocky substrata and macroalgae are essential to the physical and biological sustainability of intertidal ecosystems. In 2007 the owner of Frog Island, Nova Scotia removed boulders, cobble, and algae from an 800 ft. x 80 ft. (244 m x 24 m) section of the beach to build an erosion control rock wall around the perimeter of the island. Consequently,fish habitat provided by macrophytic algal species was destroyed. To our knowledge, there are limited published studies regarding the recovery process of macrophyticalgae after a disturbance of this magnitude. To restore the intertidal habitat,a remediation plan was proposed and implemented, followed by a five-year monitoring program. The purpose of this research was to determine a rate of macrophytic algal recolonization on Frog Island and to understand what physical and biological factors may affect the recovery process.The study site had 17 sampling transects: 14 in an experimental site and three in a control site. The research involved an analysis of percentage of algal coverage and an analysis of dry biomass. Algal coverage increased over time, increased towards the sub tidal zone from the high intertidal zone, and was significantly different between the control site and the experimental site. Dry biomass increased with vertical zonation towards the sub tidal zone, varied between two sampling seasons, and varied between the control site and the experimental site.At the end of the five-year monitoring period, dry biomass and percentage of algal coverage were still less in the experimental site than in the control site. However, there was a progressive and healthy reestablishment of Fucoid algae species to the impacted rocky intertidal section of Frog Island.

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# Chapter 1: Introduction

## 1.1 Introduction

Rocky intertidal zones are complex ecosystems with a diverse array of aquatic life. Macrophytic algae are the dominant flora found in the intertidal zone and are important for supplying food, nutrients, and shelter to intertidal organisms (Fisheries and Oceans Canada, 2010a). Diversity in the intertidal area is high and in part due to an abundance of primary producers, such as macrophytic algae, which are at the base of intertidal food webs (Figure 1).

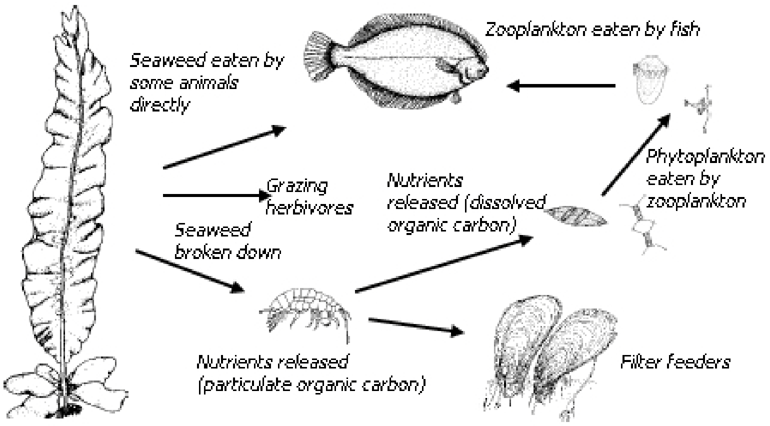

*Figure 1.* The illustration of an intertidal food web shows the importance of macrophytic algae as a primary supplier of food. From the Fisheries and Oceans Canada website. Retrieved February 4, 2011 from http://www.glf.dfo-mpo.gc.ca/e0005912#food_web

Boulders, cobble, and algae are essential to the physical and biological sustainability of intertidal ecosystems. Wentworth (1922) defines a boulder as any sedimentary rock larger than 256 mm and cobble as any sedimentary rock ranging between 64 and 256 mm in size. Boulders and cobble allow for the physical formation of tide pools, provide shelter, and supply algae holdfasts with solid surfaces for attachment. Without intact populations of algae providing food and shelter to organisms of higher trophic levels, intertidal ecosystems would collapse. The preservation of intertidal ecosystems is important, not only to wildlife, but also to humans because these zones are important spawning grounds, nursery grounds, and juvenile and adult habitat for a variety of forage fish and commercial shellfishes and finfishes. Rocky intertidal zones are sensitive to human disturbances such as induced sedimentation, pollution, coastal development, physical disruption, and resource overharvesting (Horn, 1999). Restoration of disturbed intertidal areas is important to maintain and protect the diversity, integrity, and health of intertidal species that are vulnerable to, or have been impacted by, a disturbance.

## 1.2 Background

Frog Island is located on the south shore of Nova Scotia in Mahone Bay, Lunenburg County (Figure 2). The coordinates of the island are 44 30.970N, 64 16.545W, NAD83 (Thaumas Environmental Consultants, 2007). In 2007, the owner of the island used an excavator to remove boulders and cobble from the beach to build a rock wall around the perimeter of the island for erosion control. Extraction of the boulders and cobble eliminated the substrate needed for algal growth and caused increased erosion of gravels and sand on the beach, resulting in muddy water that extended along the island and well out into the Bay (Thaumas Environmental Consultants Ltd., 2007). As a result, fish habitats were altered in an area approximately 800ft. long and 80 ft. (244 m x 24 m) wide of the intertidal zone of Frog Island and there was siltation of habitats in the adjacent subtidal area (Thaumas Environmental Consultants Ltd., 2007). This large-scale anthropogenic disturbance contravened the habitat provisions of the Fisheries Act and the Beaches Act of Nova Scotia (Thaumas Environmental Consultants Ltd., 2007). The Federal Department of Fisheries and Oceans (DFO) regulates the habitat protection provisions of the Fisheries Act under federal jurisdiction (Fisheries and Oceans Canada, 2010b). The Provincial

Department of Natural Resources regulates the Beaches Act of Nova Scotia under provincial jurisdiction (Province of Nova Scotia, 2009).

*Figure 2.* The map shows Frog Island, Nova Scotia and the impacted portion of the beach (Thaumas Environmental Consultants Ltd., 2007).

## 1.3 Purpose

The goal of this research was to determine a rate of macrophytic algal recolonization and to analyze how successful the remediation methods were on Frog Island. This research is important because there is limited published knowledge pertaining to rocky intertidal habitat restoration after an anthropogenic disturbance of this magnitude.Small-scale natural disturbances, such as the overturning of rocks by wave action, can have a positive effect on intertidal diversity by opening up space for colonization (Addessi, 2003). However, disturbances that cause widespread disruption to the habitat may require a longer recovery period, thus threatening the habitat and consequently the livelihood of species that inhabit and utilize the rocky shoreline niche. Large-scale anthropogenic disturbances that inhibit or severely slow down the colonization and growth rates of organisms are poorly documented in the literature (Addessi, 2003).

This research contributes knowledge for future rocky intertidal beach restoration initiatives. The knowledge gained from this research may be applicable to impacts such as: extreme storm events, commercial dragging, oil spills, and the management of commercial rockweed harvesting.

## 1.4 Research Questions and Hypotheses

This thesis focuses on investigating two main research questions and the corresponding hypotheses.

1. What is the post remediation rate of algal recolonization in the disturbed section of the beach on Frog Island?

Hypothesis:The primary habitat supplied by the presence of algae will be reestablished within five years after remediation on the disturbed section of the rocky intertidal area.

2. What physical and biological factors may increase/decrease the rate of algal recovery to an exposed rocky intertidal zone in Nova Scotia?

Hypotheses:

a. Algal coverage and biomass will be lowest in the high intertidal zone and will increase towards the subtidal zone.
b. Algal coverage will increase with time over the five-year monitoring period, from 2007 to 2011.

## 1.5 Scope and Boundaries

The spatial scope of this research was confined to Frog Island, Nova Scotia where an anthropogenic disturbance had caused a large-scale alteration to fish habitat. The impacted area of Frog Island was the focus of this research, but an undisturbed section of the rocky beach was included in the analysis as the control area. The temporal scale of this research restricted the analysis to data that was collected over a five-year monitoring period. The goal of this remediation was to reestablish the macrophytic algal primary production base on the impacted rocky intertidal beach. Within this document, restoration is defined as the recolonization of macrophytic algae to the area impacted.

# Chapter 2: Literature Review

This research topic is important because rockweed (Fucaceae family) is a fundamental component of temperate marine rocky intertidal ecosystems. Consequently, it is beneficial to understand how rockweeds recover, both spatially and temporally, after removal. This research aims to address the limited knowledge of the recovery process involved in recolonization of intertidal boreal, temperate marine macrophytic algae after a large-scale removal of populations has occurred through anthropogenic activity.

## 2.1 Summary of Intertidal Species

Macrophytic algae are important habitat, refuge, and habitat for food of many marine fishes and invertebrates in the intertidal area. The Canadian Department of Fisheries and Oceans (DFO) has identified a number of species that utilize the rocky intertidal shores of Atlantic Canada; these species include mollusks, crustaceans, echinoderms, worms, fishes, and algae (Fisheries and Oceans Canada, 2010). The dominant genera of macrophytic algae in the rocky intertidal zones of Nova Scotia are *Ascophyllum* and *Fucus* of the Fucaceae family. The common name for these members of the Fucaceae family is rockweed. Within the *Fucus* genera are a number of species that inhabit separate or overlapping vertical and horizontal gradients in the rocky intertidal zone (Scrosati & Heaven, 2008). Vertical gradients are determined primarily by tide dynamics, whereas horizontal gradients are determined by wave exposure. Scrosati and Heaven (2008) studied trends in the abundance of seaweeds in an intertidal zone of Nova Scotia and observed that *Fucus serratus* occurred at sheltered low intertidal areas, *Fucus spiralis* inhabited exposed sites in the high intertidal area, and *Fucus vesiculosus* with *Ascophyllum nodosum* were found across all vertical and horizontal gradients. Furthermore, the abundance of

*Ascophyllum nodosum* was less in exposed, rather than sheltered, rocky intertidal areas (Scrosati & Heaven, 2008).

*Ascophyllum* is an important habitat for intertidal fishes, in part due to its dominance on rocky intertidal shores. Black and Miller (1992) conducted a study in Nova Scotia to examine the benefits of *Ascophyllum nodosum* to intertidal fishes and identified 18 species that utilize rockweed stands as a habitat for their food at high tide. The most numerous fish that they identified were cunners, grubbies, pollock, winter flounder, Atlantic tomcod, and shorthorn sculpin. Black and Miller (1992) also collected stomach content data that indicated the fish species utilizing the intertidal zone have more food in their stomachs when *Ascophyllum nodosum* is present, rather than in its absence. Their study supports the concept that rockweed is an important provider within intertidal food webs and demonstrates that its removal may have implications at an ecosystem level. Perhaps this premise can be extended to other macrophytes that have the same functional ecology in marine habitats.

## 2.2 Reproduction in Algae

It is important to discuss the reproductive strategies of macrophytic algae because initial colonization that is necessary for remediation is dependent upon the reproductive success of either transplanted algae or algal stands along the perimeter of a clearing. The reproductive structures of *Fucus* and *Ascophyllum* are called receptacles (Bold & Wynne, 1978). Inside the receptacles are cavities called conceptacles, which contain gametangia that produce the eggs and sperm (Bold & Wynne, 1978; Pearson & Serrao, 2006). When the conceptacles release the gametangia, they sink to the bottom of the ocean and degrade their polysaccharide sheath to release the eggs and sperm (Pearson & Serrao, 2006). The temperature range for seawater to induce degradation of the egg and sperm encasement is 8-20°C (Brawley et al., 1999). Cold temperatures and low salinity inhibit the release of gametes due to the dissolution of the polysaccharide sheath (Brawley et al., 1999).

Some species of macrophytic algae are dioecious, such as *Fucus vesiculososus*, and other species are hermaphroditic, such as *Fucus spiralis* (Ladah et al., 2008). Most algae achieve colonization by releasing propagules from the parent, which are then dispersed throughout the water column (Fletcher & Callow, 1992). Algae may also successfully colonize new substrata through drift dispersal (Fletcher & Callow, 1992; Norton, 1992). Norton (1992) postulates that drifting algae may be an important process for long-distance algal colonization because floating vegetative thalli can become fertile and release propagules during transport. The most advantageous types of algae for drift dispersal are monoecious because they are capable of self-fertilization once they reach a new substrate (Norton, 1992). Furthermore, studies suggest that algal spores may colonize new areas from being transported by animals or through fecal matter **(**Buschmann & Bravo, 1990;Santelices & Paya, 1989).

## 2.3 Physical Factors Affecting Algal Colonization

The surface of the substratum is an important characteristic that may enhance or inhibit algal spore settlement. Past observations suggest that algal spores are more likely to settle on rough surfaces rather than smooth, likely due to the protection offered by small crevices **(**Ogata, 1953; den Hartog, 1959; Nienhuis, 1969;Harlin, 1974;Foster, 1975;Neushul et al., 1976; Harlin & Lindbergh, 1977;Watanuki & Yamamoto, 1990).Keser and Larson (1984) provide further evidence of algal preference for crevices from their study on algal colonization and growthin Maine. They reported that the small amount *Ascophyllum* present was growing within rock crevices and that fucoid colonization was less in areas without crevices (Keser & Larson, 1984).

Furthermore, Neushul et al.(1976)noted that the amount of algae on substrate was positively correlated with increasing surface roughness.

Substrate size and shape may also affect the amount of algae present because the size and shape of a boulder (unspecified size range) can influence how much force is required to cause a disturbance (Sousa, 1979). Sousa (1979) categorized boulders according to the newton of pull required for movement (≤ 49 N, 50-294 N, > 294 N). He examined species diversity in boulder fields and concluded that diversity is highest on boulders that are subject to intermediate disturbances. Small cobble are frequently disturbed, which means that there is usually space open for colonization. However, species that colonize small cobble often do not have enough time to grow to a substantial size before another disturbance, so diversity is low. Sousa (1979) observed that large boulders also have low diversity, which may be attributed to the fact that they are rarely overturned by waves and can become dominated by one competitive species of algae. Sousa (1979) also noted the percent of bare space on each force class of boulders. His results show that at each sampling time the percent of bare space was highest in the small class size and lowest in the large class size.

## 2.4 Environmental Factors Affecting Gamete Release and Colonization

Within the Fucaceae family of algae, morphologically and physiologically similar species reproduce at different times of the year, which demonstrates the importance of environmental coordination of reproduction (Brawley & Johnson, 1992). The following environmental cues help coordinate reproduction with favourable conditions for successful development of sporelings: salinity, temperature, light, and nutrients, (Brawley & Johnson, 1992).

### Salinity.

The ocean on the Atlantic coast of Nova Scotia overlies the Scotian Shelf. A physical characteristic of this water body is that it is comprised of three layers with different temperatures and levels of salinity. Salinity levels vary depending on depth, but the water in the Atlantic Ocean has a surface level salinity of 32%, a middle layer salinity of 32-35%, and bottom layer salinity greater than 33.5%. Salinity can be a stressor affecting the osmotic balance of intertidal rockweeds, especially during low tide when they are susceptible to changes in saline conditions through desiccation or exposure to rainwater (Chapman, 1995). In Atlantic Canada, the optimal salinity for photosynthesis is 12-34% (Chapman, 1995). Fucoid algae may be most susceptible to changes in osmotic pressure during the early stages of their life history as gametes and germlings (Wright and Reed, 1990). Wright and Reed (1990) subjected gametes and germlings to varying concentrations of artificial seawater and found that growth was suppressed in high strength solutions and stunted in diluted solutions.

### Temperature.

In addition to salinity levels, water temperature on the Atlantic coast of Nova Scotia varies. The surface layer has an average temperature of 5°C in the winter and 20°C in the summer (Stephenson & Stephenson, 1972). The middle layer, which is the coldest, has an average temperature below 5°C in both the summer and the winter. Conversely, the bottom layer has an average temperature above 5 °C during the summer and the winter. Intertidal zones can experience a wide range of temperatures varying from less than 0°C in the winter to higher than 20°C in the summer. Extreme high or low water and air temperatures can slow the growth rates of macrophytic algae, and in some instances be fatal (Chapman, 1995). Most fucoid algae in Nova Scotia reproduce during the winter so gametes, zygotes, and embryos have a degree of tolerance to cold temperatures. Bird and McLachlan (as cited in Chapman, 1995) tested the tolerance threshold of zygotes in four species of *Fucus* and discovered that zygotes exposed to freezing conditions at -15°C had complete mortality, at -10°C had variable mortality, and at -5°C and -2°C survived. A study conducted in Maine on *Ascophyllum nodosum* revealed that gamete release occurred quickly on mild sunny days and slowly on cold cloudy days (Vadas, Wright, & Miller, 1990).

### Nutrients and Light.

Nutrient availability may also be a limiting factor for development of fucoid embryos. Nitrogen, phosphorus, and iron are all important for the growth of fucoid species. Furthermore, inorganic carbon is essential for photosynthesis to occur. Macrophytic algae can obtain inorganic carbon from $CO_2$ in the atmosphere or from dissolved inorganic carbon in the ocean (Chapman, 1995). Macroalgae submerged in water have greater access to inorganic carbon than algae exposed to air (Chapman, 1995). The availability of nutrients and light can affect the distribution of macrophytic algae, depending on tolerance and adaptability of the species.

## 2.5 External Fertilization and Gamete Survival

The probability of algae achieving fertilization increases as the concentration of gametes increases because many gametes are only viable for a limited amount of time after their release (Brawley & Johnson, 1992). Factors that influence the probability of fertilization are synchrony of gamete release, the amount of gametes produced by a population, hermaphroditic individuals, and dilution or mixing of gametes by hydrodynamic forces (Brawley & Johnson, 1992; Denny & Shibata, 1989).

Synchronous gamete release can be an important process for population dynamics, including reproductive isolation, speciation, and restricted vertical distribution (Pearson &Serrao,

2006). Synchronous gamete release is triggered by the following environmental cycles: tidal, daily, seasonal, lunar and semilunar (Pearson & Serrao, 2006). There are inconsistencies amongst species and site locations as to the phase of fortnightly spawning before full moons. Thus, spawning patterns are more likely linked to tidal and daily environmental cues, rather than to lunar and semilunar cycles (Yamahira, 2004).Fucoid algae usually release gametes on a semilunar cycle during the day when light intensity is high (Pearson & Serrao, 2006). Gamete release can occur during both high and low tide events (Pearson & Serrao, 2006), but fucoid gamete release occurs predominately when the tide is low (Brawley et al., 1999). Fucoid algae benefit from synchronous spawning because it increases likelihood of recruitment and reproductive success (Pearson & Serrao, 2006).

Denny and Shibata (1989) suspect that high water motion reduces the success of external fertilization. Contrary to this belief, many researchers have concluded that fucoid algae are highly successful at external fertilization in turbulent water (Brawley, 1992; Pearson and Brawley, 1996; Serrao et al., 1996; Berndt et al., 2002; Ladah et al., 2003). Settlement of fucoid gametes occurs quickly after release because the eggs are negatively buoyant (Pearson & Serraro, 2006).

*Ascophyllum,* on the other hand, does not demonstrate high success at external fertilization, but is a long-lived perennial species that overtime outcompetes other Fucoids for space (Cousens, 1981).Vadas et al. (1990) tested the relationship between wave action and zygote survival in *Ascophyllum* and concluded that water motion reduces recruitment and survival of zygotes. Vadas et al. (1990) conducted field and laboratory experiments and noted that 85 to 99% of zygotes were removed from the substrate by the first 10 waves. Refuges, such as rock crevices and canopy, enhance the survival of *Ascophyllum* in moderate to low energy environments, but establishment of *Ascophyllum* in high-energy environments is likely due to episodic recruitment (Vadas et al., 1990). *Ascophyllum* are unlikely to grow new large patches unless synchronous recruitment is coupled with calm environmental conditions (Vadas et al., 1990). Researchers have observed that annual reproductive effort and reproductive proportion of biomass of *Ascophyllum* in exposed sites is greater than in sheltered areas, which may compensate for the inability to recruit (Cousens, 1981; Vadas et al., 1990).

Another factor that affects the growth and survival of gametes is sediment deposition. Sedimentation can hinder development of macrophytic algae by preventing the attachment of propagules to the substratum and by decreasing survival and germination success through burial of the spores (Devinny & Volse, 1978; Norton, 1978; Arakawa & Matsuike, 1992).To avoid the negative effects of sedimentation and other environmental stressors on microscopic stages of their life history, macroalgae will often reproduce through vegetative proliferation from existing structures (Chapman &Fletcher, 2002**).**

## 2.6 Disturbance and Recolonization of Macrophytic Algae

McCook and Chapman (1992) postulate that patterns of succession in macrophytic algae may be dependent on two important criteria: the severity of the disturbance and the ability of species to recover. They investigated patterns of recovery of rockweed in 50 cm x 50 cm plots after an ice-scour disturbance on an exposed rocky shore in Nova Scotia (1992). McCook and Chapman’s study analyzed secondary successional patterns in *Fucus* because some algal species remained viable after the disturbance. However, they created sterilized control plots, in which succession was primary rather than secondary because all holdfast tissue was completely removed from the substrate. Observations of *Fucus* in the control plots can indicate how recolonization is affected by the absence of holdfast tissue, further emphasizing the role of vegetative regeneration for population recovery. The results showed that most control plots had no recruitment of new algal spores and after one year the density in the control plots was substantially less than in the experimental plots, which supports the concept that vegetative regeneration may be important for rehabilitation (McCook & Chapman, 1992). The greater success of regenerating shoots over recruitment from zygotes may be because shoots are less vulnerable to environmental stressors than zygotes (McCook & Chapmam, 1992).

Recolonization of macrophytic algae is dependent on the size, shape, and location of the disturbed area, as well as the time or season that the disturbance took place (Sousa, 1985). Sousa (1985) defines patches as open spaces that result from physical disturbances and can range in size from the removal of a single species to the denudation of a large section of substrata. Different patch sizes may have different rates of colonization due to variations in the biological environment (Kim & DeWreede, 1996). For example, small-scale recruitment is dependent upon either vegetative regeneration or dispersal of gametes, so if a patch is large new recruits may not be able to reach the center of the patch (Kim & DeWreede, 1996).

Furthermore, Sousa (1985) argues that the ratio of patch perimeter to area is the leading factor influencing patch recovery. For example, small patches (definition of small patch not provided by author) can have a higher ratio of perimeter to area than large patches so the number of propagules dispersed per unit area is greater. Despite this advantage for recruitment, small patches may be negatively affected by predation and shading (Kim & DeWreede, 1996). However, colonization of algae in large patches (definition of large patch not provided by author) may also be influenced by negative factors, such as desiccation and limited dispersal distances (Sousa 1984a; Farrell, 1989).The time or season that the disturbance occurs may also affect the species composition during recovery because different species of algae release their gametes at different times of the year (Kim & DeWreede, 1996). Furthermore, tide dynamics and climate vary with the seasons (Sousa, 1985). Very few researchers have published studies about the effects of natural disturbances in rocky intertidal zones (Sousa, 1985).

Kim and DeWreede (1996) explored the effects of small-scale disturbance on algal patch recovery in a rocky intertidal community in British Columbia. In the high intertidal zone, they cleared patches of three different sizes (5 x 5, 10 x 10, and 20 x 20 cm) multiple times a year and observed the rates of recolonization by algae. Their results showed that the algae colonized the medium sized patches fastest. Kim and DeWreede believe that the negative factors described above may have stunted algae growth in the small and large plots. Their results also showed that the season-of-clearing had varying effects on recruitment across species. Species that experienced their recruitment peaks following a plot clearing achieved dominance over other species (Kim & DeWreede, 1996). One limitation of this study, when making generalizations about algal recolonization, is that the experimental patches were small and were cleared in the high intertidal zone. It is important to note that recolonization rate may vary depending on patch size, geographic location, local zonation, and algal species present (Kim & DeWreede, 1996).

## 2.7 Summary

To our knowledge there are limited published studies about colonization of macrophytic algae after a large disturbance on temperate rocky intertidal shores. The published studies that do exist are based on observations of algae colonizing relatively small cleared areas. The magnitude of the anthropogenic removal of macrophytes from Frog Island is much larger in scale than any previously published work on algal patch dynamics. By considering the influence of physical and biological factors involved in the establishment of macrophytes, this thesis contributes to the literature a better understanding of recolonization of macrophytic algae in a temperate marine rocky intertidal environment.

# Chapter 3: Method

The analysis of this remediation is based upon data collected from a five-year monitoring program. The following methods have been adapted in consultation with the authors of the Frog Island restoration reportsproduced by Thaumas Environmental Consultants Ltd. in 2007, 2008, and 2009.

## 3.1 Background

With the approval of DFO, a restoration plan was proposed and implemented by Bob Rutherford of Thaumas Environmental Consulting Ltd. and Dr. Christopher Hawkins of Triton Consultants Ltd. The purpose of the restoration plan was to reestablish pre-impact conditions in the disturbed area of Frog Island to comply with DFO fish habitat requirements. The restoration plan consisted of an initial pre-restoration survey, followed by remediation and a post-restoration five-year monitoring program.

## 3.2 Pre-Restoration Survey

A preliminary survey of the impacted rocky intertidal area was carried out by Bob Rutherford and Dr. Christopher Hawkins on September 20, 2007 to obtain baseline data and establish transects for monitoring. Monitoring involved both photographic and video sampling, which adheres to the United States Environmental Protection Agency Tier 1 protocol (2000). The Tier 1 protocol is designed to detect shore zone fish habitat loss from shore zone survey and macrophyte assessment (United States Environmental Protection Agency, 2000).  The Tier 1 assessment of macrophytes includes percent cover estimates, aerial photographs, and observations of dominant taxa (United States Environmental Protection Agency, 2000). A total of 17 transect linesfrom the rock wall to the ocean were established andspaced ca. 15 m (50 ft.)apart. Three of the transect lines were in an undisturbed control section of the beach and 14 were in the impacted site.The control section was adjacent to the impacted area of the beach **(**Figure 3). During the initial reconnaissance, a ½ $m^2$ square quadrat was used to survey each transect at ca. 1.5 m (5 ft.) intervals from the rock wall to the water line. A tapeline was used to guide the sampling of each transect (Figure 4).

*Figure 3.* A photo showing the disturbed section of the beach in comparison to the undisturbed control area (Thaumas Environmental Consultants Ltd., 2007).

*Figure 4.*A photo of the one-half meter square quadrat and tapeline that wasused for sampling (Thaumas Environmental Consultants Ltd., 2007).

## 3.3 Restoration Procedure

Restoration of the impacted beach involved two processes: importing new substrate to Frog Island and transplanting algal covered substrate from pristine areas of the beach. New substrate was transported to the island via a barge and 15 to 20 cm sized quarried rocks, large cobble, and boulders were layered over the impacted beach (Figure 5). Larger rocks were embedded in the base material to a depth 50% of their diameter and a sand gravel mix ranging from 0.2 to 2 cm in diameter was used to stabilize the substrate.

*Figure 5.* A photo showing the imported substrate (Thaumas Environmental Consultants Ltd., 2007).

Algal covered rocks were collected from undisturbed sections of the beach and embedded to a depth 50% of their diameter in the impacted site (Figure 6). A total of 96 transplant plots were established in three rows located at 25, 50, and 75% of the distance between the mean low tide and mean high tide marks.

*Figure 6.* A photo of algal covered rock transplanted to the impacted beach (Thaumas Environmental Consultants Ltd., 2007).

## 3.4 Post-Restoration Sampling

Post-restoration monitoring of algal coverage was carried out by Bob Rutherford and Dr. Christopher Hawkins annuallyfrom 2007 to 2011, following the same procedure that was used for pre-restoration sampling. Transect lengths varied each season depending on the tides, but efforts were made to maintain consistency. Photographic and video monitoring was used to obtain a complete visual representation of the transects and to record a commentary of any field observations.

## 3.5Data Analysis

The data analysis was performed by Jenny Mildon at the end of the five-year monitoring period. It included a descriptive analysis of percent algal cover and dry biomass, as well as a statistical analysis that tested the significance between variables.

### Percent Cover.

The purpose of calculating the percentage of algal coveragewas to determine the rate of algal recolonization post-remediation. Percent algal coveragewas measuredby projecting a photographic digital image for each ½ $m^2$quadrat behind a transparent grid divided into 100 small squares, with each square representing 1% coverage. All images were viewed at 640 x 480 pixels to maintain consistency of calculations.The number of small squares that had algal growth were counted to determine the percentage of algal coverage within each quadrat. Only the algae attached to the substrate by holdfasts were counted; wave thrown plants were not included in the analysis. Percent cover values had already been calculated for 2007, 2008, and 2009 by Dr. Christopher Hawkins. Those values were used in the analysis. The algal coverage data from June 2008 was not included in the statistical tests, since the site was also sampled in October 2008 and sampling occurred in the fall every other year of the monitoring period. Therefore, the June data set was considered to have a confounding effect on the statistical results. Algal coverage was compared across sampling years. Additionally, the percentage of algal coverage in the experimental area was compared to the percentage of algal coverage in the control area. Algal coverage along each transect was considered for the intertidal portion and all quadrats above the tidal zone were not included in the analysis because algae is not expected to colonize areas above the tides. Furthermore, transect A contains a section at the subtidal end that was not impacted by the disturbance. This section was included in the analysis as part of the control site and was labeled transect AC.

**Dry Biomass.**

In July and October of 2011 samples were collected by Jenny Mildon, with the assistance of Bob Rutherford and Christopher Hawkins, to measurethe dry biomass of macroalgaeinhabiting four vertical divisions of the intertidal study site.The purpose of calculating dry biomass was to determine how zonation of the intertidal area has contributed to differences in macrophyte recolonization patterns and density. Themaximum extent of seaweed growth on the substrate in the rocky intertidal study sitewas identified as the first zoneto be sampled for each transect. Using a survey level, each transect was then divided into four zones. The distance between the divisions varied for each transect, depending on the slope of the beach. The maximum extent of algae growth, which is generally characterized by the extent of the high tide, was used as the benchmark insteadof using a physical component of the beach that is always changing. For example, taking the elevation from the rock wall would be inconsistent because it is always changing due to the movement of substrate and marine debris. The maximum extent of algae was labeled as zone 3 and the subsequent three divisions as zones 2, 1, and 0, with 0 being closest to the ocean.At each location, samples were gathered from a 1/4 $m^2$ quadrat(Figure 7). Starting at line A, every second transect was sampled in the experimental section. In the control section, lines A5 and A6 were sampled.

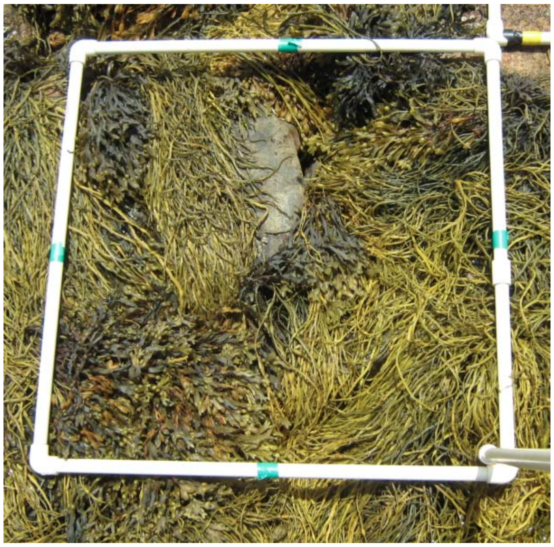

*Figure 7*. The ¼ $m^2$ quadrat that was used for gathering algal samples to calculate dry biomass.

The GPS locations were recorded at the maximum extent of algae growth for each transect(Table 1). Putty knives and industrial scissors were used to remove any plants attached to the substrate within the 1/4 $m^2$ quadrat. The samples were packed into large Ziploc® bags and labeled by combining the zone number and transect number (i.e. 3A). The samples were stored in a freezer and then dried in an industrial drying oven (Figure 8). The samples were dried at 60degrees Celsius for three consecutive days. Once the drying process was complete, silica was used as a desiccant to remove moisturewhile the dry seaweed cooled. The samples were stored in airtight containers with silica for one day.An electronicscale was used to measure the dry biomass, in grams, of each sample and the values were recorded to three decimals places.

Table 1

*The GPS Coordinates for each Transect that was Sampled for Biomass.*

| Transect | UTM Easting | UTM Northing |
|---:|---:|---:|
| A | 398845 | 4929879 |
| C | 398838 | 4929845 |
| E | 398805 | 4929833 |
| G | 398778 | 4929821 |
| I | 398747 | 4929815 |
| A1 | 398716 | 4929819 |
| A3 | 398688 | 4929826 |
| A5 | 398659 | 4929835 |
| A6 | 398657 | 4929841 |

*Figure 8.* Drying oven used to calculate dry biomass of algal samples.

**Statistical Analysis.**

For the biomass analysis, the dependent variable was algae growth. The independent variables were intertidal zonation, sampling season, and site type (i.e. control and experimental). The biomass sampling transects were divided vertically into four zones (0, 1, 2, and 3) to compare the amount of algal growth relative to tidal heights.July and October were chosen as the two sampling seasons, to compare algal growth in the summer to the fall. The control site was not altered by the anthropogenic disturbance and had intact, healthy algal plants; it was used to evaluate the progress of algalrecovery in the experimental site. The control site was coded as 1 and the experimental site was coded as 2.

For the percentage of algal coverage analysis, the dependent variable was algal growth. The independent variables were the site type, the sampling year, and the distance samples were taken along the lengthof each transect from the rock wall towards the ocean. The control section of the study site was site 1 and the impacted section was site 2. The five sampling years were 2007, 2008, 2009, 2010, and 2011.The sampling distance varied for each transect, depending on the tides.

Statistical analysis was used to investigate the significance of each of the independent variables on the dependent variable, algal growth.A standard alpha level (α = 0.01) was chosen to determine if the results were statistically significant.This significance level was chosen instead of the more commonly used alpha value, 0.05, because it is a more stringent criterion that reduces the possibility of incorrectly finding a significant difference.All statistical tests were non-parametric because the distributions were not normal and were skewed to the right, due to unequal variances and sample sizes.Descriptive statistics were calculated and then the one-sample Kolmogorov-Smirnov, Wilcoxon Rank-Sum,and Kruskal-Wallis tests were run using theR statistical program.The Kolmogorov-Smirnov test is a goodness of fit test that is used to test for normality of a distribution (Garson, 2008). It is based on the assumption of random sampling. The Wilcoxon Rank-Sum test is a non-parametric version of an independent t-test. The assumptions of the test are that the samples are a random representation of a population that do not follow a normal distribution and the variable being tested is categorical (Lund Research Ltd., 2010).The Kruskal-Wallis testis comparable to a one-way ANOVA test, except it assumes that the data is non-parametric, rather than normally distributed. It is used to comparea categorical dependent variable to an independent variable with two or more levels(Lund Research Ltd., 2010).

The annual percent change in algal coverage was determined for the control site and the experimental over the five-year monitoring program. Percent change in algal coverage was calculated by subtracting the value for the percentage of algal coverage in the previous year from the value for the percentage of algal coverage in the present year, divided by the value for the percentage of algal coverage in the previous year, multiplied by 100, and then divided by the number of years between the two values.

# Chapter 4: Results

The results are organized into two sections: percent algal coverand dry biomass. The percent cover analysis is further divided by the sampling time, to clearly illustrate the annual changes in algal distribution. The field observations described for 2007, 2008, and 2009 are a synopsis of the Frog Island reports and video commentary provided by Bob Rutherford and Dr. Christopher Hawkins.

## 4.1 Percent Algal Cover

### September 2007.

Refer to Table 2 for an overview of algal coverage from the pre-restoration sampling of Frog Island on September 20, 2007. The dashes represent quadrats that were not sampled, due to constraints by the tides. In the control transects there was zero algal coverage outside of the intertidal zone, where the tides do not reach the substrata; there was healthy growth of macrophytic algae in the intertidal area. Fewer transects were sampled in September 2007 than in other years because some restoration work had begun on transects G through J and A1 through A4. Machine and construction zone hazards prevented the sampling of these transects but did not have any algal cover (B. Rutherford, personal communication, 2011). For the statistical analysis, all transects in the impacted area were assumed to be 0, even if they were not sampled.Table 3 shows the mean percent cover of algae for each transect in September 2007. There was substantial algal coverage in the control site (M = 50, SD = 33) and the impacted site had zero algal coverage. The Wilcoxon Rank-Sum test confirmed that there was a significant difference in algal coverage between the control site (Mdn = 57) and the experimental site (Mdn = 0), $W = 2140$, $p < .01$ in September 2007.

### November 2007.

Table 5 shows the mean percent cover of algae for each transect in November 2007. The percentage of algal coverage was much greater in the control site (M = 28, SD = 31) than the experimental site (M = 2, SD = 7). The mean percent cover of algae for each of the control transects was much greater than the mean percent cover of algae in each of the experimental transects. All transects in the experimental site had less than 10% coverage. There were no quadrats sampled that had 100% coverage. The Wilcoxon Rank-Sum test confirmed that there was a significant difference in algal coverage between the control site (Mdn = 19) and the experimental site (Mdn = 0), $W = 2573$, $p< 0.01$ in November.

Refer to Table 4 for an overview of algal coverage in November 2007. There was patchy coverage in the impacted transects, which was mainly from transplanted patches and that pattern can be seen on the transects. Minor areas of storm deposited algal covered substrate were also present. Hurricane Noel hit Frog Island one day prior to the fall sampling and redistributed much of the substrate within the site, but it appears to have had no negative effect on the transplanted algal plots or the effectiveness of the rock cover placed on the beach.

Table 2

*Percent Algal Coverage in ½ $m^2$ Quadrats in the Control and Impacted Transects Sampled in September 2007*

| | Control | | Impacted | | | | | |
|---|---|---|---|---|---|---|---|---|
| Distance (ft.) | A7 | A6 | F | E | D | C | B | A |
| 5 | – | – | – | – | – | – | – | – |
| 10 | – | – | – | – | – | – | – | – |
| 15 | – | – | – | – | – | – | – | – |
| 20 | – | – | – | – | – | – | – | – |
| 25 | 0 | 0 | – | – | – | 0 | – | – |
| 30 | 0 | 0 | – | – | – | 0 | – | – |
| 35 | 0 | 52 | – | – | – | 0 | – | – |
| 40 | 68 | 57 | – | – | – | 0 | – | – |
| 45 | 88 | 63 | 0 | 0 | 0 | 0 | – | 0 |
| 50 | 48 | 83 | 0 | 0 | 0 | 0 | – | 0 |
| 55 | 80 | 37 | 0 | 0 | 0 | 0 | – | 0 |
| 60 | 78 | – | – | 0 | 0 | 0 | – | 0 |
| 65 | – | – | – | 0 | 0 | 0 | 0 | 39 |
| 70 | – | – | – | – | 0 | 0 | 0 | 97 |
| 75 | – | – | – | – | 0 | 0 | 0 | 83 |
| 80 | – | – | – | – | 0 | 0 | 0 | 59 |
| 85 | – | – | – | – | – | 0 | 0 | 84 |
| 90 | – | – | – | – | – | 0 | 0 | 39 |
| 95 | – | – | – | – | – | 0 | 0 | – |
| 100 | – | – | – | – | – | – | – | – |
| 105 | – | – | – | – | – | – | – | – |
| 110 | – | – | – | – | – | – | – | – |

Table 3

*Mean Percent Algal Coverage for September 2007*

| | Control | | | | | Experimental | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A7 | A6 | A5 | AC | Total | A4 | A3 | A2 | A1 | J | I | H | G | F | E | D | C | B | A | Total |
| Mean | 45 | 42 | – | 67 | 50 | – | – | – | – | – | – | – | – | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SD | 39 | 32 | – | 25 | 33 | – | – | – | – | – | – | – | – | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Minimum | 0 | 0 | – | 39 | 0 | – | – | – | – | – | – | – | – | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Maximum | 88 | 83 | – | 97 | 97 | – | – | – | – | – | – | – | – | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| N Valid | 8 | 7 | 0 | 6 | 24 | – | – | – | – | – | – | – | – | 3 | 5 | 8 | 15 | 7 | 4 | 107 |
| N Missing | 0 | 0 | 7 | 3 | 10 | – | – | – | – | – | – | – | – | 4 | 2 | 0 | 2 | 2 | 0 | 0 |

Table 4

*Mean Percent Algal Coverage for November 2007*

| | Control | | | | | Experimental | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A7 | A6 | A5 | AC | Total | A4 | A3 | A2 | A1 | J | I | H | G | F | E | D | C | B | A | Total |
| Mean | 27 | 44 | 19 | 24 | 28 | 0 | 0 | 3 | 3 | 1 | 0 | 0 | 0 | 8 | 0 | 4 | 2 | 4 | 0 | 2 |
| SD | 25 | 36 | 25 | 35 | 31 | 1 | 1 | 5 | 3 | 2 | 0 | 0 | 1 | 18 | 1 | 12 | 5 | 10 | 0 | 7 |
| Minimum | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Maximum | 65 | 87 | 60 | 79 | 87 | 3 | 2 | 9 | 7 | 6 | 0 | 0 | 4 | 47 | 3 | 33 | 18 | 31 | 0 | 47 |
| N Valid | 8 | 7 | 7 | 10 | 32 | 7 | 6 | 3 | 7 | 6 | 8 | 9 | 9 | 7 | 7 | 8 | 17 | 9 | 4 | 107 |
| N Missing | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table 5

*Percent Algal Coverage in ½ $m^2$ Quadrats in the Control and Impacted Transects Sampled in November 2007*

| | Control | | | Impacted | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Distance (ft.) | A7 | A6 | A5 | A4 | A3 | A2 | A1 | J | I | H | G | F | E | D | C | B | A |
| 5 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| 10 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| 15 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| 20 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| 25 | 0 | 0 | 0 | – | – | – | – | – | – | 0 | 0 | – | – | – | 0 | – | – |
| 30 | 0 | 0 | 0 | 3 | 0 | – | 0 | – | – | 0 | 0 | – | – | – | 0 | – | – |
| 35 | 8 | 25 | 0 | 0 | 0 | – | 0 | – | 0 | 0 | 0 | – | – | – | 4 | – | – |
| 40 | 18 | 71 | 0 | 0 | 0 | – | 0 | – | 0 | 0 | 0 | – | – | – | 0 | – | – |
| 45 | 26 | 56 | 33 | 0 | 0 | 9 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | – | 0 |
| 50 | 65 | 71 | 40 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | – | 0 |
| 55 | 60 | 87 | 60 | 0 | 2 | 0 | 7 | 0 | 0 | 0 | 0 | 47 | 0 | 33 | 0 | – | 0 |
| 60 | 36 | – | – | 0 | – | – | 4 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | – | 0 |
| 65 | – | – | – | – | – | – | – | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 79 |
| 70 | – | – | – | – | – | – | – | 6 | 0 | – | – | 0 | 0 | 0 | 0 | 0 | 0 |
| 75 | – | – | – | – | – | – | – | – | – | – | – | 0 | 3 | 0 | 18 | 31 | 0 |
| 80 | – | – | – | – | – | – | – | – | – | – | – | – | – | 0 | 6 | 0 | 0 |
| 85 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 0 | 0 | 0 |
| 90 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 0 | 0 | 1 |
| 95 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 0 | 0 | 0 |
| 100 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 0 | 0 | 78 |
| 105 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 0 | 5 | 20 |
| 110 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 63 |

### 2008.

Percent cover in the control site (M = 58, SD = 43) was approximately three times greater than the experimental site (M = 19, SD = 23). The Wilcoxon Rank-Sum test showed that there was a significant difference between the control site (Mdn = 70) and the experimental site (Mdn = 10), $W = 1748$, $p < 0.01$. Furthermore, there was a 19% increase in algal coverage in the experimental site between September 2007 and October 2008. Table 6 shows the mean percent coverage of algae for each transect in October 2008. Experimental transect A4 had 53% coverage, which was greaterthan control transects A7 and A6.Transect E had 41% coverage, which had equal coverage to control transect A7 and greater coverage than control transect A6. A1 had 35% coverage, which was greater than the coverage in control transect A6. Experimental transect Dhad 30% coverage, which was greater than the coverage in transect A6.

Refer to Table 7 for the percentage of algal coverage observed on June 13, 2008. The transplanted algal covered rocks were still visible but were in poor condition because wave action had redistributed the substrate. Table 8 shows that on October 24, 2008 the transplanted algal covered rocks were less apparent and more degraded than they had been during the June site visit. The June 2008 sampling showed similar results to the September 2007 sampling; no visible plant growth had occurred between site visits. However, by the fall young plants were starting to grow on boulders and in sheltered crevices (Figure 9)**.** Coverage by young plants was most predominant in areas that already had an abundance of macrophytic algae present, such as the subtidal and control sections of the beach. The distribution and density of young plants was higher than expected for this stage in the recovery process. There was no sign of the construction roadway, which had run parallel to the rock wall, and the physical components of the rocky intertidal zone had become naturalized.

Table 6

*Mean Percent Algal Coverage for October 2008*

| | Control | | | | | Experimental | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A7 | A6 | A5 | AC | Total | A4 | A3 | A2 | A1 | J | I | H | G | F | E | D | C | B | A | Total |
| Mean | 41 | 24 | 67 | 100 | 58 | 53 | 8 | – | 35 | – | 10 | 2 | 12 | 14 | 41 | 30 | 10 | 9 | 19 | 19 |
| SD | 33 | 36 | 46 | 0 | 43 | 33 | 18 | – | 37 | – | 5 | 4 | 18 | 11 | 20 | 18 | 14 | 6 | 28 | 23 |
| Minimum | 0 | 0 | 0 | 100 | 0 | 10 | 0 | – | 5 | – | 5 | 0 | 0 | 0 | 20 | 0 | 0 | 0 | 5 | 0 |
| Maximum | 70 | 95 | 100 | 100 | 100 | 85 | 40 | – | 85 | – | 15 | 10 | 50 | 30 | 70 | 50 | 50 | 15 | 60 | 90 |
| N Valid | 8 | 7 | 7 | 7 | 29 | 4 | 5 | 1 | 4 | 0 | 3 | 9 | 9 | 5 | 7 | 8 | 16 | 7 | 4 | 82 |
| N Missing | 0 | 0 | 0 | 2 | 2 | 3 | 1 | 2 | 3 | 6 | 5 | 0 | 0 | 2 | 0 | 0 | 1 | 2 | 0 | 25 |

*Figure 9.* 2008 sampling showsnoticeable young plant growth on boulder at 80 ft. in transect C.

Table 7

*Percent Algal Coverage in ½ $m^2$ Quadrats in the Control and Impacted Transects Sampled in June 2008*

| | Control | | | Impacted | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Distance (ft.) | A7 | A6 | A5 | A4 | A3 | A2 | A1 | J | I | H | G | F | E | D | C | B | A |
| 5 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| 10 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| 15 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| 20 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| 25 | 0 | 0 | 0 | – | – | – | – | – | – | 0 | 0 | – | – | – | 0 | – | – |
| 30 | 5 | 0 | 10 | 3 | 0 | – | 0 | – | – | 0 | 0 | – | – | – | 0 | – | – |
| 35 | 20 | 40 | 100 | 0 | 0 | – | 10 | – | 0 | 0 | 0 | – | – | – | 4 | – | – |
| 40 | 40 | 85 | 80 | 20 | 5 | – | 0 | – | 0 | 0 | 0 | – | – | – | 0 | – | – |
| 45 | 10 | 95 | 80 | 90 | 10 | 90 | 20 | 25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | – | 80 |
| 50 | – | – | – | – | 30 | – | – | – | – | – | 0 | 0 | 0 | 0 | 0 | – | 5 |
| 55 | – | – | – | – | – | – | – | – | – | – | – | 15 | 0 | – | 30 | – | 10 |
| 60 | – | – | – | – | – | – | – | – | – | – | – | 0 | 0 | 0 | 0 | – | 0 |
| 65 | – | – | – | – | – | – | – | – | – | – | – | 0 | 0 | 0 | 0 | 0 | 65 |
| 70 | – | – | – | – | – | – | – | – | – | – | – | 0 | 0 | 0 | 0 | 0 | 100 |
| 75 | – | – | – | – | – | – | – | – | – | – | – | 0 | – | 3 | 18 | 0 | 100 |
| 80 | – | – | – | – | – | – | – | – | – | – | – | – | – | 0 | 6 | 0 | 100 |
| 85 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 0 | 0 | 100 |
| 90 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 0 | 0 | 100 |
| 95 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 0 | 0 | 100 |
| 100 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 5 | 100 |
| 105 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 0 | 100 |
| 110 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |

Table 8

*Percent Algal Coverage in ½ m² Quadrats in the Control and Impacted Transects Sampled in October 2008*

| | Control | | | Impacted | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Distance (ft.) | A7 | A6 | A5 | A4 | A3 | A2 | A1 | J | I | H | G | F | E | D | C | B | A |
| 5 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| 10 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| 15 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| 20 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| 25 | 0 | 0 | 0 | – | – | – | – | – | – | 0 | 0 | – | – | – | 0 | – | – |
| 30 | 0 | 0 | 0 | 45 | 0 | – | 5 | – | – | 0 | 0 | – | – | – | 0 | – | – |
| 35 | 5 | 5 | 95 | 85 | 0 | – | 10 | – | 10 | 0 | 0 | – | – | – | 4 | – | – |
| 40 | 55 | 10 | 80 | 10 | 0 | – | 85 | – | 5 | 0 | 0 | – | – | – | 0 | – | – |
| 45 | 60 | 10 | 95 | 70 | 0 | 90 | 40 | – | 15 | 0 | 0 | 0 | 20 | 0 | 10 | – | 5 |
| 50 | 70 | 50 | 100 | – | 40 | – | – | – | – | 0 | 50 | 30 | 20 | 18 | 0 | – | 5 |
| 55 | 70 | 95 | 100 | – | – | – | – | – | – | 0 | 15 | 10 | 70 | 20 | 0 | – | 60 |
| 60 | 70 | – | – | – | – | – | – | – | – | 5 | 10 | 10 | 50 | 20 | 15 | – | 5 |
| 65 | – | – | – | – | – | – | – | – | – | 10 | 30 | 20 | 40 | 50 | 0 | 0 | 100 |
| 70 | – | – | – | – | – | – | – | – | – | – | – | – | 30 | 50 | 2 | 15 | 100 |
| 75 | – | – | – | – | – | – | – | – | – | – | – | – | 60 | 40 | 3 | 15 | 100 |
| 80 | – | – | – | – | – | – | – | – | – | – | – | – | – | 40 | 50 | 15 | 100 |
| 85 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 30 | 10 | 100 |
| 90 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 10 | 5 | 100 |
| 95 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 20 | 5 | 100 |
| 100 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 20 | – | – |
| 105 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| 110 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |

### 2009.

A visual evaluation of Frog Island, with no formal sampling, on May 30, 2009 revealed that there had been no noticeable change in plant growth from the fall 2008 sampling. Furthermore, the winter weather had caused negligible damage to the existing plants.The transplanted algal covered rock could not be located, despite using a GPS. There was a correlation between the distribution and density of young plant growth and the distance from non-impacted areas; however, there was no correlation between new growth and transplanted areas. There were young plants growing on rocks near the shore. Young plants that had established themselves on boulders and in crevices in 2008 had grown approximately 4 to 6 inches in frond length by 2009 (Figure 10). Arthropods, periwinkles, and barnacles were also observed on the rocks (Figure 11).

*Figure 10.* 2009 sampling shows impressive growth of new plants on boulder at 80 ft. in transect C (Thaumas Environmental Consultants, 2009).

*Figure 11.* The photo shows the presence of barnacles and periwinkles on the substrate. Rutherford, B. (2009) *Frog Island* [Video].

Refer to Table 9 for an overview of algal coverage from the fall 2009 sampling year. A storm hit Frog Island prior to sampling on October 29th, 2009 and there was cobble and gravel build up along the bottom of the rock wall. The bank was highly eroded at line J. There was only the top row of boulders showing along the wall at line F, as the cobble and gravel half buried the boulder walland there was roughly a 30° slope from 0 to 10 feet. Again, at line E, the rock wall was only showing the top boulder and the cobble and gravel had created a 45° slope from the 0 to 8 foot mark. In addition to changes in the gradient of the beach, there was also a shift in species present at line A5; there was more *Ascophyllum* in the control zone and more *Fucus* in the experimental zone.In lines A7 to A3 there was healthy and dense macrophytic algae at the subtidal end of the transects. Conversely, there was not a lot of growth in the water from line A2 to H. In transect G there was some growth in the water and in transects F to A there was once again dense growth in the water. In transect A, algal growth in the water extended across the bay to the shore on the other end of the island.

Table 9

*Percent Algal Coverage in ½ $m^2$ Quadrats in the Control and Impacted Transects Sampled in 2009*

| | Control | | | Impacted | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Distance (ft.) | A7 | A6 | A5 | A4 | A3 | A2 | A1 | J | I | H | G | F | E | D | C | B | A |
| 5 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| 10 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| 15 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| 20 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| 25 | 0 | 15 | 5 | – | – | – | – | – | – | 0 | 0 | – | – | – | 0 | – | – |
| 30 | 10 | 20 | 60 | 3 | 5 | – | 0 | – | – | 0 | 20 | – | – | – | 0 | – | – |
| 35 | 10 | 55 | 100 | 5 | 40 | – | 20 | – | 20 | 0 | 5 | – | – | – | 4 | – | – |
| 40 | 100 | 100 | 100 | 40 | 70 | – | 10 | – | 15 | 10 | 5 | – | – | – | 0 | – | – |
| 45 | 70 | 100 | 100 | 50 | 70 | 40 | 20 | 20 | 40 | 15 | 40 | 20 | 80 | 0 | 60 | – | 80 |
| 50 | 70 | 100 | – | – | 70 | 10 | – | – | – | – | 15 | 80 | 100 | 30 | 80 | – | 60 |
| 55 | – | – | – | – | – | – | – | – | – | – | 10 | 70 | 100 | 100 | 90 | – | 50 |
| 60 | – | – | – | – | – | – | – | – | – | – | – | – | 100 | 100 | 97 | – | 50 |
| 65 | – | – | – | – | – | – | – | – | – | – | – | – | 100 | 100 | 80 | 10 | 100 |
| 70 | – | – | – | – | – | – | – | – | – | – | – | – | 100 | 100 | 100 | 15 | 95 |
| 75 | – | – | – | – | – | – | – | – | – | – | – | – | 100 | – | 100 | 15 | 100 |
| 80 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 100 | 80 | 100 |
| 85 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 100 | 90 | 100 |
| 90 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 100 | 100 |
| 95 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 100 | 100 |
| 100 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 100 | 100 |
| 105 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 100 | 100 |
| 110 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |

Table 10 shows the mean percentage of algae for each transect. Average algal coverage in the experimental transects (M = 49, SD = 40) was much less than average algal coverage in the control transects (M = 73, SD = 38). It was determined, by using the Wilcoxon Rank-Sum test, that the difference between the control site (Mdn = 100) and the experimental site (Mdn = 40) is statistically significant, $W = 1286$, $p = 0.006$. Mean algal coverage in the experimental site was more than twice the observed amount from 2008, which was 19%. Transects A to F had considerably more coverage in this sampling year than in 2007 and 2008; coverage was 100% in the subtidal zone of these transects. Transect E (97%) had mean percent covergreater than control transect A7 (43%), A6 (65%), and A5 (73%). Experimental transects D (72%) and B (68%) had greater average coverage than transects A7 and A6. The mean percent cover was also higher in experimental transects A3 (51%), F (57%), C (62%), and A (60%) than in control transects A7 and A6. However, average coverage in transect A4 and G to A2 was less than 25%, with maximum coverage in each transect less than 50%.

### 2010.

There was roughly a 30% increase in mean percent coverage from 2009 to 2010 in the experimental site, from 49% to 62%. However, there was an 11% decrease in mean algal coverage in the control site from 73% to 65%. The Wilcoxon Rank-Sum test showed that the difference in percent cover between the control site (Mdn = 70) and the experimental site (Mdn = 76) is not statistically significant, $W= 1475$, p = .89. Table 11 shows, that generally, the mean percentage of algal coverage in the control transects was similar to algal coverage in the experimental transects. Table 12 shows that algae was present in all quadrats sampled in the experimental site, with the exception of transect C.Transect A has much less coverage than in the previous year.

Table 10

*Mean Percent Algal Coverage for October 2009*

| | Control | | | | | Experimental | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A7 | A6 | A5 | AC | Total | A4 | A3 | A2 | A1 | J | I | H | G | F | E | D | C | B | A | Total |
| Mean | 43 | 65 | 73 | 99 | 73 | 25 | 51 | 25 | 13 | – | 25 | 5 | 14 | 57 | 97 | 72 | 62 | 68 | 60 | 49 |
| SD | 42 | 41 | 42 | 2 | 38 | 24 | 29 | 21 | 10 | – | 13 | 7 | 13 | 32 | 8 | 45 | 44 | 41 | 14 | 40 |
| Minimum | 0 | 15 | 5 | 95 | 0 | 3 | 5 | 10 | 0 | – | 15 | 0 | 0 | 20 | 80 | 0 | 0 | 10 | 50 | 0 |
| Maximum | 100 | 100 | 100 | 100 | 100 | 50 | 70 | 40 | 20 | – | 40 | 15 | 40 | 80 | 100 | 100 | 100 | 100 | 80 | 100 |
| N Valid | 6 | 6 | 5 | 9 | 26 | 4 | 5 | 2 | 4 | 1 | 3 | 5 | 7 | 3 | 7 | 6 | 13 | 9 | 4 | 73 |
| N Missing | 2 | 1 | 2 | 0 | 5 | 3 | 1 | 1 | 3 | 5 | 5 | 4 | 2 | 4 | 0 | 2 | 4 | 0 | 0 | 34 |

Table 11

*Mean Percent Algal Coverage for October 2010*

| | Control | | | | | Experimental | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A7 | A6 | A5 | AC | Total | A4 | A3 | A2 | A1 | J | I | H | G | F | E | D | C | B | A | Total |
| Mean | 48 | 69 | 84 | 61 | 65 | 61 | 59 | 67 | 51 | 61 | 49 | 47 | 48 | 81 | 88 | 75 | 60 | 72 | 45 | 62 |
| SD | 37 | 29 | 20 | 29 | 31 | 37 | 39 | 51 | 35 | 45 | 37 | 41 | 30 | 22 | 13 | 33 | 45 | 28 | 26 | 36 |
| Minimum | 0 | 25 | 51 | 17 | 0 | 15 | 3 | 9 | 8 | 2 | 8 | 5 | 16 | 40 | 67 | 13 | 0 | 30 | 22 | 0 |
| Maximum | 97 | 98 | 100 | 100 | 100 | 100 | 96 | 98 | 100 | 100 | 99 | 100 | 90 | 99 | 100 | 100 | 100 | 100 | 68 | 100 |
| N Valid | 8 | 7 | 7 | 7 | 29 | 7 | 6 | 3 | 7 | 4 | 6 | 8 | 9 | 6 | 7 | 8 | 16 | 9 | 4 | 100 |
| N Missing | 0 | 0 | 0 | 2 | 3 | 0 | 0 | 0 | 0 | 2 | 2 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 7 |

Table 12

*Percent Algal Coverage in ½ $m^2$ Quadrats in the Control and Impacted Transects Sampled in 2010*

| | Control | | | Impacted | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Distance (ft) | A7 | A6 | A5 | A4 | A3 | A2 | A1 | J | I | H | G | F | E | D | C | B | A |
| 5 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| 10 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| 15 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| 20 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| 25 | 0 | 25 | 51 | – | – | – | – | – | – | 31 | 23 | – | – | – | 0 | – | – |
| 30 | 11 | 32 | 88 | 15 | 3 | – | 8 | – | – | 5 | 25 | – | – | – | 0 | – | – |
| 35 | 55 | 65 | 96 | 26 | 93 | – | 28 | – | 15 | 6 | 30 | – | – | – | 0 | – | – |
| 40 | 19 | 94 | 100 | 29 | 96 | – | 22 | – | 8 | 27 | 16 | – | – | – | 0 | – | – |
| 45 | 89 | 87 | 97 | 70 | 85 | 9 | 46 | 2 | 67 | 23 | 25 | 40 | 67 | 13 | 13 | – | 23 |
| 50 | 74 | 79 | 61 | 100 | 46 | 95 | 60 | 52 | 81 | 97 | 80 | 97 | 83 | 34 | 12 | – | 22 |
| 55 | 40 | 98 | 96 | 85 | 28 | 98 | 92 | 91 | 21 | 88 | 56 | 80 | 94 | 95 | 95 | – | 66 |
| 60 | 97 | – | – | 100 | – | – | 100 | 100 | 99 | 100 | 86 | 99 | 100 | 96 | 88 | – | 68 |
| 65 | – | – | – | – | – | – | – | – | – | – | 90 | 91 | 76 | 98 | 100 | 30 | 66 |
| 70 | – | – | – | – | – | – | – | – | – | – | – | 80 | 93 | 76 | 96 | 30 | 90 |
| 75 | – | – | – | – | – | – | – | – | – | – | – | – | 100 | 100 | 98 | 57 | 70 |
| 80 | – | – | – | – | – | – | – | – | – | – | – | – | – | 87 | 97 | 97 | 100 |
| 85 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 69 | 72 | 38 |
| 90 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 98 | 88 | 46 |
| 95 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 98 | 100 | 17 |
| 100 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 95 | 98 | – |
| 105 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 75 | – |
| 110 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |

### 2011.

Table 13 shows the percentage of algal coverage in the impacted transects andin the control transects. The presence of algae in the impacted site is now only 17% less than in the control site. There was no substantial increase in mean percent cover in the experimental site from 2010 (62%) to 2011 (69%).However, mean percent cover in the control site increased from 65% in 2010 to 83% in 2011. It was statistically shown, using the Wilcoxon Rank-Sum test, that the difference between algal coverage in the control site (Mdn = 100) and in the experimental site (Mdn = 91) is not significant, $W = 1734$,$p = .012$.

All of the transects had at least one quadrat with 100% algal coverage (Table 14).There was 100% coverage in the control section of transect A, which was a dramatic increase from 2010. All of the experimental transects had average algal coverage equal to or greater than control transects A7 (71%), A6 (82%), and A5 (77%), with the exception of transects A2 (67%), A1 (43%), H (41%), G (51%), and C (55%). Transect A was partially covered with grass from the adjacent salt marsh, which was not included in the analysis because it is not a macrophytic algal species. Data was not collected for line I, due to an error with the video camera.

Storms and wave action have naturally sorted the boulders and cobble that were used to restore the impacted beach in 2007 and sediment deposition has created different gradients across the beach within the study site. There is an obvious change in sediment build up between lines A7 to A4 and lines A3 to A. The rock wall, which was initially showing two boulders high, was still two boulders high in the control area from transects A7 to A4 (Figure 12), but was only showing one boulder high in the experimental area from transects A3 to A (Figure 13).

Table 13

*Mean Percent Algal Coverage for October 2011*

| | Control | | | | | Experimental | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A7 | A6 | A5 | AC | Total | A4 | A3 | A2 | A1 | J | I | H | G | F | E | D | C | B | A | Total |
| Mean | 71 | 82 | 77 | 100 | 83 | 78 | 83 | 67 | 43 | 86 | – | 41 | 51 | 85 | 78 | 90 | 55 | 85 | 83 | 69 |
| SD | 38 | 22 | 41 | 0 | 30 | 36 | 30 | 43 | 38 | 21 | – | 41 | 37 | 22 | 30 | 23 | 45 | 31 | 34 | 37 |
| Minimum | 10 | 48 | 3 | 100 | 3 | 5 | 23 | 19 | 5 | 62 | – | 6 | 6 | 56 | 30 | 34 | 0 | 9 | 33 | 0 |
| Maximum | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | – | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| N Valid | 8 | 7 | 7 | 8 | 30 | 6 | 6 | 3 | 6 | 3 | 0 | 7 | 7 | 6 | 7 | 8 | 16 | 9 | 4 | 88 |
| N Missing | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 3 | 8 | 2 | 2 | 1 | 0 | 0 | 1 | 0 | 0 | 19 |

*Figure 12.* View of rock wall from line E looking towards line F.

*Figure 13.* View from line A6 of the rock wall that is two boulders high.

Table 14

*Percent Algal Coverage in ½ m$^2$ Quadrats in the Control and Impacted Transects Sampled in 2011*

| | Control | | | Impacted | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Distance (ft.) | A7 | A6 | A5 | A4 | A3 | A2 | A1 | J | I | H | G | F | E | D | C | B | A |
| 5 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| 10 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| 15 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| 20 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| 25 | 10 | 48 | 3 | – | – | – | – | – | – | 7 | 24 | – | – | – | 0 | – | – |
| 30 | 48 | 59 | 35 | 5 | 23 | – | 11 | – | – | 8 | 6 | – | – | – | 0 | – | – |
| 35 | 95 | 76 | 100 | 91 | 94 | – | 18 | – | – | 6 | 27 | – | – | – | 0 | – | – |
| 40 | 23 | 100 | 100 | 86 | 89 | – | 5 | – | – | 21 | 42 | – | – | – | 0 | – | – |
| 45 | 100 | 97 | 100 | 88 | 100 | 19 | 54 | 62 | – | 59 | 57 | 59 | 41 | 34 | 0 | – | 33 |
| 50 | 100 | 97 | 100 | 100 | 91 | 82 | 67 | 95 | – | 89 | 100 | 56 | 30 | 94 | 26 | – | 100 |
| 55 | 91 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | – | 100 | 100 | 98 | 91 | 97 | 45 | – | 100 |
| 60 | 100 | – | – | – | – | – | – | – | – | – | – | 99 | 99 | 100 | 28 | – | 100 |
| 65 | – | – | – | – | – | – | – | – | – | – | – | 100 | 99 | 100 | 84 | 9 | 100 |
| 70 | – | – | – | – | – | – | – | – | – | – | – | 100 | 88 | 91 | 97 | 63 | 100 |
| 75 | – | – | – | – | – | – | – | – | – | – | – | – | 100 | 100 | 100 | 99 | 100 |
| 80 | – | – | – | – | – | – | – | – | – | – | – | – | – | 100 | 99 | 97 | 100 |
| 85 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 95 | 100 | 100 |
| 90 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 99 | 97 | 100 |
| 95 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 100 | 100 | 100 |
| 100 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 99 | 100 | 100 |
| 105 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 100 | – |
| 110 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |

**2007-2011.**

Algal coverage increased each year in the control site and the experimental site (Figure 14). The mean percentage of algal coverage in the control site was 50% in 2007 and 83% in 2011. The mean percentage of algal coverage in the experimental site was 0% in September 2007 after the disturbance had occurred and 69% in 2011 after restoration and the five-year monitoring program were complete.

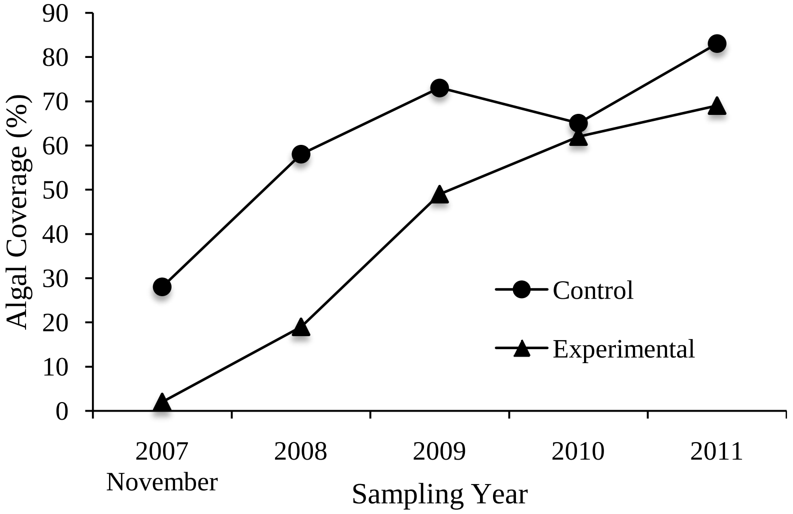

*Figure 14.*The percentage of algal coverage increased over the five year sampling period in both the control site and the experimental site.

Time also had a significant effect on percentage of algal coverage. The Kruskal-Wallis test was used to show that there was a significant difference in algal coverage across sampling years in the control site $c^2$ (5, N = 167) = 46.13, p < .01. Additionally, there was a significant difference across sampling years in the experimental site $c^2$ (5, N = 558) = 364.17, p < .01. Overall, there was a significant difference in percentage of algal coverage over time in the control and experimental sites combined $c^2$ (5, N =725) = 366.02, p < .01.

The rate of change each year for percentage of algae cover is shown in Figure 15. The rate of change in algal coverage was much higher in the impacted section of the beach than in the undisturbed area. There was an average rate of increase of 38% in the control site and 262% in the experimental site (Table 15). In the experimental site, algal coverage increased at a rate of 850% from 2007 to 2008 and declined in subsequent years. From 2010 to 2011, the rate of change in algal coverage in the impacted site was only 11%. Interestingly, algal coverage declined by 11% in the control site from 2009 to 2010.

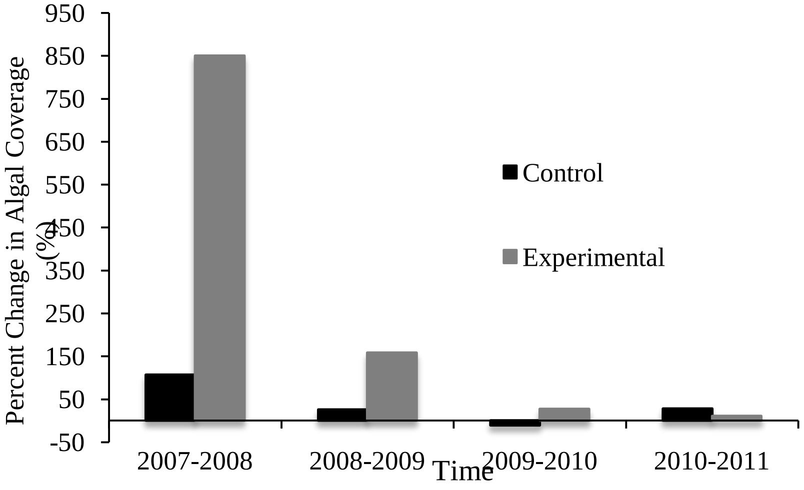

*Figure 15.* Percent change in the percentage of algal coverage over the five-year monitoring period.

Table 15

*Post Restoration Percent Change in Percentage of Algal Coverage*

| | Control | Experimental |
|---|---|---|
| 2007-2008 | 107 | 850 |
| 2008-2009 | 26 | 158 |
| 2009-2010 | -11 | 27 |
| 2010-2011 | 28 | 11 |
| 2007-2011 | 39 | 670 |
| Average | 38 | 262 |

## 4.2 Dry Biomass

It was determined, through statistical analysis using the one-sample Kolmogorov-Smirnov test, that there was a significant difference among all the dry biomass values (Mdn =157.895 g/0.25 $m^2$) in all of the sampling transects, *z* = -2.53, *p*< .01. Further analysis with the Wilcoxon-Mann-Whitney test was used to compare the dry biomass values of the control group (Mdn = 609.683 g/0.25 $m^2$, M = 605.844 g/0.25 $m^2$, SD = 519.663)with the experimental group (Mdn = 131.198 g/0.25 $m^2$, M= 223.521 g/0.25 $m^2$, SD = 297.590), for July and October combined, which showed that there was a significant difference between the control and experimental areas, *z* = -2.807, *p* = .005.

In the control transects and in the experimental transects, the mean biomass of macroalgae was greater in October than in July (Table 16, Figure 16).Furthermore, Table 17 shows that in July and in October mean biomass was highest in zone 0 and lowest in zone 3. The Wilcoxon-Mann-Whitney analysis was used to investigate the effect of season on the differences in biomass values. It was determined that there is a significant difference between July (Mdn = 54.720 g/0.25 $m^2$) and October (Mdn = 335.379 g/0.25 $m^2$) biomass values,*z* =  -3.03, *p* = .002.

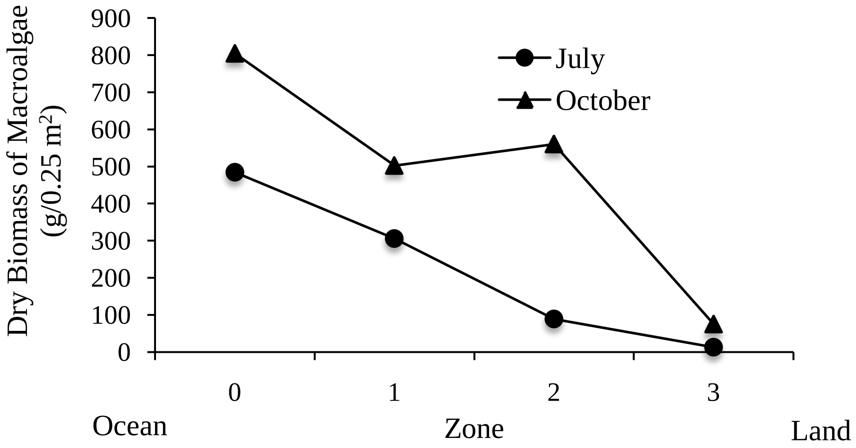

*Figure 16.* A comparison of July and October algal dry biomass in four different zones of the rocky intertidal beach.

Table 16

*Mean Dry Biomass (g/0.25 m$^2$) of Macroalgae Collected in the Control and Experimental Sites in Each Sampling Season*

| | Control | | | Experimental | | |
|---|---|---|---|---|---|---|
| Sampling Time | Mean (SD) | N Valid | N Missing | Mean (SD) | N Valid | N Missing |
| July | 499.188 (540.335) | 8 | 0 | 139.221(239.411) | 29 | 0 |
| October | 712.500 (510.602) | 8 | 0 | 359.339 (337.004) | 18 | 11 |

Table 17

*Total Mean Dry Biomass (g/0.25 m$^2$) Across Four Vertical Zones For the Control and Experimental Sites Combined in July and October*

| | July | | | | October | | | |
|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 0 | 1 | 2 | 3 |
| Mean | 484.045 | 305.353 | 88.975 | 12.554 | 804.404 | 502.701 | 559.828 | 75.044 |
| SD | 422.479 | 444.9 | 145.631 | 16.569 | 422.12 | 344.473 | 477.214 | 78.631 |
| Maximum | 1130.05 | 1421.78 | 420.79 | 54.72 | 1339.21 | 1109.65 | 1551.79 | 189.85 |
| N | 9 | 9 | 9 | 10 | 4 | 8 | 8 | 6 |

An analysis of the July and October sampling months combined shows that there was a general trend that the total mean biomass of macroalgae was greatest closest to the ocean, in zone 0, and decreased towards the high tide mark of the rocky intertidal beach (Figure 17).

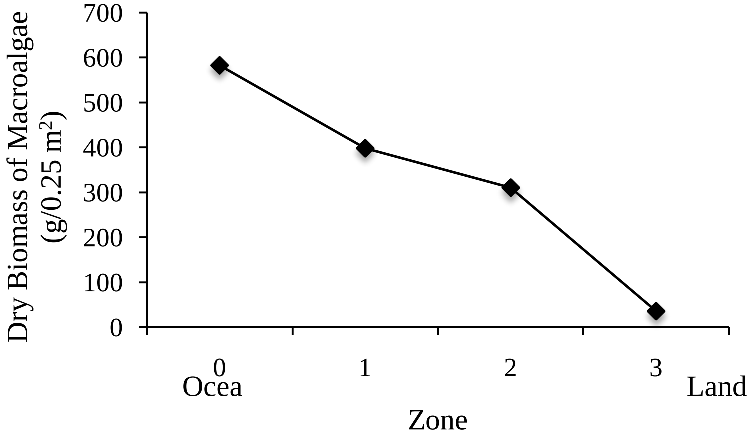

*Figure 17.* Total mean biomass of macroalgae in each zone for the control transects and experimental sites from July and October combined.

The exception to this trend is that the mean biomass of algae in the control area was greatest in zone 1, rather than in zone 0 (Table 18). The experimental area had a steady decrease in algal biomass away from the subtidal zone towards the high tide mark (Figure 18).

Table 18

*Comparison of Mean Dry Biomass (g/0.25 m$^2$) of Macroalgae in the Control and Experimental Sites in Four Vertical Zones of the Rocky Intertidal Beach*

| | Control | | | Experimental | | |
|---|---|---|---|---|---|---|
| Zone | Mean (SD) | N Valid | N Missing | Mean (SD) | N Valid | N Missing |
| 0 | 747.630 (324.937) | 4 | 0 | 509.278 (470.717) | 9 | 5 |
| 1 | 985.389 (389.019) | 4 | 0 | 217.556 (163.728) | 13 | 1 |
| 2 | 635.922 (680.519) | 4 | 0 | 210.439 (251.612) | 13 | 1 |
| 3 | 54.434 (68.824) | 4 | 0 | 29.839 (53.940) | 12 | 4 |

An analysis of July alone revealed that the samples followed the same trend as July and October combined (Figure 19). Table 19 contains mean biomass values for each of the control transects in July. Table 20 contains mean biomass values for each of the experimental transects in July.

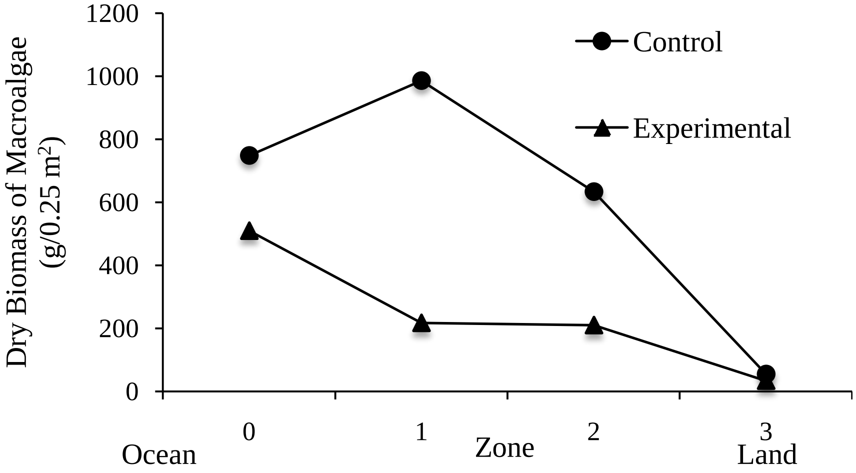

*Figure 18.* Comparison of algal dry biomass in the control and experimental sites across four vertical zones for July and October combined.

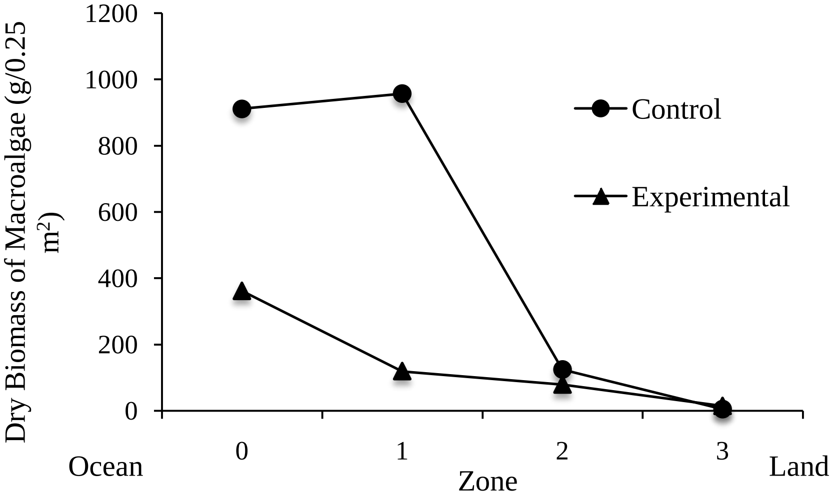

*Figure 19.*The dry biomass of macroalgae samples collected from four zones in the control and experimental sites in July 2011.

Table 19

*Dry Biomass (g/0.25 m$^2$) of Macroalgae Samples Collected in the Control Transects in July 2011*

| Zone | A5 | A6 | Mean (SD) | N |
|---:|---:|---:|---:|---:|
| 0 | 727.573 | 1094.463 | 911.018 (259.430) | 2 |
| 1 | 1421.775 | 491.792 | 956.783 (657.598) | 2 |
| 2 | 212.974 | 35.817 | 124.395 (125.269) | 2 |
| 3 | 9.106 | 0 | 4.553 (6.439) | 2 |

Table 20

*Dry Biomass (g/0.25 m$^2$) of Macroalgae Samples Collected in the Experimental Transects in July 2011*

| Zone | A3 | A1 | I | G | E | C | A | Mean (SD) | N |
|---:|---:|---:|---:|---:|---:|---:|---:|---:|---:|
| 0 | 592.829 | 218.465 | 0 | 141.285 | 151.006 | 300.732 | 1130.052 | 362.053 (385.534) | 7 |
| 1 | 120.682 | 261.623 | 0 | 0 | 210.732 | 157.895 | 83.682 | 119.231 (99.867) | 7 |
| 2 | 0 | 0 | 0 | 0 | 0 | 420.785 | 131.198 | 78.855 (158.507) | 7 |
| 3 | 26.660 | 8.014 | 5.078 | 7.700 | 0 | 54.720 | 5.180 | 14.554 (18.005) | 7 |

The Kruskal-Wallis test was used to determine the variability of biomass values in the four different tidal zones of the control and experimental transects combined. There was a statistically significant difference among tidal zone 0 (Mdn = 592.829 g/0.25 $m^2$), zone 1 (Mdn = 272.667 g/0.25 $m^2$), zone 2 (Mdn = 212.974 g/0.25 $m^2$), and zone 3 (Mdn = 8.546 g/0.25 $m^2$) for biomass readings, $c^2(3, N = 63) = 17.821, p < .01$.

An analysis of October alone revealed that there was not a steady decrease in biomass from the subtidal area towards the high intertidal (Figure 20). Mean biomass in the control group was greatest in zone 2, and was greater in zones 1 and 2 than in zone 0 (Table 21). In the experimental group, biomass decreased from the low intertidal towards the high intertidal area, with the exception of zones 1 and 2, which were almost equal (Table 22). Zone 2 had a mean biomass that was 31.685 g/0.25 $m^2$ greater than zone 1. The maximum biomass value, 1551.792 g/0.25 $m^2$, was collected from zone 2 of control transect A5 in October.

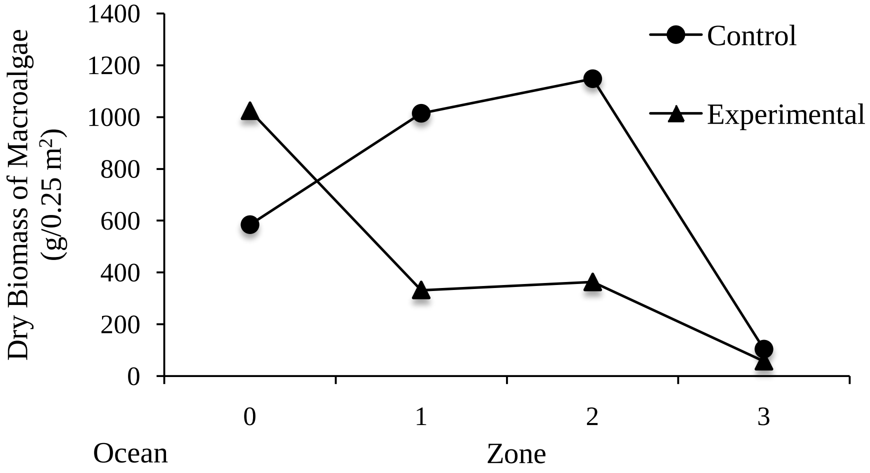

*Figure 20.* The dry biomass of algae samples collected in October 2011.

Table 21

*Dry Biomass (g/0.25 m$^2$) of Macroalgae Samples Collected in the Control Transects in October 2011*

| Zone | A5 | A6 | Mean (SD) | N |
|---:|---:|---:|---:|---:|
| 0 | 317.16 | 851.324 | 584.242 (377.711) | 2 |
| 1 | 1109.649 | 918.339 | 1013.994 (135.277) | 2 |
| 2 | 1551.792 | 743.105 | 1147.449 (571.828) | 2 |
| 3 | 58.402 | 150.229 | 104.316 (64.931) | 2 |

Table 22

*Dry Biomass (g/0.25 m$^2$) of Macroalgae Samples Collected in the Experimental Transects in October 2011*

| Zone | A3 | A1 | I | G | E | C | A | Mean (SD) | N |
|---:|---:|---:|---:|---:|---:|---:|---:|---:|---:|
| 0 | 1339.213 | 709.919 | – | – | – | – | – | 1024.566 (444.978) | 2 |
| 1 | 296.987 | 580.046 | 116.435 | 272.667 | 348.665 | 378.817 | – | 332.270 (151.796) | 6 |
| 2 | 372.786 | 359.096 | 322.092 | 0 | 308.658 | 821.096 | – | 363.955 (263.193) | 6 |
| 3 | 51.783 | 0 | 0 | 0 | 189.850 | 103.231 | – | 57.477 (76.889) | 6 |

# Chapter 5: Discussion

The results show a progressive and healthy reestablishment of macrophytic algae to the impacted rocky intertidal section of Frog Island over the course of the five-year monitoring program. Over the five-year periodit had been observed that algal species such as *Fucus* and *Ascophyllum* recolonizing the impacted site. In the impacted zone, the rate ofincrease of algalcoverage was high at the beginning of the study, but overtime it gradually decreased. Algae colonized the impacted site fast and likely because there was a large area for young plants to establish themselves, without having to compete with other plants for space.

At the end of the five-year monitoring period, dry biomass and percentage of algal coverage were still less in the experimental site than in the control site. Statistically, there was a significant difference in the medians of algal coverage between the control and experimental group at the onset of the study in 2007, which was expected since pre-existing algal species and the substrata on which they grow had been completely removed from the impacted beach by the anthropogenic disturbance. There was also a significant difference between the control and experimental sites in 2008 and 2009. There was no significant difference between the control and experimental sites in 2010 and 2011. It is important to consider the descriptive statistics by comparing mean values, which give a better representation of the results than the medians of data sets with high variance. A comparison of the mean values supports the results from the statistical analysis. For example, in 2008 there was a substantial difference between the means of the two sites because algal coverage in the experimental site was only one third that of the control site. In 2009 mean algal coverage in the experimental site had increased by more than 50% from the previous year. However, mean algal coverage in the experimental site was only 67% that of the control site, which indicates that algae was still in the process of recolonizing the impacted site because a notable difference in coverage still existed between the two sites. In 2010 there was only a 3% difference between algal coverage in the control site and in the experimental site, which suggests that the impacted site had successfully reached pre-impact conditions. In 2011 the14% difference between the control site and the experimental site was greater than the 3% difference observed in 2010.However, mean algal coverage in the experimental site was 84% that of the control site, which supports the claim that after five years algae had successfully recolonized the experimental site to a healthy level for supplying habitat to intertidal species.

Statistical analysessupport the hypotheses that there is significant difference in dry biomass between the sampling seasons, betweenthe control site and the experimental site, and across vertical zones (0, 1, 2, and 3). Overall, there was a significant difference amoung all biomass samples collected from all the quadrats sampled in July and October combined. The results from this study concur with Sousa’s (1985) findings that recolonization of macroalgae is dependent on time, season, and location. Intertidal vertical zonation, which was distinguished by zone number for biomass sampling and by distance for percent cover, was an important variable affecting algal recolonization. Sousa speculated that colonization of algae in a large disturbed area is affected by desiccation and limited dispersal distance. It is likely that desiccation and dispersal distance limited the rate of algal colonization from the low intertidal to the mid intertidal zone in the disturbed section of Frog Island because there was high variability in vertical distribution of macroalgae.

Biomass was greatest in the low intertidal zone and decreased towards the high intertidal zone. Moreover, the first area to be colonized by new plants in all of the transects was the low intertidal zone; subsequent growth proceeded into the mid intertidal zone over time. These trends are largely due to increased submergence time in the low intertidal zone, which increases the amount of time for eggs and sperm to disperse and settle on the substratum (Fletcher & Callow, 1992; Norton, 1992). Increased submergence time also increases the availability of nutrients that are important for development, such as inorganic carbon, which is more abundant in the water than in the air (Chapman, 1995). Another explanation as to why new plants first colonized the low intertidal zone is that Fucoid algae perform synchronous spawning to increase the likelihood of reproductive success (Pearson & Serrao, 2006). This mode of spawning can take place during high tide events, but it occurs primarily during low tides.

The majority of the transplanted algal covered rocks were still in place after Hurricane Noel hit Nova Scotia in 2007, which shows that the method for transplanting was successful. However, due to the failure to locate the transplanted algal covered rock during the 2009 site visit the value of this method in unclear at this time. Nevertheless, initial growth of algae was observed to occur near areas dense in healthy algae populations. This observation is not surprising, since most macrophytic algae species colonize new substratum by propagule release from parent plants and vegetative regeneration (Fletcher & Callow, 1992). McCook and Chapman (1992) postulated that vegetative regeneration is more important for algal colonization than recruitment from zygotes. Transect A4, located adjacent to the control site, and transect A, located at the perimeter of the impacted site, established considerable algal coverage early on in the monitoring program because they were near healthy parent plants. It is also likely that the impact from the anthropogenic disturbance was less in these two transects because they are located on the perimeter of the experimental site. The degree of impact from the removal of boulders and cobble from the intertidal zone was dependent on the extent of the tides on the day of the disturbance, which may explain why transect A had 100% cover from 70 to 105 ft. along the sampling line in June 2008.

There was a difference between biomass values in the experimental site and the control site. Algal biomass was less in the experimental site, which is likely because the plants are younger than those in the control site. Algae in the control transects are older because the site was unaltered by the anthropogenic disturbance. As algal plants age, the fronds increase in width and mass (Eckersley and Garbary, 2007), which explains, in part, why biomass was greater in the control site.

The shift in algal species, from *Ascophyllum* in the control site, to *Fucus* in the experimental site, may be attributed to changes in wave and wind exposure. The control site is sheltered by an island and the experimental site is more exposed. Therefore, the experimental site receives more energy crashing onshore than the control site. *Ascophyllum* has difficulties colonizing exposed rocky intertidal zones because its zygotes are vulnerable to turbid wave motion and survival rates are low (Vadas et al., 1990). *Fucus*,on the other hand,has effective external fertilization in high-energy environments because its eggs are negatively buoyant (Pearson & Serraro, 2006). The dominance of *Ascophyllum* in the control site, and the lack of its presencein the experimental site, could be a function of successional patterns. Over time, *Ascophyllum* can outcompete other Fucoids for space and, once established, can thrive for long periods of time (Cousens, 1981).

Physical characteristics of the beach varied between the control site and the experimental site, which further suggests that the degree of energy exposure plays a role in shaping the physical and biological ecology of the study site. There were slope differences across transects, which is likely correlated to energy exposure and deposition of sediment along the rock wall.

Sections of the beach with steeper slopes, such as lines G to J, had less algal growth in the low intertidal and subtidal zones because the end of the transects dropped off quickly into deep water. In the control area the rock wall is still showing two boulders high, but in the experimental site the rock wall has been buried and is showing only one boulder high in these central transects. Biologically, sediment build up can deter algal growth and recruitment of gametes by covering spores and inhibiting attachment to the substratum (Devinny & Volse, 1978; Norton, 1978; Arakawa & Matsuike, 1992). Sediment build up in transects A2 to G may explain why there were few algae plants present at the end of the five-year monitoring period.

Seasonality had an effect on algal growth because there was a significant difference in the median biomass values between the July and October sampling months. Biomass was likely greater in October than in July because environmental conditions are favourable for algal growth in the summer months, when water temperatures are warm and sunlight is abundant. Eckersley and Garbary (2007) concluded that *Ascophyllum* grows best from the spring to the falland showed that growth rates increase with increasing temperature up to 25°C.Seasonal variation in environmental stressors may have also affected the percentage of algal coverage. Ice scour and winter storms may have damaged existing algal plants and reduced the viability of gametes for development. For example, transect A had minimal coverage in 2007, healthy coverage in 2008 and 2009, and then minimal coverage again in 2010; these inconsistencies may be a result of storm events moving the substratum and dislodging algal plants.

In 2008 and 2009 new growth was observed in the fall, but not in the spring, which may be explained by seasonal factors affecting reproduction. For example, water temperatures ranging between 8 and 20°C are most effective for dissolving the polysaccharide sheath that incases the gametes and ocean temperatures during Nova Scotia winters are usually less than 5°C on the surface (Brawley et al., 1999). Despite the fact that average water temperature in the bottom layer can be greater than 5°C, it is likely that cold temperatures lower the gamete success and productivity of algae during the winter months. However, fucoid algae in Nova Scotia reproduce during the winter so tolerance to cold temperatures is high (Chapman, 1995).

Kim and DeWreede (1996) observed that the season of clearing had an effect amoung species on recruitment patterns to cleared patches in the intertidal zone, since different species reproduce at different times of the year. Most Fucoids in Nova Scotia reproduce during the winter (Chapman, 1995), but *Ascophyllum* reproduces in the spring (Vadas et al., 1990). Restoration of the impacted beach on Frog Island occurred in the fall, prior to the winter spawning of *Fucus*, which may explain why *Fucus* was the dominant species in the experimental site.

The two major limitations of this research were the location of the study site and the tides. Frog Island is accessed by sea or air, so site visits were dependent on the availability of a helicopter or a boat. Since the study site was a rocky intertidal beach, it was crucial to investigate the tide times before travelling to the island to ensure that the study site would be exposed. Once the tides were low, it was important to work at a fast pace to ensure that all of the sampling was completed. Tidal height and transportation to the island were both limiting factors for the October 2011 sampling, when percentage of algal cover and biomass samples were both being collected. Many of the zone 0 biomass samples were not obtained because the tides were too high to expose the sampling site. Another limitation was that the sample size was much greater in the impacted site than the control site, which increased the variability and skewed the data to the right.

The following recommendations pertain to future research on the recovery process involved in the recolonization of macrophytic algae: document the range of species present to understand successional patterns; include a larger sample size to reduce variability; collect biomass samples throughout the course of the monitoring period to establish an accurate relative growth rate; and collect samples more than once a year to determine seasonal effects on growth rates. Survey elevations along the transect would have been useful in determining the degree of rock movement and the changing location of the high tide mark as the beach changed shape.Most importantly, the high tide mark must be established on the transects and analysis of the algae recruitment should begin at the high tide mark, rather than above the high tide mark, to improve the accuracy of the results.

To our knowledge, intertidal habitat restoration of this nature and magnitude has never been done. This research has provided insight into physical and biological factors that affect the patterns of recolonization of macrophytic algae to boreal, temperate marine rocky intertidal zones.

# References

Adessi, L. (1994). Human disturbance and long-term changes on a rocky intertidal community. *Ecological Applications, 4*(4), 786-797. doi:10.2307/1942008

Arakawa, H. & Matsuike, K. 1992. Influence on insertion of zoospores, germination, survival, and maturation of gameto- phytes of brown algae exerted by sediments. *Nippon Suis. Gakk., 58,* 619–25. (as cited in Chapman and Fletcher, 2002).

Berndt M. L, Callow J. A, Brawley S. H. (2002) Gamete concentrations and timing and success of fertilization in a rocky shore seaweed. *Mar Ecol Prog Ser., 226*, 273–285. doi:10.3354/meps226273 (as cited in Ladah et al., 2008).

Bird, C. J. & McLachlan, J. (1974). Cold-hardiness of zygotes and embryos of Fucus (Phaeophyceae: Fucales). *Phycologia, 13,* 215-225. (as cited in Fletcher & Callow, 1992).

Black, R. & Miller, R. J. (1992). Utilization of areas of Ascophyllum nodosum by fish in southwest Nova Scotia (Research Report).

Bold, H. C. & Wynne, M. J. (1978). Introduction to the algae: structure and reproduction. New Jersey: Prentice Hall Inc.

Brawley S. H. (1992). Fertilization in natural populations of the dioecious brown alga Fucus ceranoides and the importance of the polyspermy block. *Mar Biol (Berl), 113*, 145–157. doi: 10.1007/BF00367648 (as cited in Ladah et al., 2008).

Brawley, S. H. & Johnson, L. E. (1992). Gametogenesis, gametes and zygotes: an ecological perspective on sexual reproduction in the algae. *European Journal of Phycology, 27*(3), 233-252. doi: 10.1080/00071619200650241

Brawley, S. H., Johnson, L. E., Pearson, G. A., Speransky, V., Li, R., & Serrao, E. (1999). Gamete release at low tide in fucoid algae: maladaptive or advantageous? American *Zoologist, 39*(2), 218-229. Retrieved from http://www.jstor.org/stable/3884245

Buschmann, A. H. & Bravo, A. (1990). Intertidal amphipods as intertidal dispersal agents of carpospores on Iridaea laminariodes (Gigartinales, Rhodyohyta). *Journal of Phycology, 26*, 417-420. (as cited in Fletcher & Callow, 1992).

Chapman, A. (1995). Functional ecology of fucoid algae: twenty-three years of progress. *Phycologia, 34*(1), 1-32.

Chapman, A. S. & Fletcher, R. L. (2002). Differential effects of sediments on survival and growth of Fucus serratus embryos (Fucales, Phaeophyceae). *Journal of Phycology, 38*(5), 894-903. Retrieved from http://web.ebscohost.com.ezproxy.library.dal.ca

Cousens, R. (1981). The population biology of Ascophyllum nodosum (L.) Le Jolis, Ph.D. thesis, Dalhousie University, Halifax.

Denny, M. W. & Shibata, M. F. (1989). Consequences of surf-zone turbulence for settlement and external fertilization. *The American Naturalist, 134*(6), 859-889. Retrieved from http://www.jstor.org/stable/2462013

Devinny, J. S. & Volse, L. A. (1978). Effects of sediments on the development of Macrocystis pyrifera gametophytes. Mar. Biol. 48, 343–8. (as cited in Chapman & Fletcher, 2002). Farrell, T.M. (1989). Succession in a rocky intertidal community: the importance of disturbance size and position within a disturbed patch. *J. exp. Mar. Biol. Ecol., 128*, 57 78. (as cited in Kim & DeWreede, 1996).

Eckersley, L. K. & Garbary, D. J. (2007). Developmental and environmental sources of variation on annual growth increments of *Ascophyllum nodosum* (Phaephyceae). *Algae*, *22*(2), 107-116. doi:10.4490/algae.2007.22.2.107

Fisheries and Oceans Canada. (2010a). Rocky shores. Retrieved from http://www.glf.dfo-mpo.gc.ca/e0005912

Fisheries and Oceans Canada. (2010b). *Application of the habitat protection provisions of the Fisheries Act to existing facilities and structures.* Retrieved from http://www.dfo-mpo.gc.ca/habitat/role/141/1415/14155/position-eng.htm

Fletcher, R. L. & Callow, M. E. (1992). The settlement, attachment and establishment of marine algal spore. *British Phycological Society, 27*, 303-329.

Foster, M. S. (1975). Regulation of algal community development in a Macrocystis pyrifera forest. *Mar. Biol., 32*, 331-342. (as cited in Fletcher & Callow, 1992).

Garson, D. G. (2008). One-sample Kolmogorov-Smirnov goodness-of-fit test. Retrieved from http://faculty.chass.ncsu.edu/garson/PA765/kolmo.htm

Harlin, M. M. (1974). The surfaces seaweeds grow on may be a clue to their control. *Maritimes (Univ. R.I. Grad. Sch. Ocean), 19,* 7-8. (as cited in Fletcher & Callow, 1992).

Harlin, M. M. & Lindbergh, J. M. (1977). Selection of substrata by seaweeds: optimal surface relief. *Mar. Biol. 40,* 33~40. (as cited in Fletcher & Callow, 1992).

Hartog, C. Den. (1959). The epilithic algal communities occurring along the coast of the Netherlands. *Wentia, 1,* 1-241. (as cited in Fletcher & Callow, 1992).

Horn, M., Martin, K., & Chotkowski, M. (1999). Introduction. In M. Horn, K. Martin, & M.

Chotkowski (Eds.), Intertidal fishes: life in two worlds. (pp. 1-6). California: Academic Press.

Keser, M. & Larson, B. R. (1984). Colonization and growth of Ascophyllum nodosum (Phaeophyta) in Maine. *Journal of Phycology, 20*, 83-87.

Kim, J. H. & DeWreede, R. E. (1996). Effect of size and season of disturbance on algal patch recovery in a rocky intertidal community. *Marine Ecology Progress Series, 133*, 217-228.

Ladah LB, Bermudez R, Pearson GA, Serrã o EA (2003) Fertilization success and recruitment of dioecious and hermaphroditic fucoid seaweeds with contrasting distributions near their southern limit. *Mar Ecol Prog Ser, 262,* 173–183. doi:10.3354/meps262173 (as cited in Ladah et al., 2008).

Ladah, L. B., Feddersen, F., Pearson, G. A., & Serrao, E. A. (2008). Egg release and settlement patterns of dioecious and hermaphroditic fucoid algae during the tidal cycle. *Marine Biology, 155,* 583-591. doi: 10.1007/s00227-008-1054-4

Lund Research Ltd. (2010). Laerd statistics. Retrieved from http://statistics.laerd.com/statistical-guides/hypothesis-testing-3.php

McCook, L. J. & Chapman, A. R. (1992). Vegetative regeneration of Fucus rockweed canopy as a mechanism of secondary succession on an exposed rocky shore. *Botanic Marina, 35,* 35-46.

Neushul, M., Foster, M.S., Coon, D. A., Woessner, J. W. & Harger, B. W. W. (1976). An in situ study of recruitment, growth and survival of subtidal marine algae: techniques and preliminary results. *J. Phycol., 12,* 397-408. (as cited in Fletcher & Callow, 1992).

Nienhui, P. H. (1969). The significance of the substratum for intertidal algal growth on the artificial rocky shore of the Netherlands. Int. Revue ges. *Hydrobiol. Hydrog., 54,* 207-215. (as cited in Fletcher & Callow, 1992).

Norton, T. A. (1978). The factors influencing the distribution of Sac- corhiza polyschides in the region of Lough Ine. *J. Mar. Biol. Assoc. UK, 58,* 527–36. (as cited in Chapman & Fletcher, 2002).

Norton, T. A. (1992). Dispersal by macroalgae. *European Journal of Phycology, 27*(3), 293-301. doi: 10.1080/00071619200650271

Ogata, E. (1953). Some experiments on the settling of spores of red algae. *Bull. Soc. P1. Ecol., Tokyo, 3,* 128-134.(as cited in Fletcher & Callow, 1992).

Pearson GA, Brawley SH (1996) Reproductive ecology of Fucus distichus (Phaeophyceae): an intertidal alga with successful external fertilization. *Mar Ecol Prog Ser 143,* 211–223. doi: 10.3354/meps143211 (as cited in Ladah et al., 2008).

Pearson, G. A. & Serrao, E. A. (2006). Revisiting synchronous gamete release by fucoid algae in the intertidal zone: fertilization success and beyond? *Integrative and Comparative Biology, 46*(5), 587-597. doi:10.1093/icb/icl030

Province of Nova Scotia. (2009). Beaches regulations under section 13 of the Beaches Act. Retrieved from http://www.gov.ns.ca/just/regulations/regs/beachreg.htm

Santelices, B. & Paya, J. (1989). Digestion survival of algae: some ecological comparisons between free spores and propagules in fecal pellets. *Journal of Phycology, 25*, 693-699. (as cited in Fletcher & Callow, 1992).

Scrosati, R. & Heaven, C. (2008). Trends in abundance of rocky intertidal seaweeds and filter feeders across gradients of elevation, wave exposure, and ice scour in Eastern Canada. *Hydrobiologia, 603,* 1-14. doi: 10.1007/s10750-007-9160-8

Serrao, E. A., Pearson G, Kautsky L, Brawley S. H. (1996) Successful external fertilization in turbulent environments. *Proc Natl Acad Sci USA, 93*(11), 5286–5290. doi:10.1073/pnas.93.11.5286 (as cited in Ladah et al., 2008).

Sousa, W. P. (1979). Disturbance in marine intertidal boulder fields: the nonequilibrium maintenance of species diversity. *Ecology, 60*(6), 1225-1239. Retrieved from http://www.jstor.org/stable/1936969.

Sousa, W. P. (1984). Intertidal mosaics: patch size, propagule availability, and spatially variable patterns of succession. *Ecology, 65,* 1918-1935. (as cited in Kim & DeWreede, 1996).

Sousa, W. P. (1985). Disturbance and patch dynamics on rocky intertidal shores. In S. T. A. Pickett & P. S. White (Eds.), The ecology of natural disturbance and patch dynamics (pp. 101-124). Orlando: Academic Press Inc.

StatSoft, Inc. (2011). Electronic statistics textbook. Retrieved from http://www.statsoft.com/ textbook/.

Stephenson, T. A. & Stephenson, A. (1972). Life between tidemarks on rocky shores. San Francisco: W. H. Freeman and Company.

Thaumas Environmental Consultants Ltd. (2007). Frog Island restoration report 2007.

Thaumas Environmental Consultants Ltd. (2008). Frog Island restoration report 2008.

Thaumas Environmental Consultants Ltd. (2009). Frog Island restoration report 2009.

United States Environmental Protection Agency. (2000). Estuarine and coastal marine waters: bioassessment and biocriteria technical guidance. Retrieved from http://water.epa.gov/scitech/swguidance/standards/criteria/aqlife/biocriteria/upload/2009_04_22_biocriteria_States_estuaries_estuaries.pdf

Vadas, R. L., Wright, W. A., & Miller S. L. (1990). Recruitment of Ascophyllum nodosum: wave action as a source of mortality. *Marine Ecology Progress Series, 61*, 263-272.

Watanuki, A. & Yamamoto, H. (1990). Settlement of seaweeds on coastal structures. *Hydrobiologia*, *204/205*, 275-280. (as cited in Fletcher & Callow, 1992).

Wentworth, C. K. (1922). A scale of grade and class terms for clastic sediments. The Journal of Geology, 30(5), 377-392. Retrieved from http://www.jstor.org/stable/30063207

Wright, P. J. & Reed, R. H. (1990). Effects of osmotic stress on gamete size, rhizoid initiation and germling growth in fucoid algae. European Journal of Phycology, 25(2), 149-155. doi: 10.1080/00071619000650141

Yamahira K. 2004. How do multiple environmental cycles in combination determine reproductive timing in marine organisms? A model and test. *Functional Ecology, 18*, 4–15. (as cited in Pearson & Serrao, 2006).

# Glossary

Anthropogenic disturbance – disturbance caused by human activity

Biomass – the mass of an organism, species, or community in a given area

Dioecious – a group of organisms with separate male and female individuals

Ecosystem – a biological system of organisms and the abiotic components of the environment with which they interact

External fertilization – unity of a sperm cell and an egg cell outside the body of the reproducing organism

Fucoid – most abundant macrophytic algal species in Nova Scotia and belonging to the family Fucaceae

Gametangia – the organ or cells from which gametes originate

Gamete – reproductive cells

High intertidal zone – section of the intertidal zone that is furthest from the ocean, so it is exposed to air most of the time

Hydrodynamic – force resulting from the motion of water

Intertidal zone – above water at low tide and below water at high tide

Low intertidal zone – lowest section of the intertidal area, so it is submerged under water most of the time

Macrophytic algae – large algal plants that are visible with the naked eye

Mid intertidal zone – middle section of the intertidal zone that receives equal exposure to air and water

Monoecious – individual organism that has both male and female reproductive parts

Niche – position of a species in its ecosystem

Osmotic pressure – pressure that is applied to a solution to prevent the flow of water across a semi-permeable membrane

Perennial – plant that lives more than two years

Polysaccharide sheath – protective barrier

Propagule – a reproductive spore or any number of other plant parts that will establish a new plant

Quadrat – a square area used to isolate a sample

Recruitment – addition of individuals to a population through survival of the juvenile organisms

Remediation – process of correcting a problem

Spawning – release of eggs and sperm by aquatic organism into the water column

Sporeling – a young plant that develops from a germinated spore

Succession – changes in species present in ecological communities overtime

Synchronous spawning – simultaneous release of gametes to increase the likelihood of fertilization

Temperate – moderate climate between the tropic and polar regions, with distinct seasons

Transect – a line along which scientists count the occurrence of an organism or phenomena

Transplant – the deliberate movement of an organism from one location to another area

Trophic level – the position of an organism in the food chain

Vegetative regeneration – asexual reproduction by which algal plants reproduce from existing vegetative parts, rather than by spores

Vertical zonation – vertical divisions of species in the intertidal zone that tolerate different environmental conditions

Zygote – cell that results from the fusion of two gametes through sexual reproduction