THE EFFECTS OF ACID MINE DRAINAGE AT BRITANNIA BEACH, B.C., ON *FUCUS GARDNERI* AND ASSOCIATED INTERTIDAL ALGAE

by

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Abstract

Copper ore was extracted from Britannia Mine, British Columbia, Canada, from 1902 until the mine ceased operations in 1974. Rain, snowmelt and groundwater now percolate through the mine tunnels, producing an acidic solution of dissolved metals known as Acid Mine Drainage (AMD). A portion of the AMD from the mine flows into Britannia Creek, which in turn flows into Howe Sound, 50 km north of Vancouver, B.C. This study examined the effects of this effluent on the distribution of intertidal macroalgae with a focus on *Fucus gardneri* Silva, a seaweed which thrives 2 km from the mouth of Britannia Creek but is absent from the shore near the Creek. *F. gardneri* provides habitat and food for benthic invertebrates, which are a major food source for chum salmon fry and chinook salmon fry and smolts.

Algal communities were quantified at 7 intertidal stations to the north and south of the mouth of Britannia Creek and at 6 similar stations at nearby Furry Creek, a reference site. Algal cover was almost non-existent within 200 m of the mouth of Britannia Creek, and *F. gardneri* was completely absent on the 600 m of shoreline south of Britannia Creek and on 1000 m of shoreline north of the same Creek. There was, however, a heavy cover of filamentous green algae, mainly *Enteromorpha compressa* (L.) Link, at sites 300 m and 700 m south and north of Britannia Creek, respectively, suggesting that these algae can better tolerate AMD. Experimental work consisted of transplanting *F. gardneri*-covered cobbles from a control site to Britannia Beach and monitoring the plants' growth, survivorship and copper content. In five experiments conducted from June 1997 to November 1998, plants moved to within 100 m of Britannia Creek generally had lower survivorships and lower growth rates than plants at the control site, as well as higher tissue copper concentrations. Survivorship and growth rates of plants moved to areas farther from Britannia Creek (300-700 m) were not significantly different from control plants.

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1. GENERAL INTRODUCTION

1.1. Motivation for Research

The research in this thesis was part of a comprehensive examination by the Department of Fisheries and Oceans (D.F.O.) of the impact of acid mine drainage (AMD) on the marine ecosystem at Britannia Beach, British Columbia. D.F.O. is particularly interested in the effects of AMD on salmon and salmon habitat in the surrounding waters. The D.F.O. project involved measurement of environmental factors and metal concentrations in the area and the impacts of AMD on salmon food organisms. An important food source for the salmon is the community of benthic invertebrates that are closely associated with the intertidal brown alga *Fucus gardneri* Silva (Nassichuk 1975). Therefore, *F. gardneri* may be critical for the maintenance of the salmon productive capacity of the area. The shoreline near Britannia Beach is almost completely devoid of *F. gardneri* which does, however, inhabit beaches just a few kilometers from the mouth of the Creek. The research presented here aimed to determine the effects that AMD has on algae in the Britannia Beach area, with a particular focus on *F. gardneri* . These effects, if detrimental, may then directly or indirectly decrease the productive capacity of the Britannia Beach area for salmon by alteration of their food web.

1.2. Background Information

1.2.1. Acid Mine Drainage

Acid Rock Drainage (ARD) is the naturally occurring oxidation of pyrite (FeS_2), the metal-containing ore which was mined at Britannia Mine during its operation. The reaction equation (Boult *et al.* 1994) is:

$$4\,FeS_2\,(s) + 15\,O_2 + 8\,H_2O \Rightarrow 2\,Fe_2O_3 + 16\,H^+ + 8\,SO_4^{2-}$$

This process has two primary consequences: (1) Production of large quantities of sulfuric acid, and (2) Release of heavy metal ions (e.g., Cu^{2+}, Zn^{2+}, Cd^{2+}) that are bound up in the pyrite ore.

While ARD is a naturally occurring process, the tunneling that necessarily takes place during mining activities can increase its severity by increasing the surface area of rock that is exposed to oxygen and water. Acid mine drainage (AMD) is the special case of ARD that is significantly aggravated by mining activities. Subsequent reference to this process will be to acid mine drainage, as the mine workings are the major source of drainage at Britannia Beach (see below).

At Britannia Mine, rainwater, spring snow-melt and groundwater enter the mine workings mostly through open pits at the top (Figure 1.1; Chretien 1997). This water then flows through the underground workings of the mine, reacts with the ore, and exits the mine through two portals (Price *et al.* 1995):

- The 2200 portal, which emerges from the mine 700 m above sea level. The effluent from this location flows into Jane Creek, which then merges with Britannia Creek approximately 6 km from Howe Sound.
- The 4100 portal, which exits the mine 67 m above sea level. This effluent is combined with local sewage and flows to a 30 m-deep outfall in Howe Sound.

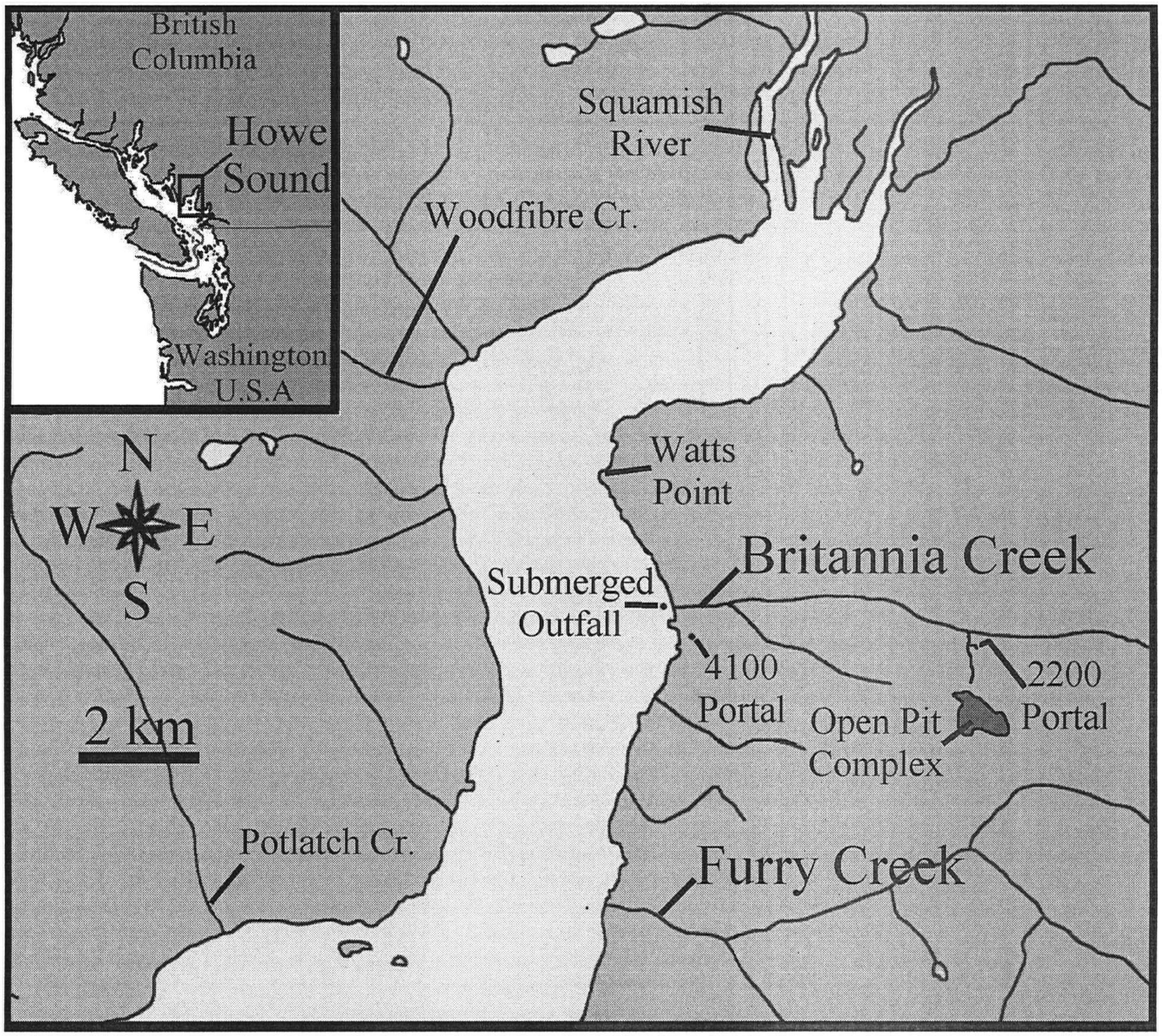

Figure 1.1. Relative location of Britannia and Furry Creeks, mine features and geographical features mentioned in the text. Adapted from Price *et al.* (1995) and Grout *et al.* (1998).

Studies by R. McCandless of Environment Canada (unpublished data) estimate the average loading of copper, zinc and cadmium in Britannia Creek as 0.328, 0.316 and 0.005 tonnes per day, respectively. R. McCandless (unpublished data; Figure 1.2) and Chretien (1997; Figure 1.3) found a distinct seasonal variation in metal loading in the Creek with peaks in the spring and fall seasons.

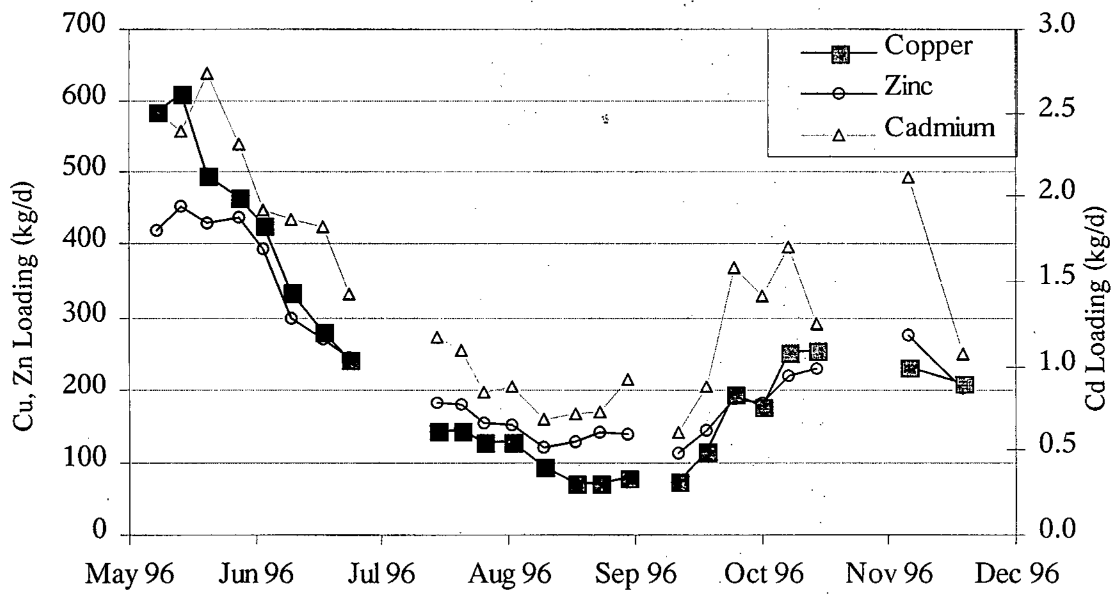

Figure 1.2. Combined daily loadings of Cu, Zn and Cd from Britannia Creek and the submerged outfall into Howe Sound. Data from R. McCandless (unpublished data). Graph compiled by J. Grout.

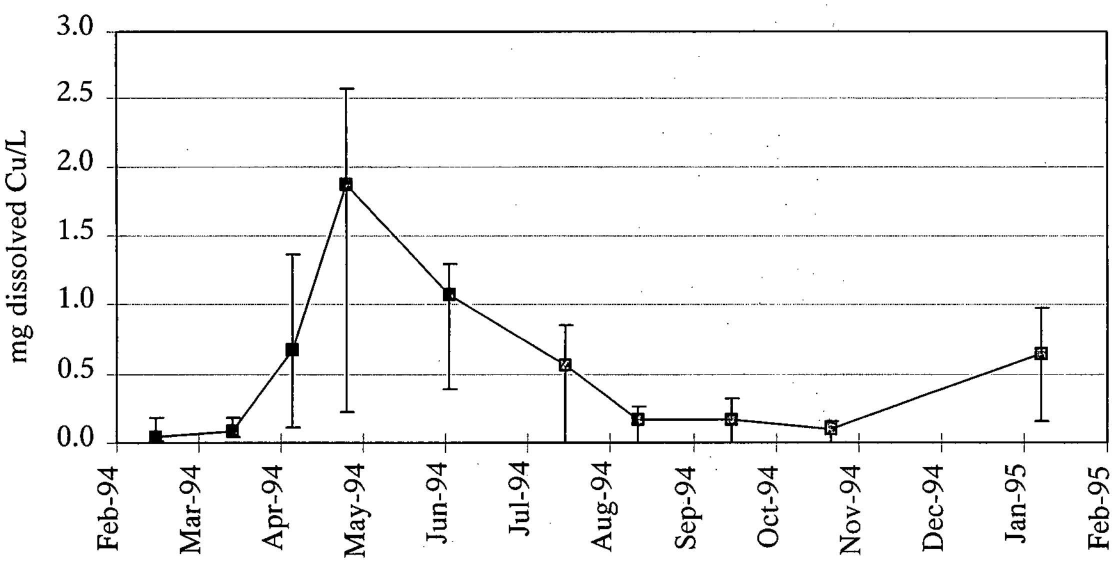

Figure 1.3. Dissolved copper concentrations in Howe Sound near the mouth of Britannia Creek from March 1994 to January 1995. Values are mean of 8 samples taken along a transect covering the entire mixing zone of Britannia Creek, within approximately 400 m of the Creek mouth. Error bars are the maximum and minimum values recorded at each time point. From Chretien (1997).

Chretien (1997) explains the seasonality of metal loadings based on differential flow rates of water into the mine. During winter most precipitation falls as snow at higher elevations; the resulting low flow rates into the mine lead to low metal loadings out of the portals. However, some water stays in the mine, where it continually reacts with ore in tunnel walls and accumulates oxidation products. As spring snow-melt occurs at high elevations, the meltwater flowing through the mine flushes the accumulated AMD from the tunnels, resulting in a pronounced peak in metal loading. During late summer, little precipitation or meltwater enters the mine, so water again accumulates in the mine. Increased precipitation in the fall again flushes this accumulated AMD from the mine and into Britannia Creek, resulting in a second, albeit less pronounced, loading peak (Chretien 1997).

There are three major metal components to the AMD at Britannia Beach. While it is beyond the scope of this study to causally link any effects observed in field experiments at Britannia Beach to a specific metal, this study will focus on copper. Cadmium has a very low loading in Britannia Creek relative to copper (Figure 1.2). Zinc has been generally found to be much less toxic to algae than copper (Hargreaves & Whitton 1976; Munda & Hudnik 1986; Lobban & Harrison 1994). It appears, then, that copper is the most likely component of AMD which might cause biological effects. Consequently, much of the data and discussion in this thesis will concern copper. It should be kept in mind, however, that results can only be attributed to AMD in general, and not to any specific component thereof.

1.2.2. Local Oceanography

Britannia Beach lies on the eastern shore of Howe Sound approximately 10 km south of the mouth of the Squamish River (see Figure 1.1). The oceanography of the Sound is strongly influenced by this river, which is the major source of freshwater to the Sound. Chretien (1997) examined the salinity and temperature of the waters near Britannia Beach. He found a strong thermocline from May to September, with temperatures of 15 °C at the surface and 7-12 °C at depths below 10 m. There was also a pronounced halocline, with salinities of <3 at the surface and ~30 below 10 m. These patterns of stratification were virtually the same at sites near the shore and in the middle of Howe Sound. The halocline and thermocline indicate the presence of a freshwater lens, caused by the Squamish River during freshet (Chretien 1997). This stratification virtually disappears, however, from October to April; surface temperatures during this period were 5-10 °C, while those at depths greater than 10 m were ~8 °C. Salinities were ~22 at the surface and ~30 at depths greater than 10 m.

Buckley (1977) and Stronach *et al.* (1992) examined the surface flow pattern of the waters near Britannia Beach (Figure 1.4). There is a net down-inlet current due to the flow from the Squamish River. The main current in upper Howe Sound flows southward along the western side of the Sound. There is, however, a counterclockwise gyre, which breaks from the main southward flow near Porteau Cove and carries water northward along the shoreline at Britannia Beach. This gyre is observed at low tide when surface flow is dominated by river-induced currents. Different flow patterns may be observed, however, due to wind and tidal flows (Buckley 1977). Pond (1992) states that wind-induced currents totally dominate the surface flow pattern. These flow patterns may have important ramifications for the transport of AMD as it flows into the Sound, as the effluent from Britannia Creek and the submerged outfall may be predominantly carried in one direction or another upon entry to the estuary depending on the prevailing conditions at the time.

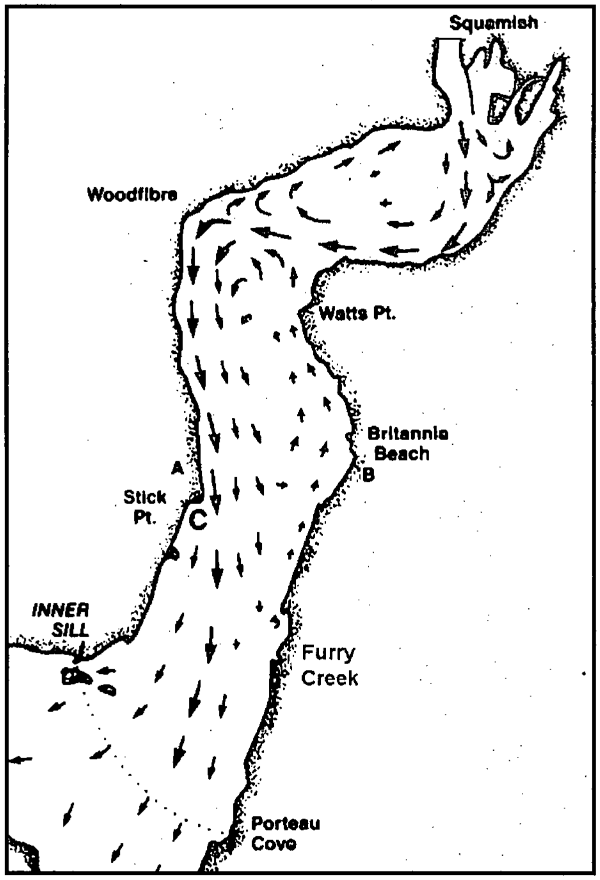

Figure 1.4. General surface circulation patterns in upper Howe Sound. Longer arrows indicate faster flow rates. From Thomson (1981).

1.2.3. Copper Chemistry

Wherever pollutants are released into a marine system, chemical processes may affect the degree to which those pollutants act upon nearby communities. Heavy metals may exist in many different forms in aquatic environments. The partitioning of metals amongst these forms is dependent on the physical and chemical conditions of their environment. It is helpful to consider this partitioning of metals as it can significantly alter the ability of the metal to impact the biota of interest. Given the focus of this study, the following review deals only with copper.

1.2.3.A. Copper Speciation in Aquatic Systems

Copper species can be broadly categorized into three groups of decreasing size:

particulate, colloidal and dissolved forms. Particulate species of copper are those which are retained by a 0.45 μm filter (Spear & Pierce 1979). Copper may become part of the particulate phase by precipitating with inorganic ligands, forming insoluble organic complexes, or adsorbing on surfaces of other particles (e.g., clay minerals, hydrous metal oxides, organic matter). Some materials, such as humic acids and hydrous iron oxides, can form colloids in aqueous systems (Horne 1969). Copper is known to bind to some of these colloids, and substantial portions of the total copper can be present in a colloidal form (Sholkovitz 1976; Sholkovitz 1978). These colloids, while not truly dissolved forms of the metal, are sometimes inadvertently included in measurements of the latter, as they can often pass through a 0.45 μm filter. Copper can be found in various dissolved forms in aqueous systems. The simplest aqueous form of copper is the hydrated ion, $Cu(H_2O)_6^{2+}$, also know as "free" copper. One or more of the six water molecules associated with the Cu^{2+} ion can then be replaced by a variety of ligands. These ligands may be organic (e.g., amino acids) or inorganic (e.g., carbonate, hydroxide).

1.2.3.B. Estuarine Changes in Speciation

Estuaries are areas of rapid transition; river water, with its low pH (typically 5.0-7.0, occasionally up to 8.0, in various unpolluted creeks near Britannia Beach; Price *et al.* 1995) and relatively low solute concentration, mixes with seawater which has a high pH (typically 7.5-8.5; Valiela 1995) and is a much more concentrated solution of salt ions (Leckie & Davis 1979). A significant alteration of the speciation of trace metals, including copper, might be expected during this mixing process. Copper has been observed in many situations to behave in a non-conservative manner during estuarine mixing (Windom 1975; Boyle 1976; Boyle 1979; Girvin *et al.* 1977; Sholkovitz 1978; Sholkovitz & Copland 1981; Hunt 1983), that is, its concentration is changed by factors other than mixing and dilution. Non-conservative processes can result in addition or removal of copper from the dissolved pool. Addition of copper to the dissolved pool would likely occur through the dissociation of copper from various complexes and particulates, while removal would entail the formation of complexes or adsorption to particulates and their subsequent removal from the water column by sedimentation.

As metal-loaded freshwater from organic-poor rivers, such as those flowing into Howe Sound, mixes with relatively metal-free seawater in an estuary there may be a trend towards dissociation of copper from suspended matter (Girvin *et al.* 1977; Thomas & Grill 1977) and from organic substances (Nelson 1985; van den Berg *et al.* 1989). However, this apparent release of copper into the dissolved pool might actually be a result of the metal's association with iron colloids, which are themselves released from suspended particulates during estuarine mixing (Fletcher *et al.* 1983). The dissociation of copper from suspended and organic matter is a result of increased competition by seawater anions and cations for metals and adsorption sites, respectively. As might be expected, the decrease in prevalence of adsorbed and organically bound fractions is concurrent with an increase in inorganic complexation (Spear & Pierce 1979).

The change in ionic strength upon mixing with seawater can result in the coagulation and sedimentation of colloidal particles, a process referred to as flocculation. Since copper is strongly bound by these colloids (Steeman Nielsen & Kamp-Nielsen 1970; Boyle *et al.* 1977; Huang *et al.* 1977), much of the total copper in river water can be removed through flocculation. Laboratory and field experiments have shown that 30-40% of copper can be removed through flocculation (Sholkovitz 1976; Boyle 1979; Sholkovitz & Copland 1981).

The behaviour of copper as it enters an estuary is likely to be quite variable among different areas. While the ratios of major elements in the oceans are quite uniform, many other components which affect copper speciation, such as dissolved organic matter, suspended particulate matter and other metals, can be quite variable. It is therefore extremely difficult to compare metal concentrations of any type in one area to those in another. For example, the percentage of dissolved copper which is biologically available at Britannia Beach may be much higher or lower than that at other polluted estuaries worldwide. This difficulty must be kept in mind when metal concentrations are measured and interpreted.

1.2.3.C. Copper chemistry at Britannia Beach

Chretien (1997) conducted detailed surveys of copper speciation in and near Britannia Creek. He found that 92% of the copper was in dissolved form 100 m upstream from the Creek mouth. The amount of copper transferred from the dissolved phase to the particulate phase during estuarine mixing varied over the year from 0-82%, with a mean and median of ~30%. The amount of copper which precipitated in the mixing zone was strongly correlated with the concentration of copper in Britannia Creek such that higher concentrations of copper in the Creek resulted in more copper being removed from solution. This removal of copper from solution was attributed mainly to precipitation as hydroxides, hydroxy-carbonates, and hydroxy-sulphates.

Dissolved copper concentrations in Howe Sound, 400 m from the mouth of Britannia Creek, were higher in surface waters (mean = 13 μg/L) than in subsurface waters (mean = 1.9 μg/L at depths ≥10 m). Overall, Chretien (1997) found that the dispersion of metals from Britannia Creek occurs within the surface layer of Howe Sound rather than in the entire water column. This concentration of metals in the surface layer may have serious consequences for intertidal organisms as metal-contaminated Creek water will be diluted over a much larger area than if mixing was more homogenous with depth.

1.2.4. Interactions between Copper and Algae

1.2.4.A. Bioavailability of Copper Species

A metal is considered to be in a biologically available state when it can be taken up by an organism and can react with its metabolic machinery (Campbell *et al.* 1988). The bioavailability of almost any substance is strongly organism-specific (Campbell *et al.* 1988). Perhaps the most general statement that can be made about bioavailability of metals is that it is critically dependent on speciation (Sunda & Guillard 1976; Stauber & Florence 1987; Phinney & Bruland 1994; Gledhill *et al.* 1997). It has been generally accepted that free copper (II) is the form of copper that is most available to almost all organisms (Sunda & Guillard 1976; Anderson & Morel 1978; Sunda & Lewis 1978; Brand *et al.* 1986; Nor 1987; Campbell *et al.* 1988). However, Sylva (1976) expresses some reservations regarding this hypothesis, which he asserts is unproven and possibly too exclusive (also, see below).

1.2.4.B. Uptake

Cellular uptake of copper can be by active, facilitated or passive transport (Campbell *et al.* 1988; Phinney & Bruland 1994). As with other organisms, the principal source of copper to macroalgae is generally recognized to be free cupric ion (Luoma 1983; Gledhill *et al.* 1997). However, there is some evidence that sediment-bound metal may be taken up or "scavenged" from sediments by *Fucus* spp. (Luoma *et al.* 1982). There is seasonal variation of uptake rate and concentration of several heavy metals in *Ascophyllum nodosum* (Eide & Myklestad 1980) and *Fucus vesiculosus* (Riget *et al.* 1995), both fucoids (Fucales, Phaeophyceae). There is also interannual variation; body burdens of copper, zinc and cadmium varied over 3 years by factors of 2.5, 4 and 2, respectively (Riget *et al.* 1995).

1.2.4.C. Functions and Requirements

Copper, despite its widely documented harmful effects on organisms when present in high concentrations, has been shown to be essential to life (Bowen 1966; Lewis & Cave 1982). It has several functions in the biochemistry of plants (Bidwell 1979). In plants, copper plays an exclusively catalytic role. It is a part of a number of important enzymes, including polyphenol oxidase and ascorbic acid oxidase. It is also present in plastocyanin in chloroplasts and may be involved in nitrate reduction (Bidwell 1979). Gledhill *et al.* (1997) state in their review that free copper concentrations of 6.3×10^{-6} to 6.3×10^{-4} $\mu g\ L^{-1}$ are thought to be optimal for marine microalgae. Despite its undoubted importance to organisms, copper is probably never a limiting nutrient in natural waters (Lewis & Cave 1982).

1.2.4.D. Detrimental Effects

Sorentino (1979) outlined the stages of toxicity to phytoplankton which occur as the concentration of copper increases. Low concentrations affect the permeability of the cell membrane, causing K^+ loss and changes in cell volume. Higher concentrations of copper may be transported to the cytoplasm and then to chloroplasts, where copper inhibits photosynthesis by uncoupling electron transport to $NADP^+$. If even higher concentrations are present, the copper binds chloroplast proteins and other cell proteins, causing degradation of chlorophyll and other pigments. At the highest concentrations irreversible damage to chloroplast lamellae occurs, preventing photosynthesis and eventually causing death.

The effects of copper are variable amongst species of macroalgae; for example, the sensitivities of five fucoid seaweeds to copper varied by a factor of three (Strömgren 1980). This author found a 50% reduction in growth of all species at copper concentrations of 50-75 μg/L.

Copper and zinc have been observed to have reduced toxicity in the presence of algal exudates (Ragan *et al.* 1980; Schramm 1993). Macroalgae release metal-binding compounds, such as polyphenols (Gledhill *et al.* 1997), and some metal binding compounds also exist in the cell wall (Lobban & Harrison 1994).

Trace metals may interact with each other in macroalgae, causing a variety of changes in uptake and toxicity of one or both metals. A series of metals were applied singly and in pairs to *Fucus vesiculosus* at a salinity of 31.5 in experiments by Munda & Hudnik (1986). Copper induced mortality within 20 days at concentrations of 2500 and 5000 $\mu g L^{-1}$, but manganese and cobalt reduced copper lethality at lower copper levels, allowing minimal growth. Copper uptake did not appear to be affected by the presence of other metals, including zinc and cadmium. Also, copper was accumulated to the same degree when applied with other metals as when applied on its own.

Salinity can affect the toxicity of copper to some algae. An increase in salinity has been shown to reduce copper toxicity in *Cladophora* sp., a green alga (Betzer & Kott 1969). This may be due to a change in copper speciation such that less copper is in bioavailable forms. Alternatively, the additional cations in waters of higher salinity may compete with copper ions for binding sites on the surface of the alga. This effect may be important at Britannia Beach, as *F. gardneri* is exposed to different salinities at different times of the year (see section 1.2.2). Thus, toxicity may vary seasonally, with more severe copper toxicity during the spring freshet.

One aspect of copper toxicity to macroalgae which must be considered is the differential sensitivities of various life history stages to copper. Microscopic stages such as gametophytes, gametes and zoospores appear to be especially sensitive. This may be due to their high surface-area-to-volume ratio relative to macroscopic stages. Zoospore release and development of gametophytes were sensitive to copper in the brown algae *Laminaria saccharina* (Chung & Brinkhuis 1986) and *Macrocystis pyrifera* (Anderson *et al.* 1990), while settlement and germination of spores were relatively tolerant in *Laminaria saccharina* (Chung & Brinkhuis 1986). Scanlan & Wilkinson (1987) found that spermatozoa and newly fertilized eggs of *Fucus* spp. were more sensitive to several biocides than 3-week-old germlings and adult plants. This trend may also hold for copper. Copper may inhibit algal reproduction by reducing the ability of the sperm to find the egg, perhaps by interfering with a pheromone which is thought to be involved in this process (Maier & Müller 1986; Lobban & Harrison 1994).

Contradictory results have been obtained when examining the effect of pH on toxicity of copper to microalgae. In a review of the literature, Campbell & Stokes (1985) found that uptake and toxicity of metals in a variety of aquatic biota, including microalgae, decreased with decreasing pH. Toxicity of copper to the green alga *Chlorella pyrenoidosa* was lower at acidic pH in the experiments of Steeman Nielsen & Kamp-Nielsen (1970). Inhibitory effects of copper on *Scenedesmus quadricauda*, another green alga, increased 76-fold from pH 5.0 to 6.5 (Peterson *et al.* 1984). These findings are unexpected given that copper activity normally increases with decreasing pH. The authors of the above studies explained their observations by a mechanism involving competition between H^+ and Cu^{2+} for cellular binding sites.

In contrast to the above studies, copper toxicity to *Aphanizamnion gracile* and *Oscillatoria redekei*, both cyanobacteria, in experiments by Lüderitz & Nicklisch (1989) increased at acidic pH. Toxic effects of copper on *Scenedesmus quadricauda* were also enhanced at acidic pH (Starodub *et al.* 1987). This discrepancy points out the importance of site- and species-specific factors in determining copper toxicity.

1.2.4.E. Tolerance

Macroalgae are likely more tolerant of copper than are microalgae (Nor 1987; Gledhill *et al.* 1997). Some of this tolerance may be conferred by exudates (Ragan *et al.* 1980; Xue & Sigg 1990; Schramm 1993; Gledhill *et al.* 1997). In some instances macrophytes can tolerate copper ion activities up to 10^{-5} M (Nor 1987). Ship-borne populations of *Ectocarpus siliculosus* (Phaeophyceae) which have been exposed to copper from anti-fouling paints are tolerant to copper concentrations ten times higher than populations from unpolluted areas (Russell & Morris 1970). Estuarine fucoid algae from 'high copper' areas were more tolerant of copper toxicity than the same species from 'low copper' estuarine situations (Bryan 1971; Gledhill 1997). Correa *et al.* (1996) examined the heritability of copper tolerance in *Enteromorpha compressa* (Chlorophyta) in Chile. Plants from copper-polluted shores were able to withstand much higher concentrations of copper. However, their progeny showed no such tolerance.

A possible mechanism of copper tolerance in *Fucus vesiculosus* and *F. serratus* is through internal detoxification. Smith *et al.* (1986) found much of the copper in these plants, collected from acid-mine-drainage-polluted shores, to be localized in physodes, which are membrane-bound organelles containing high concentrations of metal-binding polyphenols. Smith *et al.* (1986) suggest this may reduce the toxicity of the copper by sequestering it in an area where it can have relatively little effect on the metabolism of the plant.

1.2.5. *Fucus gardneri*

Fucus gardneri Silva is a prominent feature of the littoral zone in most of Howe Sound. The plant grows on variably sized substrata, from bedrock to small pebbles which are sometimes buried in sand. It is the dominant alga in the mid-intertidal in most of upper Howe Sound, from Porteau Cove to Watts Point on the east side of the Sound, and from Potlatch Creek to Woodfibre Creek on the west side (pers. obs.; see Figure 1.1). The alga is subject to quite variable salinities throughout the year. In Howe Sound, surface salinities were observed as low as 3 in areas with healthy growth of *F. gardneri*, while winter salinities reached highs of 20 (pers. obs.). Some fucoids live in estuaries where they are subject to both full strength seawater and fresh water in half a day (Chapman 1995). These algae are also quite tolerant of desiccation. Johnson *et al.* (1974) found that *F. distichus* had photosynthetic rates up to 6 times higher in air than in water. Under the more extreme conditions of summer midday low tides, *F. gardneri* thalli in Howe Sound were observed to be apparently completely desiccated such that the fronds were black and extremely brittle and shriveled (pers. obs.). Yet, after repeated desiccation to this point, the same plants were observed in apparently healthy condition after the tide came up. The plant's remarkable tolerance of extremes in desiccation and salinity lead to its ability to survive in the mid-intertidal and in upper Howe Sound, respectively.

1.2.5.A. Importance

F. gardneri is of interest in the current DFO project because of its associated fauna and as a source of organic carbon to the estuarine environment. Nassichuk (1975) examined the relationships between *F. gardneri* and invertebrate fauna in Howe Sound. He found a wide variety of invertebrates associated with the seaweed, including gastropods (littorines and limpets), isopods, amphipods and chironomid larvae. Some members of the last two groups, as well as certain copepods, are important food sources for juvenile chinook (*Oncorhynchus tshawytscha*) and chum (*Oncorhynchus keta*) salmon (Levings & McDaniel 1976; Levings &

Riddell 1992), which feed in the intertidal zone after leaving freshwater. It is possible that, regardless of direct effects of AMD on salmon and their prey, *F. gardneri* biomass may be reduced, thereby reducing habitat for salmon food organisms and ultimately resulting in a lower productive capacity of the area for salmon.

A study by Levings and McDaniel (1976) determined that the invertebrate community near Britannia Beach was extremely reduced when compared to unpolluted sites. They found a wide variety of organisms, including molluscs, copepods, amphipods, isopods and several insect groups, on either side of the Creek at distances of 1.5 km. In contrast, only a single insect group and one pelagic amphipod were found on the beach at Britannia Creek. Numbers of organisms were also extremely low; only one organism of one species was found in each of three quadrats. While this study was conducted when the mine was still in operation and would therefore be expected to show more severe detriments to the local biota due to other mine-related disturbances, it nevertheless raises the possibility of reductions in intertidal productivity.

1.2.5.B. Life history and Biology

F. gardneri is in the order Fucales, class Phaeophyceae. The plant is a perennial which lives up to five years (van den Hoek *et al.* 1995). It has a gametic life history with only a diploid vegetative stage. This monoecious gametophyte produces antheridia and oogonia in cavities (called conceptacles) on the thallus surface (van den Hoek *et al.* 1995). The gametes are large, non-motile eggs (typically 75 μm in diameter) and small, biflagellate spermatozooids. Fertilization has been found to occur both within the conceptacle (McLachlan *et al.* 1971; Nassichuk 1975) and after the gametes have been released (Pollock 1969).

Once fertilization has occurred the eggs must be dispersed. Burrows & Lodge (1951) demonstrated that propagules of *Fucus* spp. can colonize at least 23 m from parent plants on a shore without seaweed. Chapman (1995) reviewed work which suggests that most settlement occurs within ~1 m of the parent plant. After fertilization, the zygote secretes a glue-like substance which helps it adhere to the substratum upon settlement (Nassichuk 1975).

1.2.6. Statistical Methods

It is useful to briefly address the statistical methods which will be used to assess the significance of results obtained in the following experiments. Two types of errors can occur in a statistical test of a null hypothesis: a Type I error, in which the null hypothesis is rejected when it is true, or a Type II error, in which the null hypothesis is not rejected when it false. While the probability of a Type I error is usually determined through the selection of a significance level or α (typically 0.05), the probability of a Type II error, β, is often not addressed (Underwood 1996). This β value determines the power of a statistical test, which is calculated as $1 - \beta$, and is best described as the probability of detecting a difference between two means when a difference actually exists. As an example of how various parameters of an experiment will determine the probabilities of various outcomes, the following is the equation provided by Zar (1996) to calculate the power of a one-tailed one-sample Student's t-test, which is identical to the paired t-tests in Chapter 3:

$$t_{\beta(1),\nu} = [\delta/\sqrt{(s^2/n)}]-t_{\alpha(1),\nu} \qquad \text{(eqn. 1.1)}$$

where $t_{\beta(1),\nu}$ is the t-value associated with a given β at ν degrees of freedom, δ is the minimum detectable effect size, s is the standard deviation of the attribute under examination and $t_{\alpha(1),\nu}$ is the one-tailed t-value associated with a given α. The value of $t_{\beta(1),\nu}$ obtained is translated into a value of β and the power of the test is calculated as $1 - \beta$.

There is a tradeoff in any statistical analysis in the selection of experimental parameters. One can assume that the variability of the population, s^2, is fixed and that the sample size, n, will be set to the maximium possible given resource-related constraints. If there is sufficient previous information, the minimum detectable effect size can be set at a desirable level. If these steps are taken, there are only two parameters left undefined: α and β. A decrease in α translates into an increase in β, and vice versa. Therefore, for any given experiment, the researcher is left with a choice of: (1) setting one of these parameters to a pre-determined level, or (2) attempting to balance the two parameters.

Most researchers choose the first option and set $\alpha = 0.05$. The result of this choice is that the ability of the statistical test employed to detect a biologically significant difference (i.e., the power of the test) may be quite low. In the context of environmental monitoring, the consequences of the power of statistical tests, and of setting α and β, are critical (Underwood 1996). For the purpose of illustration, consider a simple experiment which compares the growth rates of plants exposed to AMD with those at a control site. A typical experiment would set α at 0.05 with the result, given other constraints on experiments, that β might become 0.25. In this case, the chance of a Type II error (i.e., of not detecting a difference that actually exists between control and treatment plants) is 5 times that of a Type I error (i.e., detecting a difference that does not actually exist). The consequence of this discrepancy in error probabilities is that there is an inherent bias in the experiment toward making an error that would, in this example, erroneously fail to detect an effect of AMD on plant growth rates.

The alternative procedure is to set α and β equal to one another. In the experiment described above, α and β would be set at 0.122. In this case, either type of error is equally likely. In an examination of environmental effects of AMD, this would seem to be a more logical procedure, as there is no obvious justification for biasing the experiment towards a Type II error. If α and β are set to different values, there should be some justification for introducing the bias into an experiment. All parameters should be set according to the specific circumstances of the particular study. The values of both α and β, as well as the justification for these values, should be reported.

Unfortunately, many studies are limited in the amount of background information which is available. This information is necessary to determine what minimum detectable effect size and variance values are appropriate. If no previous examinations have been conducted on the system, it will be very difficult to determine the level at which these parameters should be set. In such studies, *a priori* power analyses, as described above, are very difficult to apply objectively. A different approach which may be taken is an *a posteriori* power analysis. This approach consists of gleaning effect sizes and variances from the experiments, then estimating the power of the statistical tests after they have been conducted. While this approach does not allow a genuine adjustment of α and β values, it does provide useful information on the likelihood that the tests resulted in errors. The results can then be applied to the design of any subsequent experiments. Furthermore, they can provide insight into the usefulness of the experiments in inferring conclusions about the questions being examined.

1.3. Research Hypotheses

Given all the information outlined above, it is possible to formulate a series of hypotheses which can be tested mensuratively and experimentally:

1. *F. gardneri* plants constitute a smaller proportion of cover near Britannia Beach than in reference areas.
2. Filamentous green algae constitute a smaller proportion of surface cover near Britannia Beach than in reference areas.
3. *F. gardneri* plants are shorter near Britannia Beach than in reference areas.
4. Extant *F. gardneri* plants near Britannia Beach produce fewer gametes than those in reference areas.
5. *F. gardneri* plants near Britannia Beach will have a higher body burden of copper than those at reference sites.
6. Growth rates of adult *F. gardneri* transplanted to Britannia Beach will be lower than those at control sites.
7. Survivorship of adult *F. gardneri* transplanted to Britannia Beach will be lower than that at control sites.
8. Copper body burden of *F. gardneri* transplanted to Britannia Beach will be higher than that at control sites.

Hypotheses 1 through 5 will be addressed in Chapter 2; hypotheses 6 through 8 will be addressed in Chapter 3.

2. DISTRIBUTION AND REPRODUCTIVE FUNCTION OF ALGAE NEAR BRITANNIA CREEK IN RELATION TO ACID MINE DRAINAGE

2.1. Introduction

At the outset of this investigation, there had been some quantification of the intertidal fauna near Britannia Beach (e.g., Levings and McDaniel 1976; Grout *et al.* 1998, 1999), but no such work had been done on algae. There was a need, then, to quantify the algal community to determine what, if any, differences exist between Britannia Beach and other, uncontaminated sites.

Aside from a thin layer of green algae in the high intertidal, there is no apparent life within approximately 100 m of Britannia Creek. Farther from this creek, a dense cover of filamentous green algae and a few scattered barnacles appear on cobbles and boulders. Still farther from Britannia Creek, about 1000 m north and 600 m south, there is the first sign of *Fucus gardneri* Silva. These plants appear to be somewhat diminutive in both length and breadth. As one moves past this point, *F. gardneri* cover gradually increases to levels similar to those at other places in upper Howe Sound. (pers. obs.)

A series of hypotheses (section 1.3) concerning *F. gardneri* plant length, cover and gamete production and filamentous green algal cover were formulated and tested. The sampling program was designed to examine both the areas where *F. gardneri* is absent and the fringe areas where it grows nearest to Britannia Creek. Sampling was also done in several seasons to determine if patterns may be visible at some times but not at others.

2.2. Methods

2.2.1. Dissolved Copper in Water

Dissolved copper concentrations in water at a series of stations along the east and west shores of Howe Sound (Figure 2.1) were measured in an associated study of the effects of AMD on the blue mussel (*Mytilus edulis*; Grout *et al.* 1999). Collections were done at four times in 1998: April 29, May 15, May 28 and June 8. Samples were collected from surface water and immediately filtered through a 0.45 μm polycarbonate filter into acid-washed polyethylene bottles. This filtration removed particulate copper, as dissolved copper is thought to better reflect the amount of metal available to organisms (see section 1.2.4.A). Samples were acidified with 1 mL of concentrated nitric acid and returned to the laboratory. Metal analysis was conducted by graphite furnace atomic absorption spectrometry (GF-AAS).

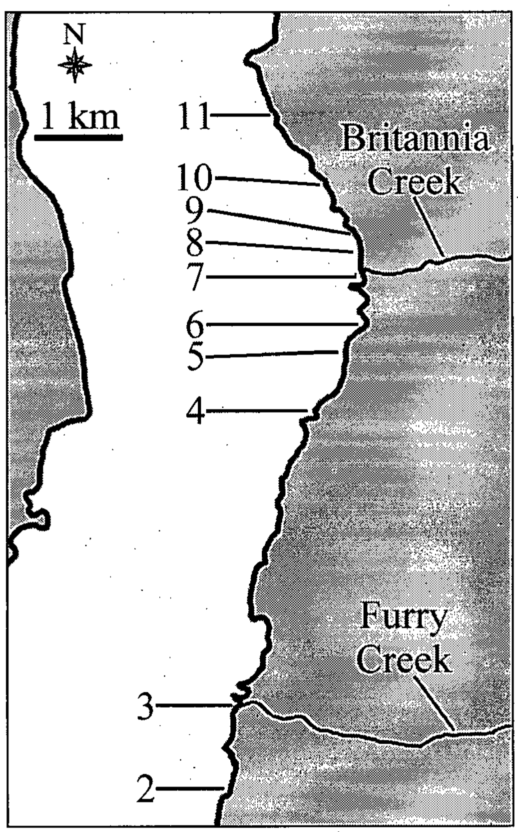

Figure 2.1. Locations of stations where dissolved copper was measured. From Grout and Levings (in preparation). Map from Canadian Hydrographic Service Chart #3526.

2.2.2. Quantification of *Fucus gardneri* length and algal cover

The locations of transect stations are indicated in Figure 2.2. All further references to individual transect stations are abbreviated as, for example, BB-D or FC-D, where BB and FC represent Britannia Beach and Furry Creek, respectively, and the last letter corresponds to the transect station itself. The labels are such that stations with the same label roughly match each other for distance from the appropriate creek mouth and substratum. For example, sites BB-B and FC-B are ~800-1000 m north of their respective creeks and both consist of a relatively steep rocky intertidal zone.

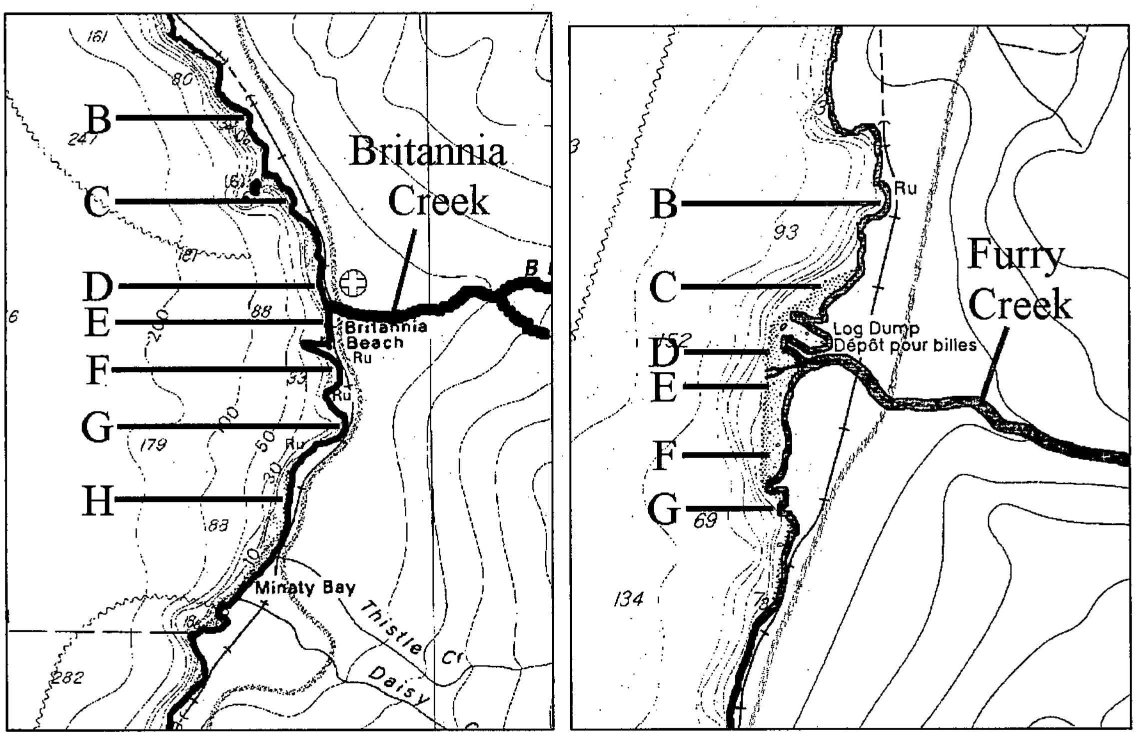

Figure 2.2. Locations of transect stations at Britannia Beach (left) and the corresponding control stations at Furry Creek (right). 1 cm = 350 m. From Canadian Hydrographic Service Chart #3526.

Stations were chosen in pairs at each of the two sites, Britannia Beach and Furry Creek. A gradation of distances from Britannia Creek was desired based on the assumption that there is a gradient of decreasing AMD concentration as one moves away from Britannia Creek. Stations at Britannia Beach were chosen to assess this gradient. A similar gradation was then sought at Furry Creek. The Furry Creek stations were intended to act as a control for the effects of the freshwater inflow from Britannia Creek. Where the influence of the Creek on salinity and turbidity was minimal due to the much greater influence of the Squamish River (i.e., during freshet), the sites could be considered as spatial replicates. Stations at Furry Creek were therefore chosen to match the distance from Britannia Creek as closely as possible. At the same time, substratum type and size can have important effects on distribution of *F. gardneri* and other algae. An attempt was thus made to select matching stations in each area with similar substratum types. Finally, an important consideration was safe access to the stations in all weather conditions and at all times of day. Access to the north of Britannia Beach was hindered by a train tunnel, while that north and south of Furry Creek was hindered by the extreme steepness of the intertidal and the backshore areas.

Sampling was conducted over two or three days on the lowest tides of each month. Transect surveys were conducted in June, July, August, October and December 1998.

The area of study at each transect station consisted of a 20 m horizontal reach of the intertidal zone. The vertical limits of the transect station were set by the limits of the *F. gardneri* zone. The upper and lower limits of the *F. gardneri* zone (typically 3.0 m and 1.5 m above chart datum, respectively) were measured at all stations where this alga grew and then extrapolated to stations from which it was absent. A horizontal transect line was laid along the top or bottom of the station. Three vertical transects were then randomly placed along the horizontal line and a 25 cm by 25 cm quadrat was randomly placed at three points along each vertical line, for a total of nine quadrats per transect station. The quadrat was pre-strung with nylon string in a grid pattern with squares 1.5 cm x 1.5 cm, and 20 of the intersection points were randomly marked with pieces of coloured wire.

Percent "canopy" cover estimates were obtained by recording the organism or substratum type under each of the marked points in the quadrat. Percent "surface" cover was then obtained by recording the object under all points after the canopy of *F. gardneri* had been moved aside. Categories assessed were: *F. gardneri*, filamentous green algae, rock (any size >2 mm), sand, mussel and barnacle. Due to the difficulty of identifying filamentous green algae in the field, all species were grouped into one functional group for purposes of cover data. Samples were taken at several stations during each collection period, returned to the laboratory and identified using the keys of Gabrielson *et al.* (1989). Other species of algae were occasionally encountered and were recorded as miscellaneous algae, then identified in the laboratory.

F. gardneri plant lengths were then measured. Five plants were selected randomly in each quadrat as the individual that was closest to each of five randomly marked intersection points. Plant length was measured as the distance from the holdfast to the end of the longest frond.

2.2.3. Oocyte Release

Sampling was conducted concurrently with the transect surveys. Collections took place in July, August, October and December 1998. Plants were collected haphazardly from the middle of the *F. gardneri* zone within 20 m of the transects. Fronds were sought which appeared to be reproductive, namely those that had swollen receptacles and conceptacles, were dark in colour and were covered in a large amount of exudate (Pollock 1969; DeWreede, pers. comm.). Three samples were collected at each station. Plants were pulled from the substratum by hand, placed in open plastic bags and transported on ice to the laboratory.

Oocyte release was induced by following the procedures of Pollock (1969) with slight modifications. Plants were left in the dark in their open collection bags for 48 hours at 4 °C. Non-reproductive portions of the fronds were then removed by cutting off areas where no swollen conceptacles were visible. The reproductive tips (called conceptacles) were then gently hand-scrubbed in running freshwater (dechlorinated West Vancouver city water, temperature 13-15 °C) for one minute, and were then repeatedly doused with this same running water in a 300 mL, 8 cm dish for one minute. The tissue was then immersed in still freshwater for 10 minutes. This water was removed and replaced with seawater from the West Vancouver Laboratory (W.V.L.) seawater system (salinity 27-33, temperature 7-10°C). After sitting in seawater for 10 minutes, receptacles were removed and rinsed into the sample dish. Oocytes were then counted under a dissecting microscope. For samples with large numbers of oocytes, a subsample was counted by mixing vigourously, then counting a delineated portion of the dish. Receptacle tissue was kept for surface area measurement. This was done by pressing tissue between two sheets of plexiglass, photocopying them, and scanning the photocopies using a computer image scanner. The area of each sample was calculated using SigmaScan Pro 5.0. Oocytes counts were then normalized to the surface area of the plant tissue which had produced them.

2.2.4. Copper body burden in *Fucus gardneri*

F. gardneri were collected from the middle of their vertical distribution, approximately 2.0 m above chart datum, in August 1998 concurrently with the transect data collection. Three plants were collected at each station. These plants were returned to the laboratory, rinsed and hand scrubbed three times with seawater from the W.V.L. seawater system and sent to ASL Laboratories (Vancouver, B.C.) for copper content analysis. Fresh plants were air dried in a laminar flow fumehood at ambient temperature, ground and then ashed at 470°C for 24 hours in a muffle furnace. Ashed material was digested in a 1:1 mixture of concentrated nitric acid and concentrated hydrochloric acid at 95°C for 2 hours. Copper analysis was carried out using Flame Atomic Absorption Spectrophotometry (FAAS).

2.2.5. Statistical analyses

All statistical comparisons were carried out in one of three computer programs: Microsoft Excel 5.0, Systat 7.0 or SPSS 8.0. *F. gardneri* percent cover, plant length, oocyte release, copper body burden and filamentous green algal cover were all compared across sites using a one-way analysis of variance (ANOVA) with $\alpha = 0.05$. At some stations, certain measurements yielded values of zero in all quadrats; for example, percent cover of *F. gardneri* at stations BB-C through BB-F was consistently 0. These measurements could not be analyzed by ANOVA as they have no variance. These stations were omitted from the ANOVA, but the results can be interpreted based on their obvious contrast with stations with high values for the measurement in question. If significant differences were detected, a Student-Newman-Keuls (SNK) test was used. The SNK test compares all stations to each other and forms homogeneous groups of stations. These groups are constructed so that stations within a given group are not significantly different from each other at $\alpha = 0.05$, but are significantly different from stations in all other groups. Occasionally, the ANOVA will detect differences, but the SNK test will be unable to form any homogeneous groups due to the latter test's lower power.

Some violations of the assumptions of parametric statistics, namely the assumptions of equal variances and of normal distributions, were detected using Levene's test and the Kolmogorov-Smirnov test, respectively. Transforming the data did not remove these violations. Most non-parametric procedures, while not requiring normality of the data, still require equal variances in all samples. While ANOVA and SNK tests do make the assumptions listed above, they are recognized to be very robust to departures from normality and equality of variances (Zar 1996, Underwood 1997). Therefore, parametric ANOVA and SNK tests are used despite violations of assumptions.

2.3. Results

2.3.1. Dissolved copper in water

Figure 2.1 indicates the locations of sampling for dissolved copper concentrations, and Figure 2.3 shows the concentration of copper found at these stations. Concentrations of dissolved copper are consistently highest at station 7, which is nearest the mouth of Britannia Creek. Copper concentrations are elevated to the north of the Creek mouth (stations 8 and 9) during all data collections but one (station 9 on April 29). No such elevation is evident to the south of Britannia Creek (station 6). A temporal trend, consistent with Chretien (1997) and R. McCandless' (unpublished data) findings, is evident with copper concentrations increasing to a peak in late May, then declining.

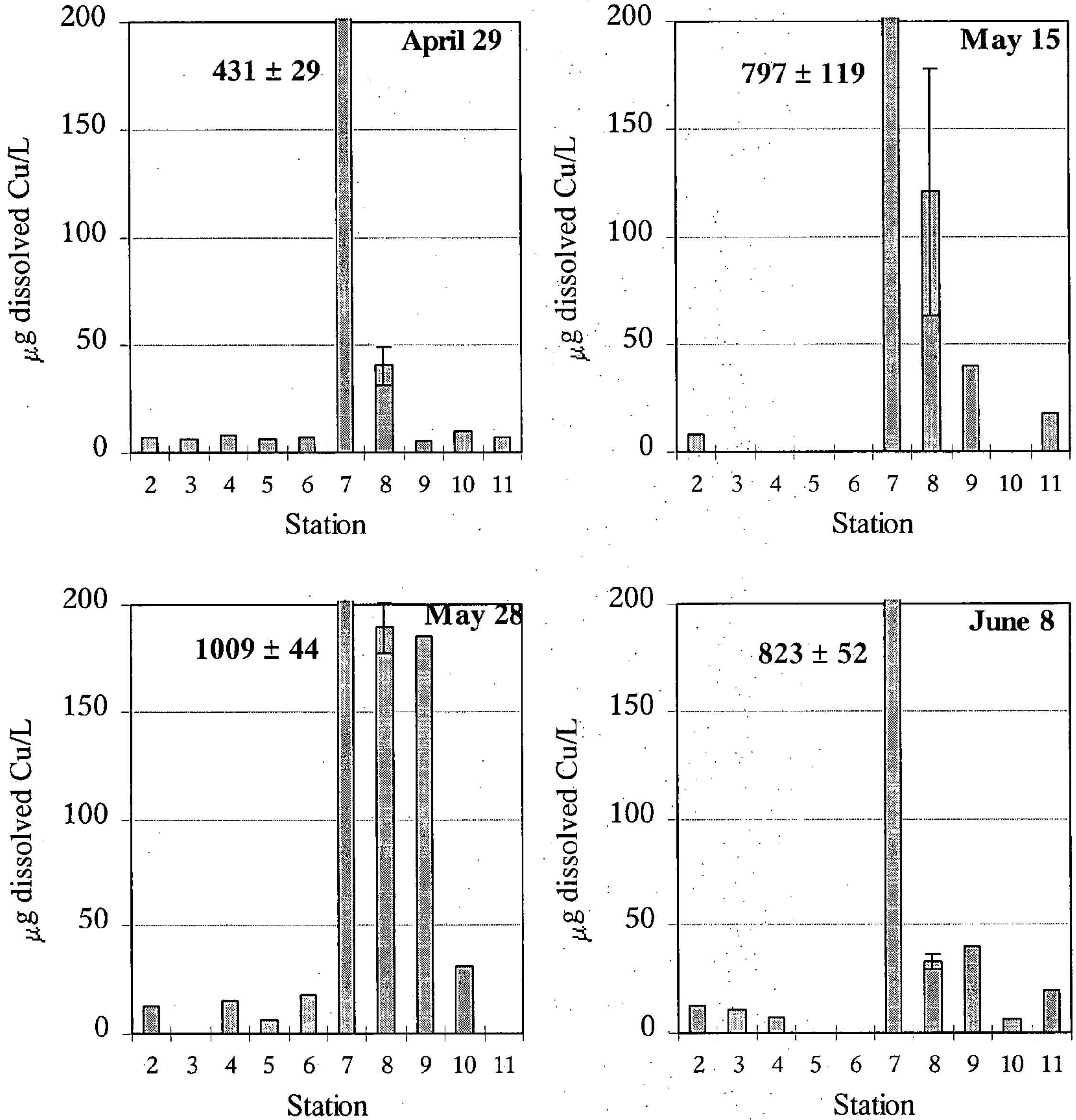

Figure 2.3. Concentration of dissolved copper in Howe Sound surface from April-June 1998. Zero values indicate concentrations below the detection limit of 5 µg Cu L^{-1}. Stations 7 and 8 comprised 3 samples each; error terms are the standard errors for these measurements. All other stations comprised only one sample per time point. Values for station 7 are reported as numbers to allow clear presentation of values at other stations, which were much lower. From Grout and Levings (in preparation).

The variability in metal dispersal is apparent in several aspects of these data. First, the large error bars at station 8 on May 15 indicate variability of copper concentrations on a small (<10 m) spatial scale. Second, the variation in differences between copper levels at stations 8 and 9 indicates the complexity of circulation processes which, in one case (June 8), leads to slightly higher metal concentrations at the station farther north of Britannia Creek. This variability leads to great difficulty in trying to correlate any other observations with specific concentrations of copper.

2.3.2. *Fucus gardneri* cover

Percent cover estimates for *F. gardneri* are presented in Figure 2.4. Results from statistical tests are shown in Table 2.1. Cover of *F. gardneri* was quite variable at all sites and at all time points. No *F. gardneri* was found at any time at stations BB-C, BB-D, BB-E or BB-F. Outside of this zone of *F. gardneri* absence, however, no significant differences were detected among estimates of *F. gardneri* cover at any stations, with one exception. This lack of significant differences occurs despite an apparent trend toward lower cover of *F. gardneri* at stations BB-G and BB-H than at FC stations. A general temporal trend is visible as a peak in *F. gardneri* cover in July, with steadily decreasing cover to a minimum in December.

2.3.3. Filamentous green algal cover

Percent cover of filamentous green algae is presented in Figure 2.5. All numbers were obtained from surface cover data as opposed to canopy cover to avoid bias at sites with high cover of *F. gardneri*. Results of statistical analyses are listed in Table 2.2.

Filamentous green algae generally comprised two groups: *Enteromorpha intestinalis* (L.) Link and *Ulothrix* spp. Further identification of the latter was not possible due to variability in specimens within the ranges listed in the keys. In addition to these two species, a thin layer of *Chlorella* spp., a single-celled green microalga, was found on the rocks within 10 m of the mouth of Britannia Creek. This alga is regarded as a freshwater alga (Stein 1975), which explains its

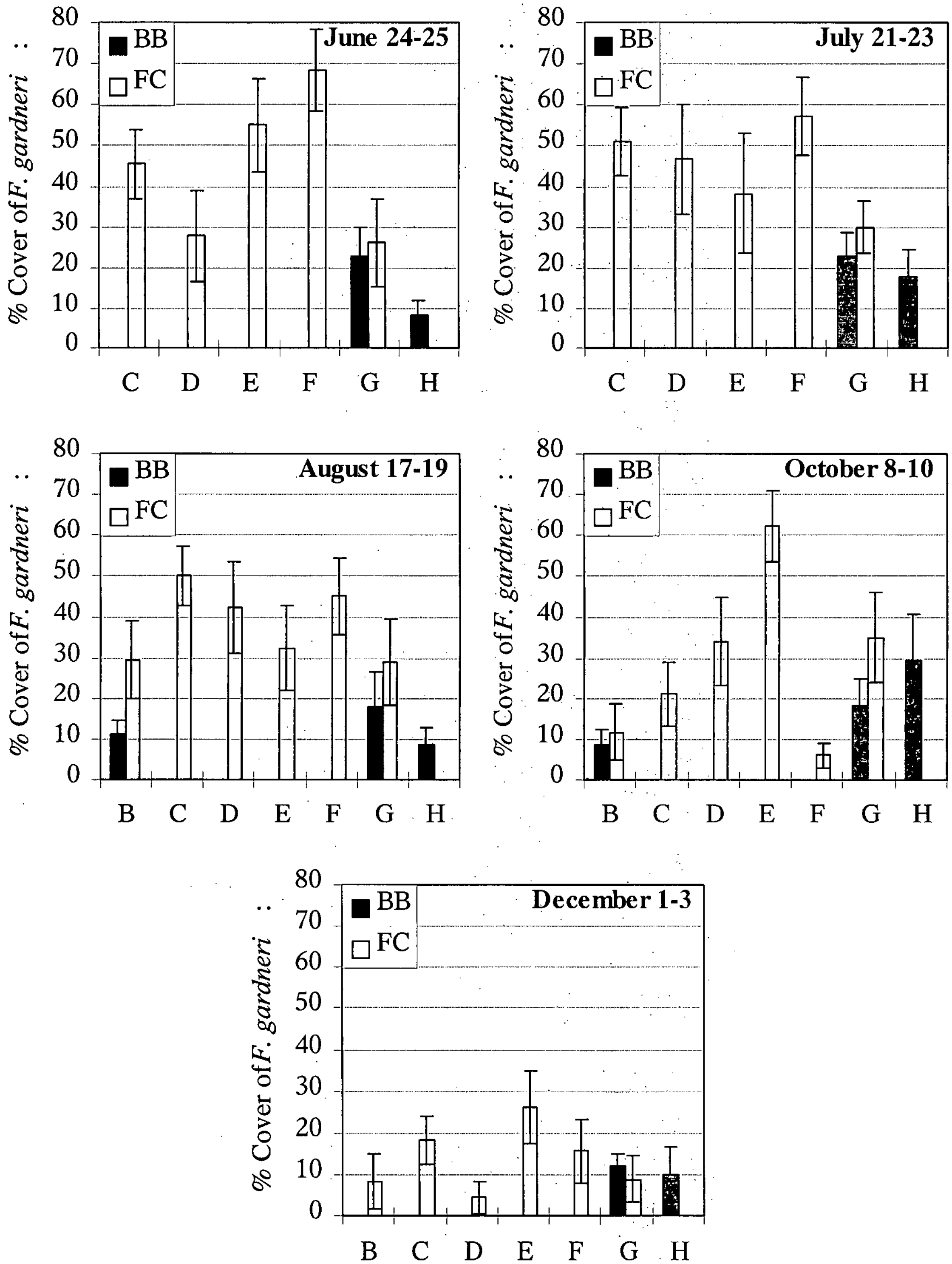

Figure 2.4. Percent cover of *Fucus gardneri* as measured from June to December 1998. BB = Britannia Beach. FC = Furry Creek. See Figure 2.2 for locations of sampling sites. Sampling was not conducted at sites B until August. Error bars are ± 1 standard error; n = 9 for all stations.

Table 2.1. Statistical analysis of *Fucus gardneri* percent cover from transect study. $\alpha = 0.05$ in all tests. BB = Britannia Beach. FC = Furry Creek. See Figure 2.2 for locations of sampling sites. Stations BB-C, BB-D, BB-E and BB-F were omitted in all months due to complete lack of *F. gardneri*. Station BB-B was omitted in December only. SNK tests were conducted if the ANOVA detected significant differences. All stations within a set of square brackets comprise a homogeneous group. See section 2.2.5 for explanation of SNK grouping.

Sampling Period	P-value from ANOVA	SNK grouping	
June	**<0.001**	no homogeneous groups detected	
July	0.051	N/A	N/A
August	**0.008**	no homogeneous groups detected	
October	**<0.001**	[FC-E]	All other BB and FC
December	0.307	N/A	N/A

limited distribution at Britannia Creek. Furthermore, it formed a layer only 2-3 cells thick on rocks in a very small portion of the study area and thus contributes very little to marine primary production in this area. Consequently, this alga is not discussed further here.

Filamentous green algal cover tended to be higher at all stations near Britannia Creek than at stations near Furry Creek. Cover of filamentous green algae was significantly higher at stations BB-C and BB-F than at all other stations in June, July and August. An additional statistically significant difference was detected in December, although the relatively high cover of filamentous green algae at station BB-F in December appeared to be composed entirely of senescing plants. Cover of filamentous green algae was highest at all sites in the summer months, with a decline in October and an almost complete lack of filamentous green algae in December.

2.3.4. *Fucus gardneri* plant length

Lengths of plants at each station are presented in Figure 2.6. Some sample sizes were <9 because some quadrats contained no *F. gardneri* and so were not included in the analysis. Most

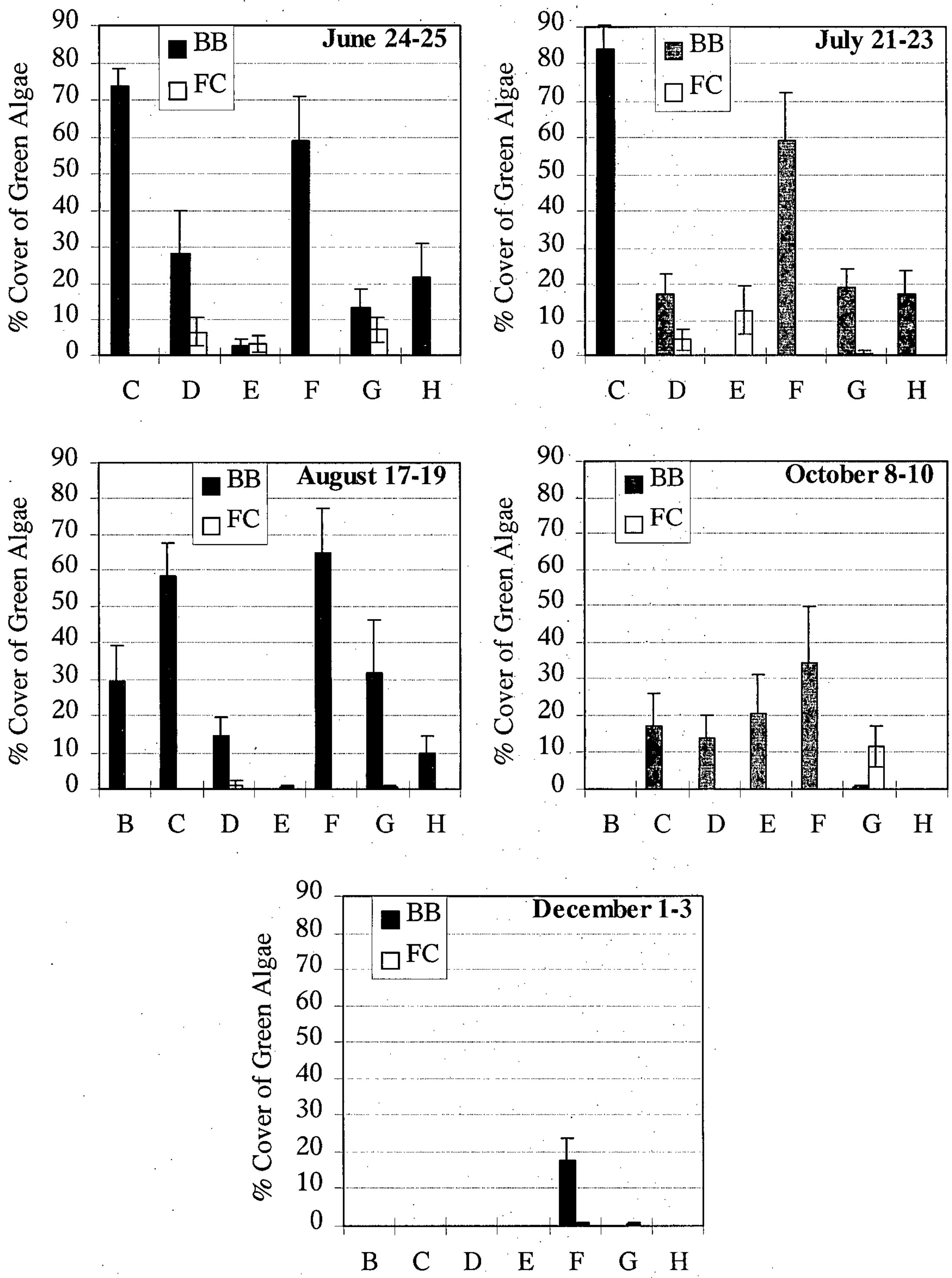

Figure 2.5. Percent cover of filamentous green algae as measured from June to December 1998. BB = Britannia Beach. FC = Furry Creek. See Figure 2.2 for locations of sampling sites. Sampling was not conducted at sites B until August. Error bars are ± 1 standard error. n = 9 for all stations.

Table 2.2. Statistical analysis of filamentous green algal cover from transect study. $\alpha = 0.05$ in all tests. BB = Britannia Beach. FC = Furry Creek. See Figure 2.2 for locations of sampling sites. SNK tests were conducted if the ANOVA detected significant differences. See section 2.2.5 for explanation of SNK grouping.

Sampling Period	P-value from ANOVA	SNK grouping	
June	**<0.001**	[BB-C, BB-F]	All other BB and FC
July	**<0.001**	[BB-C, BB-F]	All other BB and FC
August	**<0.001**	[BB-C, BB-F]	All other BB and FC
October	0.199	N/A	N/A
December	**0.002**	[BB-F]	[FC-F, FC-G]

of the sample sizes, however, were ≥7. Results of statistical tests are presented in Table 2.3.

Plant lengths, like the other measures taken, are quite variable at most times and locations. *F. gardneri* at Britannia Beach stations tended to be shorter than those at Furry Creek, but, while some differences were detected by the ANOVA, they were not elucidated by the SNK test. Plants appeared to be longest in June and July, and length then declined to a minimum in December.

2.3.5. Oocyte release

July and August collections yielded extremely low numbers of oocytes. For example, of three *F. gardneri* samples from a given site, often only one would yield oocytes, with usually less than 5 egg cells released. In contrast, October and December samples yielded very high numbers of oocytes, frequently more than 600 in a given sample. Therefore, only October and December data are presented and analyzed (Figure 2.7). Results of statistical tests are presented in Table 2.4. Significantly more oocytes were released by *F. gardneri* from station BB-B than at all other stations in October, while there were no differences among other stations. No

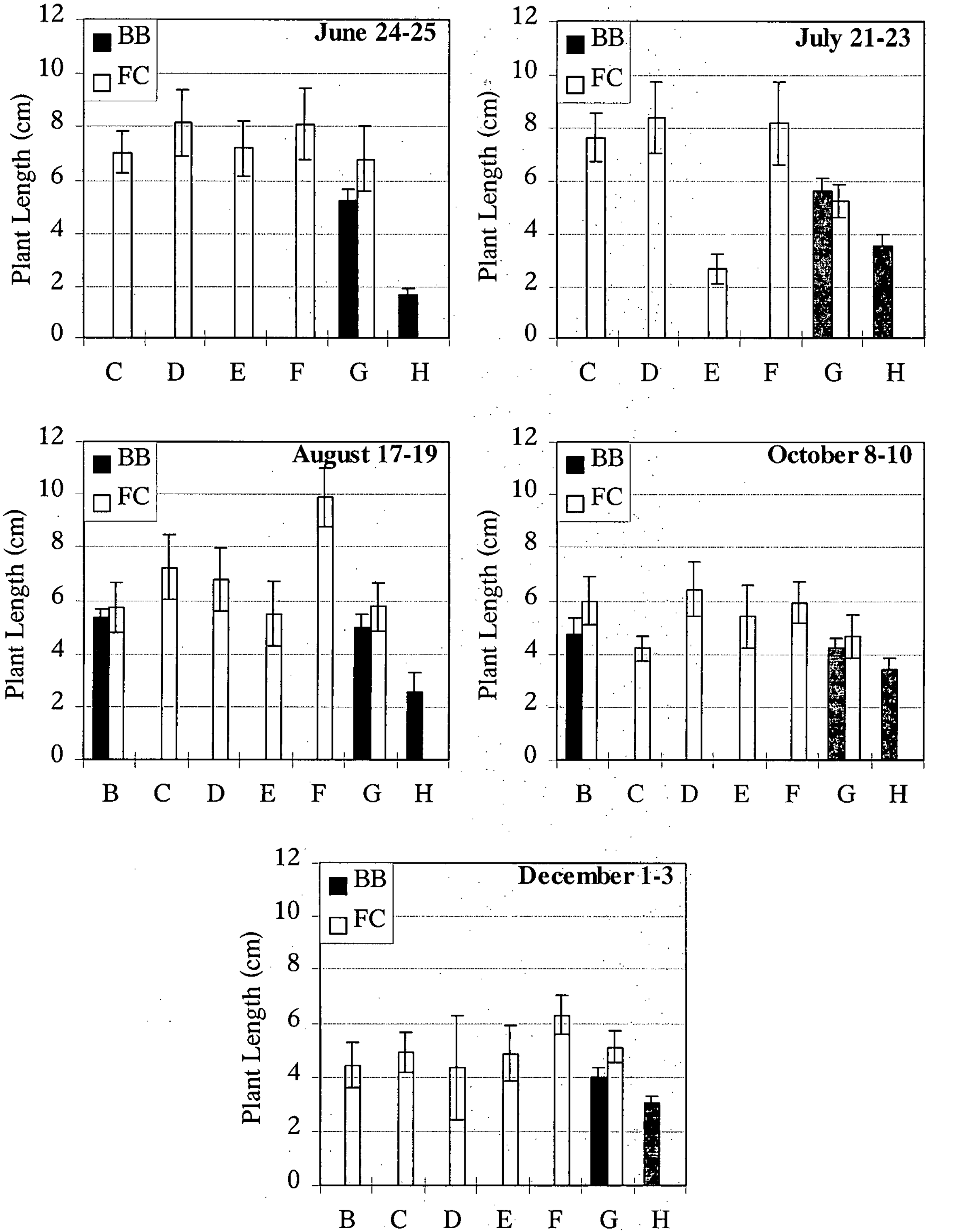

Figure 2.6. Mean length of *Fucus gardneri* as measured from June to December 1998. **A**, June 24-25; **B** July 21-23; **C**, August 17-19; **D** October 8-10, **E**, December 1-3. BB = Britannia Beach. FC = Furry Creek. See Figure 2.2 for locations of sampling sites. Some stations had no *F. gardneri* (see Figure 2.4), so no plant lengths are given. Sampling was not conducted at sites B until August. Error bars are ± 1 standard error. n varied from 5 to 9, averaging 7.9, at sites with *F. gardneri*.

Table 2.3. Statistical analysis of *Fucus gardneri* plant length from transect study. $\alpha = 0.05$ in all tests. BB = Britannia Beach. FC = Furry Creek. See Figure 2.2 for locations of sampling sites. SNK tests were conducted if the ANOVA detected significant differences. See section 2.2.5 for explanation of SNK grouping.

Sampling Period	P-value from ANOVA	SNK grouping	
June	**<0.001**	no homogeneous groups detected	
July	**<0.001**	no homogeneous groups detected	
August	**0.001**	no homogeneous groups detected	
October	0.157	N/A	N/A
December	0.350	N/A	N/A

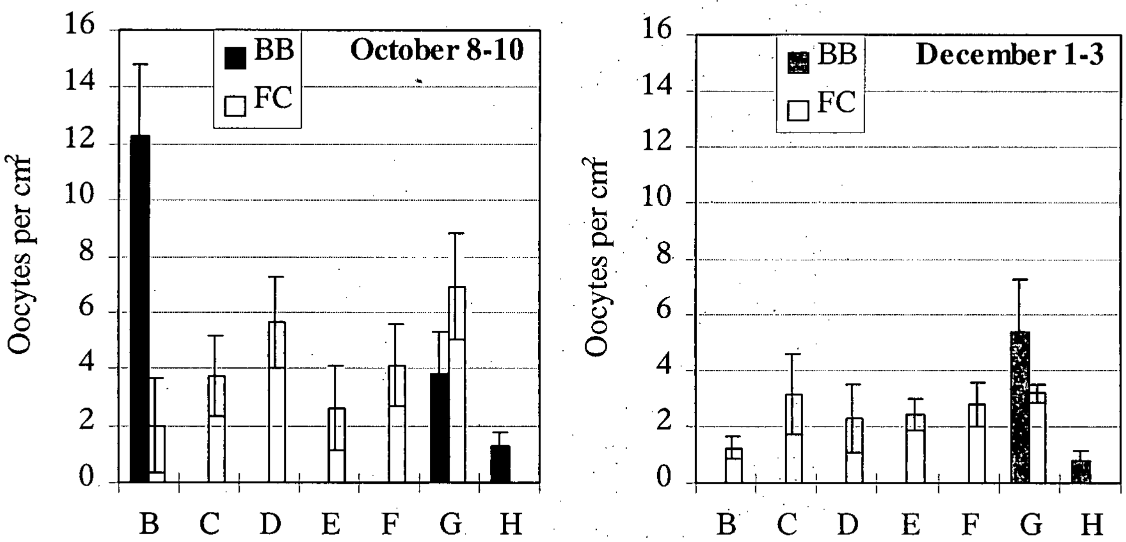

Figure 2.7. Oocyte release from *Fucus gardneri* as measured in October and December 1998. BB = Britannia Beach. FC = Furry Creek. See Figure 2.2 for locations of sampling sites. Some stations had no *F. gardneri* (see Figure 2.4), so no oocyte counts are given. In October, n = 3 at all sites; in December, n = 3 at BB-G and FC-G, n = 4 at FC-C, n = 5 at all other stations. All values are normalized to the surface area of the source plant material.

significant differences were detected among oocyte releases from December samples. There is no general tendency toward higher or lower oocyte releases at Britannia Beach.

Table 2.4. Statistical analysis of oocyte release. $\alpha = 0.05$ in all tests. BB = Britannia Beach. FC = Furry Creek. See Figure 2.2 for locations of sampling sites. SNK tests were conducted if the ANOVA detected significant differences. See section 2.2.5 for explanation of SNK grouping.

Sampling Period	P-value from ANOVA	SNK grouping	
October	**0.006**	[BB-B]	All other BB and FC
December	0.105	N/A	N/A

2.3.6. Copper body burden in *Fucus gardneri*

Results of copper body burden measurements are shown in Figure 2.8. Results of statistical comparisons are shown in Table 2.5. Copper body burdens in *F. gardneri* from all Britannia Beach stations are significantly higher than those in algae from Furry Creek stations.

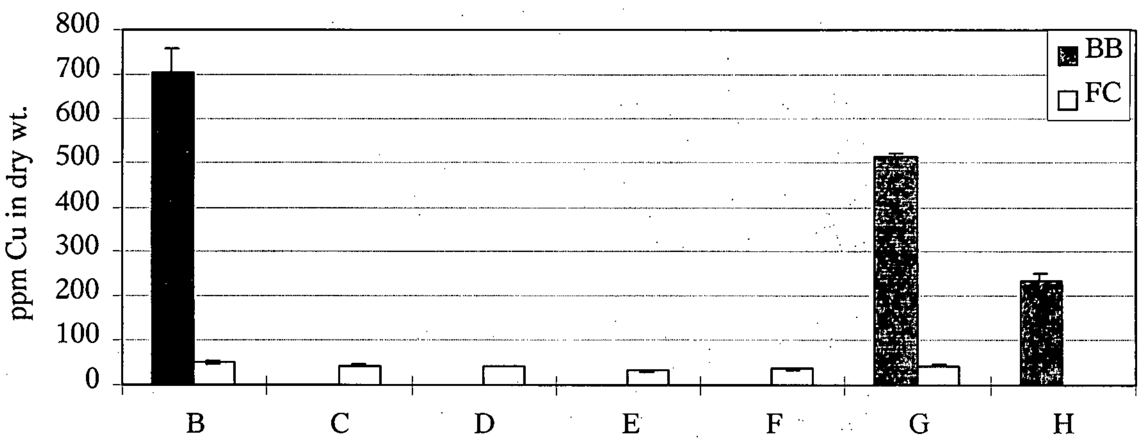

Figure 2.8. Copper body burden in dry weight of *Fucus gardneri* collected August 1998. BB = Britannia Beach. FC = Furry Creek. See Figure 2.2 for locations of sampling sites. Some stations had no *F. gardneri* (see Figure 2.4), so no plants were collected. Error bars are ± 1 standard error. n = 3 at all sites.

Table 2.5. Statistical analysis of copper body burden in *Fucus gardneri*. $\alpha = 0.05$ in all tests. BB = Britannia Beach. FC = Furry Creek. See Figure 2.2 for locations of sampling sites. SNK tests were conducted if the ANOVA detected significant differences. See section 2.2.5 for explanation of SNK grouping.

Cu in plants	Sampling Period	P-value from ANOVA	SNK grouping			
	August	**<0.001**	[BB-B]	[BB-G]	[BB-H]	All FC

2.4. Discussion

2.4.1. Dissolved copper in water

The measurements of copper concentrations in seawater are limited in several respects. First, the samples were taken over only a five week period. While this is very useful information for this particular interval, these data give limited insight into metal dispersal at other times of the year. The data from Chretien (1997; Figure 1.3) provide a better picture of dissolved copper levels over the entire year, but no spatial trend can be inferred from his data.

A second limitation of the copper concentration data is that they measure only dissolved copper. Due to the highly variable speciation of copper in estuarine water, it is extremely difficult to use one measure of copper concentration to accurately assess and predict effects on biota. Measuring dissolved copper as opposed to total copper is one way of reducing error, as free copper is likely the form of the metal that is most available to organisms. However, dissolved copper includes not only free metal, but also some organically bound, inorganically complexed and colloidal copper, forms which can be less available for uptake by organisms. Additionally, Luoma *et al.* (1982) have found evidence that *Fucus vesiculosus* can accumulate particulate copper. If this occurs with *F. gardneri* at Britannia Beach, dissolved copper would not be the only source of the metal to the algae.

Much useful information can, however, be gathered from these data. A spatial trend of copper is clearly visible (Figure 2.3). The most striking feature in all four graphs is the spike of copper at site 7, directly off the mouth of Britannia Creek. It is quite apparent that the high loading of copper in the Creek translates into elevated concentrations of dissolved copper in Howe Sound, at least in the immediate vicinity of Britannia Creek.

In addition, the dominant dispersal pattern of copper from Britannia Creek is visible in the elevated dissolved copper levels at stations 8 and 9 and the concurrent lack of consistently high copper levels at station 6. This pattern is consistent with the surface circulation pattern near Britannia Beach described by Buckley (1977; Figure 1.4), which causes the plume of Britannia Creek to flow northward as it enters Howe Sound. The dispersal of metals might also be responsible for the asymmetry in *F. gardneri* cover around the Creek, as is evident in Figure 2.4.

2.4.2. *Fucus gardneri* cover

A conspicuous absence of *F. gardneri* from the shoreline near Britannia Creek was apparent at the outset of this study in the spring of 1997. Stations BB-C, BB-D, BB-E and BB-F were all completely devoid of this alga (see Figure 2.2). The area where *F. gardneri* was absent, measured in a straight line from the Creek mouth, extended over a total of approximately 1600 m. Stations BB-B and BB-G are the nearest locations to the north and south of Britannia Creek, respectively, where *F. gardneri* grows. BB-B is approximately 1000 m north of the Creek mouth, while BB-G is approximately 600 m to the south of the Creek. The cover of *F. gardneri* at these two stations, along with an additional station to the south of the Creek (BB-H) was monitored and compared to a similar series of stations near Furry Creek. An analysis of variance detected significant differences in the cover of *F. gardneri* among stations which supported the alga in three of five months: June, August and October 1998 (Table 2.1). The SNK test only formed homogeneous groups in October, however, with FC-E having a higher percent cover of *F. gardneri* than all other sites. This general lack of differences is due to the high variances that were present at all sites. *F. gardneri* is patchily distributed on the scale of the quadrats used (25 cm x 25 cm; pers. obs.), resulting in high variances and, therefore, low power of any statistical tests.

A trend is evident in the data, however. In all months except December, the percent cover of *F. gardneri* at all the Britannia Beach stations where these algae were present was lower than at all Furry Creek stations, although the differences were not significant (Figure 2.4; Table 2.1). This suggests that there may be a small effect of AMD on the cover of *F. gardneri* at these stations which was not detectable using the methods and sample sizes in this study. The biological importance, in terms of algal biomass and associated fauna, of so small a difference as that observed at these stations is debatable. Measurement of biomass might be a more appropriate way of determining this biological significance. The lack of any trend toward lower *F. gardneri* cover at Britannia Beach in December is the result of a general decrease in algal cover which occurs at most other sites.

The absence of *F. gardneri* from the 1600 m surrounding Britannia Creek, which was not included in the statistical analysis, is obvious from the data presented in Figure 2.4. The asymmetry of the area from which *F. gardneri* is absent, with a greater area of absence north of Britannia Creek than south, is consistent with the dispersion of metals and circulation patterns in Howe Sound, as described above. Any relationship between the distribution of AMD and the absence of *F. gardneri* which might be inferred from these observations is exclusively correlative. However, AMD appears to be the most likely cause of the disrupted distribution of this alga near Britannia Creek. All other creek mouths observed in upper Howe Sound, including Furry, Potlatch and Woodfibre Creeks (see Figure 1.1 for locations), are dominated by a thick cover of *F. gardneri* (pers. obs.). An alternative explanation for the dearth of *F. gardneri* at Britannia Creek relative to Furry Creek might be the higher turbidity and lower salinity the plants would encounter at the former location due to its proximity to the Squamish River, which dominates the salinity regime in upper Howe Sound during freshet. However, extremely dense populations of *F. gardneri* were found to the north of Britannia Creek at Watts Point (see Figure 1.1 for location; pers. obs.), which is much closer to the Squamish River. As well, the west side of Howe Sound (e.g., the mouth of Woodfibre Creek) encounters higher turbidity and lower salinity than Britannia Beach during freshet (Stockner *et al.* 1977, Grout *et al.* 1999). Despite these patterns of freshwater distribution, however, the mouth of Woodfibre Creek has *F. gardneri* percent cover in excess of 80% in some locations (pers. obs.). Salinity and turbidity do not appear to be viable explanations for the lack of *F. gardneri* at Britannia Beach.

2.4.3. Filamentous green algal cover

In general, filamentous green algal assemblages in areas where *F. gardneri* was present comprised both *Enteromorpha intestinalis* and *Ulothrix* spp., while those at the stations near Britannia Creek from which *F. gardneri* was absent contained only *E. intestinalis*. These filamentous green algae have a seasonal pattern of abundance, taking advantage of high sunlight and warm temperatures during the summer months, then dying back in the fall and winter. This temporal trend is very evident in the measurements shown above (Figure 2.5), and is consistent with findings elsewhere (Prange 1976; Pomeroy 1977; Munda & Markham 1982) that filamentous green algae tend to have sharp seasonal peaks in biomass. These species appear to be well adapted to summer growth; several studies (Kim & Lee 1993; Einav *et al.* 1995; Kim & Lee 1996) have found that *Enteromorpha* spp. are very tolerant of high temperatures, desiccation and fluctuations in salinity.

At stations BB-D and BB-E (see Figure 2.2 for locations of stations) on either side of the mouth of Britannia Creek, cover of all algae was generally very low (Figures 2.4 and 2.5). It appears that AMD concentrations at these stations are high enough, at least periodically, to preclude any growth by marine algae. Farther from the Creek, at stations BB-C and BB-F, filamentous green algal cover is significantly higher than that at all other stations (Figure 2.5; Table 2.2). Still farther away from Britannia Creek, cover of green algae was again lower where *F. gardneri* occurred (Figures 2.4 and 2.5). Filamentous green algal and *F. gardneri* cover in June, July and August were negatively correlated when stations BB-D and BB-E were excluded (Table 2.6).

Table 2.6. Correlation analysis of mean green algal percent cover and *Fucus gardneri* percent cover at Britannia Beach and Furry Creek stations. Stations BB-D and BB-E were excluded due to the presumed severe influence of AMD on filamentous green algae. n = 9 stations for June and July, n = 11 stations for August.

Month	Spearman correlation coefficient	P-value for correlation
June	-0.966	**<0.001**
July	-0.929	**<0.001**
August	-0.862	**0.001**

The most likely explanation for the heavy cover of *Enteromorpha intestinalis* near Britannia Creek is that this alga can tolerate higher concentrations of AMD than can *F. gardneri*. Several authors have found *Enteromorpha* spp. to be much more tolerant of copper than other algae. Correa *et al.* (1996) exposed *Enteromorpha compressa* to varying concentrations of copper in culture and found growth rates to be unaffected by ≤635 μg copper L^{-1}. Reed & Moffat (1983) exposed *E. compressa* from both ship-fouling (i.e., copper paint-exposed) and non-fouling populations to varying concentrations of copper. They found that the growth rate of plants which had previously been exposed to the metal were unaffected by ≤609 μg copper L^{-1}, while that of plants from non-fouling populations was decreased by 114 μg copper L^{-1}. These results suggest that tolerance to copper is built up through exposure. In comparison with Reed & Moffat's (1983) results, heavy *E. intestinalis* cover was found near Britannia Creek at sites which were exposed to dissolved copper levels ≤190 μg Cu L^{-1}. Direct comparison is difficult, however, as the speciation of the metal at Britannia Beach is likely different from that in Reed & Moffat's (1983) laboratory experiments. Furthermore, the temporal variability of dissolved metal levels in Howe Sound and the different species of algae used in the two studies makes any direct comparison overly ambitious.

Castilla (1996) examined algal communities at Caleta Palito, Chile over a 19-year period. From 1975 to 1990, untreated mine tailings with 6000-7000 μg copper L^{-1} in the tailing water were discharged directly onto the intertidal near the Salado River. Castilla (1996) found that *Enteromorpha compressa* cover in the intertidal increased from <10% to >90% within 3 years of the initiation of tailing dumping. After 1990, tailings were treated to remove solids, after which the "clear tailing water" was released into the Salado River. Castilla (1996), in 1994, measured 2400 μg dissolved copper L^{-1} at the mouth of this river and 26.8-31.8 μg dissolved copper L^{-1} at a site 50 m south of the river mouth. He found that *E. compressa* remained the dominant alga in the area four years after this modification of dumping procedures. Finally, he observed that *E. compressa* dominated the intertidal up to 7 km north of the river mouth, comprising >80% of the cover. These data suggest that *Enteromorpha* spp. often persist—and sometimes flourish—in copper-polluted environments where other algae cannot survive. Several authors (Say *et al.* 1990; Castilla 1996) cite this alga as a "sentinel" species: one which can survive where other algae cannot in areas of pollution by copper and other metals. This also appears to be the case at Britannia Beach, where *Enteromorpha intestinalis* is the dominant organism in terms of cover and biomass in the intertidal areas where *F. gardneri* is excluded.

Filamentous green algae are generally very limited in their distribution, however, wherever *F. gardneri* is abundant, often living in the high intertidal at the fringe of *F. gardneri*'s vertical limits (pers. obs.). Previous studies have examined the interactions among *Fucus* spp., ephemeral (i.e., seasonal) algae, including *Enteromorpha* spp., and herbivores such as *Littorina* spp. (Lubchenco 1983). Lubchenco (1983) proposed that in the absence of littorine grazing, ephemeral algae may inhibit the recruitment of juvenile *Fucus* spp. The inhibition is only temporary, however, as the seasonal ephemeral algae die out in the fall, allowing recruitment of *Fucus* spp. Qualitative observations at all sites in Howe Sound suggest that littorines are absent from the areas without *F. gardneri* (pers. obs.). Whether this absence is a result of acid mine drainage or the lack of perennial algae (i.e., food items) is not clear. It might be suggested that AMD eliminates littorine grazers from the intertidal, resulting in inhibition of *F. gardneri* by filamentous green algae. However, the extreme seasonal variation in the abundance of the latter would likely rule out this possibility. A more likely scenario, suggested by Lubchenco's (1983) study, is that *Fucus* spp. and littorines are excluded from the area near Britannia Beach by AMD, allowing *Enteromorpha* spp. unhindered access to intertidal habitat. At other locations, *Littorina* spp. preferentially feed on ephemeral species (Granado & Caballero 1991) and reduce the cover of filamentous green algae. While this model may apply at Britannia Beach, it is very speculative to extrapolate results obtained with different species of grazers and fucoids in New England to British Columbia. Chapman (1995) reviews several studies which suggest that Lubchenco's (1983) model may be site-specific, as other researchers have found results contrary to hers. Lubchenco's (1983) model is suggested here as one possible explanation for the patterns seen in Howe Sound; much experimental work would be necessary to confirm or refute its applicability to the findings in this study.

Another possible explanation for the heavy cover of filamentous green algae at stations BB-C and BB-F is that they are limited by copper in natural environments. Thus, the concentrations of copper at stations BB-D and BB-E may be toxic to these algae, while those at stations BB-B and BB-G were limiting. This hypothesis is not, however, supported by the work of Correa *et al.* (1996), who found that *E. compressa* in Chile grew equally well in 0, 63.5 and 635 μg copper L^{-1}. The concentrations of dissolved copper found at stations BB-B and BB-G (<5-25 μg copper L^{-1}) are well within this range. As well, Lewis & Cave (1982) state, based on an extensive review of the literature, that copper is probably never a limiting nutrient in natural waters.

2.4.4. Length of *Fucus gardneri*

Qualitative examination of *F. gardneri* nearest Britannia Creek prior to the outset of this study suggested that they were shorter than those at Furry Creek. Analyses of variance detected significant differences in mean length of *F. gardneri* among stations in June, July and August, but these differences were not clarified by the SNK test (Figure 2.6, Table 2.3). This finding is similar to that for *F. gardneri* cover (section 2.4.2); there was a trend toward shorter plant lengths at some Britannia Beach stations, although this trend was less pronounced and less consistent than that for *F. gardneri* cover. These differences might be statistically significant if larger sample sizes had been used, but the biological significance of such differences could again be questioned.

A temporal trend in plant lengths was evident in plants at Furry Creek, with a peak in plant length in July, then a steady decline into December. Thom (1983) found a similar trend in *F. gardneri* in Puget Sound, Washington State, where plants were shortest in February and longest in May and June. Interestingly, Ang (1991) found that *F. gardneri* (reported as *F. distichus*) in False Creek, British Columbia, were generally shorter than those at Furry Creek, and were longer on average in winter than in summer. The reason for this discrepancy over so short a geographical distance (~50 km) is not clear.

2.4.5. Oocyte release

July and August samples yielded very low numbers of oocytes. While the specimens had the characteristics of reproductively mature plants, they may have been in the early stages of maturity. As a consequence, it is possible that not many oocytes were mature enough to be released. By October, however, the plants may have been mature enough to release oocytes. Plants at only one station released significantly more oocytes than plants at others: plants at BB-B released significantly more oocytes than plants at other stations in October (Figure 2.7; Table 2.4). This is the opposite result of that which was hypothesized. It is possible that the populations were simply undersampled, and that the result was obtained by chance. Alternatively, the population at BB-B may comprise a homogenous cohort of plants which all enter their reproductive peak simultaneously. It is difficult to support or refute either of these possibilities because no *F. gardneri* were found at BB-B during the December survey.

Another critical consideration is the viability of the oocytes produced at stations BB-B, BB-G and BB-H. It is possible that these oocytes would not germinate in any area as a result of AMD toxicity during their pre-release development. Also, spermatozoa may be detrimentally affected by AMD, leading to a reduced reproductive capacity for the plants which is not detected by counting oocytes. Several studies reviewed in section 1.2.4.D (Chung and Brinkhuis 1986; Scanlan and Wilkinson 1987; Anderson *et al.* 1990) raise the possibility that microscopic algal propagules may be very sensitive to copper. There are no conclusive differences among the stations which support the original hypothesis that plants near Britannia Beach would produce fewer oocytes. However, this does not rule out other possible reproductive effects.

2.4.6. Copper body burden in *Fucus gardneri*

Plants at all three stations near Britannia Creek had significantly higher body burdens of copper than those near Furry Creek (Figure 2.8, Table 2.5). The term "body burden" is used here to describe the amount of copper which has been internalized by the plant, as well as metal which has been strongly bound outside the thallus. The plants were rinsed in seawater, as opposed to more aggressive chemical treatments, to remove any metal which is loosely associated with the plant, but to leave metal which is more strongly bound. The weaker rinse was employed for two reasons: (1) to make results comparable with literature values, and (2) copper does not necessarily need to be internalized to exert effects on organisms. Sorentino (1979) cites studies which show that low concentrations of copper can bind cell proteins and affect the permeability of the cell membrane. This suggests that external copper should be considered along with internal copper.

There have been numerous studies of metal content in *Fucus* spp. (Table 2.7), although most have examined habitats in Europe and fucoid algae other than *F. gardneri*. The levels of copper in this study agree well with those measured by Dunn *et al.* (1992) in Howe Sound. The slightly higher levels of copper Dunn *et al.* (1992) found at most sites may be partly attributed to the higher concentration of dissolved copper which would likely have been present at the time they collected, as AMD from the 4100 mine level was being discharged directly into Britannia Creek. Overall, the copper concentrations found in *F. gardneri* in Howe Sound appear to be

Table 2.7. Concentrations of copper in *Fucus* spp. and *Ascophyllum* spp., both fucoids. All studies rinsed algae in seawater before analysis. From: [1]Forsberg *et al.* 1988, [2]Söderlund *et al.* 1988, [3]Pedersen 1984, [4]Barreiro *et al.* 1993, [5]Bryan 1983, [6]Foster 1976, [7]Riget *et al* 1995, [8]Ho 1984, [9]Morris & Bale 1975, [10]Dunn *et al* 1992, [11]Current study.

Organism	**ppm Cu in dry wt.**	**Location**	**Comments**
F. vesiculosus	4.0-6.5 [1]	Baltic Sea	Unpolluted, exposed sites
F. vesiculosus	5.7-17.3 [1]	Baltic Sea	Sheltered, more polluted sites
F. vesiculosus	1.6-9.8 [2]	Baltic Sea	Expansion of sampling from [1]
F. vesiculosus	5.0-9.8 [3]	Norway	West coast fjord
F. vesiculosus	2-8 [4]	Spain	Lower estuary, mine water-polluted
F. ceranoides	30-60 [4]	Spain	Upper estuary, mine water-polluted
F. vesiculosus	4-37 [5]	England	Other estuaries
F. vesiculosus	293 [5]	England	Fal Estuary (mine water-polluted)
F. vesiculosus	7.4-10 [6]	England	Menai Straits
A. nodosum	6-18 [6]	England	Menai Straits
F. vesiculosus	1.30-3.30 [7]	Greenland	Unpolluted site
F. vesiculosus	(18) [8]	England	Tamar Estuary (unpolluted)
A. nodosum	(26) [8]	England	Tamar Estuary (unpolluted)
F. vesiculosus	(534) [8]	England	Fal Estuary (mine water-polluted)
A. nodosum	(476) [8]	England	Fal Estuary (mine water-polluted)
F. vesiculosus	3.82-14.3 [9]	England	Bristol Channel
F. gardneri	>300-960 [10]	Howe Sound	Near Britannia Beach
F. gardneri	60-70 [10]	Howe Sound	Lower Howe Sound
F. gardneri	209-803 [11]	Howe Sound	Near Britannia Beach
F. gardneri	30.3-56.2 [11]	Howe Sound	Near Furry Creek

substantially higher than those found in similar seaweeds in Europe. This is likely due in part to higher levels of copper in Howe Sound water relative to other places. However, *F. gardneri* may not be directly comparable to the species examined in Europe, as it may accumulate more metal from similar concentrations in water. As well, differences in salinity, pH and other parameters affecting copper speciation and uptake may differ in the areas considered. Uptake of copper by this alga is further examined in Chapter 3.

While bulk collection of algae without consideration of age of tissue may introduce some errors, several studies (Forsberg *et al.* 1988; Söderlund *et al.* 1988; Carvalho *et al.* 1997) have found no consistent difference between copper levels in growing and older tissues. It seems that a sample incorporating tissues of a variety of ages is a valid method for obtaining an average body burden of copper.

2.4.7. Statistical Methods

Despite some deviations from normality and equality of variances among samples, parametric statistical procedures were employed throughout this chapter. Analyses of variance and Student-Newman-Keuls tests are quite robust to violations of assumptions (Zar 1996, Underwood 1997). Underwood (1996) makes a strong argument for applying the precautionary principle in environmental monitoring. This principle, in the context of this study, is applied in trying to balance the probabilities of Type I and Type II errors (see section 1.2.6). Non-parametric procedures would reduce the probability of making a Type I error because they make fewer assumptions about the populations being examined. However, non-parametric procedures are inherently less powerful than parametric tests (Zar 1996). Additionally, the non-parametric equivalent of analysis of variance, the Kruskal-Wallis test, requires equal variances in all populations, an assumption which was sometimes violated in the above experiments. Parametric tests were employed in all analyses above to maximize the power of the analyses.

In numerous tests, the ANOVA detected significant differences, but the post-hoc test failed to elucidate them. The only data in which consistent patterns were detectable using statistical tests was the higher cover of filamentous green algae at stations BB-C and BB-F than at all other sites. Given the distinct, visible nature of this phenomenon upon qualitative observation of the beach, it seems unlikely that the pattern detected is an artifact of the statistics employed. Indeed, if any problem may be suggested, it is that the power of the methods used was insufficient to detect more subtle differences which may exist in all community parameters. This does not appear to be a problem in the statistical methods themselves, but rather in the survey methods employed. Due to the patchiness of the intertidal at the scale examined, larger and more quadrats would likely have reduced the standard errors of the measurements taken.

2.5. Conclusions

Dissolved copper concentrations were extremely elevated in the immediate vicinity of Britannia Creek, but fell off quickly within 200-300 m. There were also elevated concentrations of copper further to the north of the Creek, up to 1000 m away.

A series of hypotheses were presented in section 1.3, and the first five of these hypotheses are addressed in this chapter. *F. gardneri* is completely absent on 1000 m of coastline to the north of the Creek and 600 m south of the Creek. At the fringes of this zone, however, no differences were detected in mean length of *F. gardneri* or in percent cover between Britannia Beach stations and reference sites at Furry Creek. Thus the results support hypotheses 1 and 3 in this zone of *F. gardneri* absence, but not elsewhere. Filamentous green algae were sparse very close to Britannia Creek, and reached very high cover levels farther from the Creek where *F. gardneri* was absent. Cover of these green algae was much lower at sites where *F. gardneri* is abundant. Hypothesis 2, therefore, appears to apply to sites within 100 m of Britannia Creek, but the opposite situation—higher cover of green algae at Britannia Beach sites than at Furry Creek—exists 300-700 m from Britannia Creek. *F. gardneri* plants near Britannia Beach did not produce fewer oocytes than those at reference stations, but copper burden of *F. gardneri* tissues were elevated in relation to those at reference sites. Hypothesis 4 is therefore not supported by the above experiments, while Hypothesis 5 is strongly supported by the very high levels of copper in algal tissue.

No indisputable causative links can be drawn between any of these observations and AMD from Britannia Mine. However, all the evidence in this study suggests that AMD plays a substantial role in producing the above results. The causative role of AMD in *F. gardneri* distribution will be examined using results from transplant experiments in Chapter 3.

With regard to the Department of Fisheries and Oceans' study of salmon productive capacity, the above findings have important implications. Assuming that there is a strong dependence of juvenile salmon on *F. gardneri* and its associated fauna, AMD emanating from the Britannia mine may be severely or totally eliminating this food-organism habitat. Effects of AMD on the algal communities farther from the Creek appear to be limited to enrichment of metal content. This does not rule out the potential for direct effects of AMD on the fish or on their food organisms. Another potential ramification of AMD could be vertical food chain transfer of metals from algae through their food organisms to salmon. While there is a possibility of biomagnification, Kay (1984) and Campbell *et al.* (1988) conclude from literature reviews that this phenomenon is quite rare for copper. In any case, there appears to be a strong probability that AMD reduces salmon productive capacity in the Britannia Beach area.

3. TRANSPLANTATION OF *FUCUS GARDNERI* TO BRITANNIA BEACH

3.1. Introduction

Chapter 2 examines the communities of algae at Britannia Beach and compares them to reference areas near Furry Creek. The most striking feature of the Britannia Beach area is the complete absence of *Fucus gardneri* Silva, the dominant species at nearby sites in upper Howe Sound. Combined with elevated levels of copper in plants <1000 m from the Creek and the dispersion pattern of Acid Mine Drainage (AMD) from the Creek, these observations suggest that AMD in the Creek may be responsible for the atypical algal community structure.

This hypothesis, however, is based only on the correlation of community structure with copper concentrations in seawater. To better establish a causative link between AMD and *F. gardneri* distribution, experimental manipulation of the plants is necessary. While experimental manipulation can only be carried out to a very limited degree in the field, one way of examining the effects of AMD on *F. gardneri* is to move previously unaffected plants into the zone of AMD influence and observe changes in certain ecological parameters. This approach was taken in this study by transplanting adult and juvenile *F. gardneri* from near the mouth of Furry Creek to several sites on either side of the mouth of Britannia Creek and measuring their growth rates, survival, percent cover and copper body burden.

3.2. Methods

3.2.1. Transplant of Adult *Fucus gardneri*

Five adult transplants were conducted over an 18 month period on the following dates:

June 23 1997, November 2 1997, February 15 1998, June 12 1998 and August 10 1998.

The beach near Furry Creek has abundant growth of *F. gardneri*, typical of much of Howe Sound, and was selected as a source area for plants to move to Britannia Beach. It was also the recipient site for control plants, which were transplanted in the same manner as those moved to Britannia Beach, but were moved to other sites at Furry Creek. Much of the *F. gardneri* near Furry Creek, especially at stations FC-C, FC-D, FC-E and FC-F (see Figure 2.2), grew on rocks 5-35 cm in diameter. These rocks provided useful experimental units whereby an entire rock could be moved to the appropriate site with its associated plants. This largely avoided the possibility of damaging the plants during their removal and re-attachment, an alternative transplant method. It could also arguably make the results more generalizable to natural, unmanipulated populations of *F. gardneri*, as the cobble provides a micro-environment to which the plant is normally exposed.

Rocks with *F. gardneri* growing on them were selected haphazardly in pairs at the source area. An attempt was made to select plants from over their entire vertical range (typically 1.5-3.0 m above chart datum), as well as over a 100-200 m horizontal area to make results more generalizable to the entire population. A trade-off was necessary in the size of rocks to make them small enough to carry by hand, but large enough so as not to be swept away by wave action after transplant. Experience showed that, for these particular sites, rocks 15-25 cm in diameter usually fulfilled both requirements. Rocks were also selected based on percent cover of *F. gardneri*; a reasonably high (>80%) cover was deemed necessary. Finally, rocks were selected in pairs, where each member was similar in size (± 5 cm), percent cover and average plant length of *F. gardneri* (visual estimate), and within 1 m of each other in their original position on the gently sloped beach. The purpose of this pairing was to justify using paired statistics in analyzing results, which is generally a more powerful method than unpaired statistics, and requires fewer assumptions about the data. The elevation from which each rock was taken was estimated using a leveling pole to measure vertical distance from the water line, then relating this measurement to predicted tides (Canadian Hydrographic Service 1997, 1998).

Selected rocks were tagged with numbered flagging tape and grouped on the beach. Rocks were then randomly assigned to treatments (i.e., transplant sites) so that one member of each pair was moved to a site near Britannia Beach, while the other was moved to the appropriate control site near Furry Creek.

Depending on the time of year, a boat or van was used to move the rocks to Britannia Beach. In June 1997, June 1998 and August 1998 rocks were moved in the bottom of a small, open boat. Due to the need to work at night in November 1997 and February 1998, rocks were placed in a van and driven 5 km to Britannia Beach. Rocks were moved from the recipient site to the control site at Furry Creek by carrying them along the beach by hand or on a wooden platform.

The sites chosen for the transplant experiments are shown in Figure 3.1. The experimental sites to which the rocks were moved were selected based on a number of criteria. The first was the presumed gradient of AMD effects with distance from Britannia Creek. Once an appropriate site was chosen, the location on the beach was chosen to fall at the mean elevation of all rocks' original positions at Furry Creek. The site was also selected for its substratum composition, so that it would be possible to dig a hole in which to place the rocks. Control sites were then chosen at Furry Creek so that they and the Britannia Beach sites were similar distances from their respective creeks. Ice cream pails, 5.7 L and 22 cm in diameter, were used as a base in which to place the rocks. The pails could be dug into the substratum much deeper than the rocks

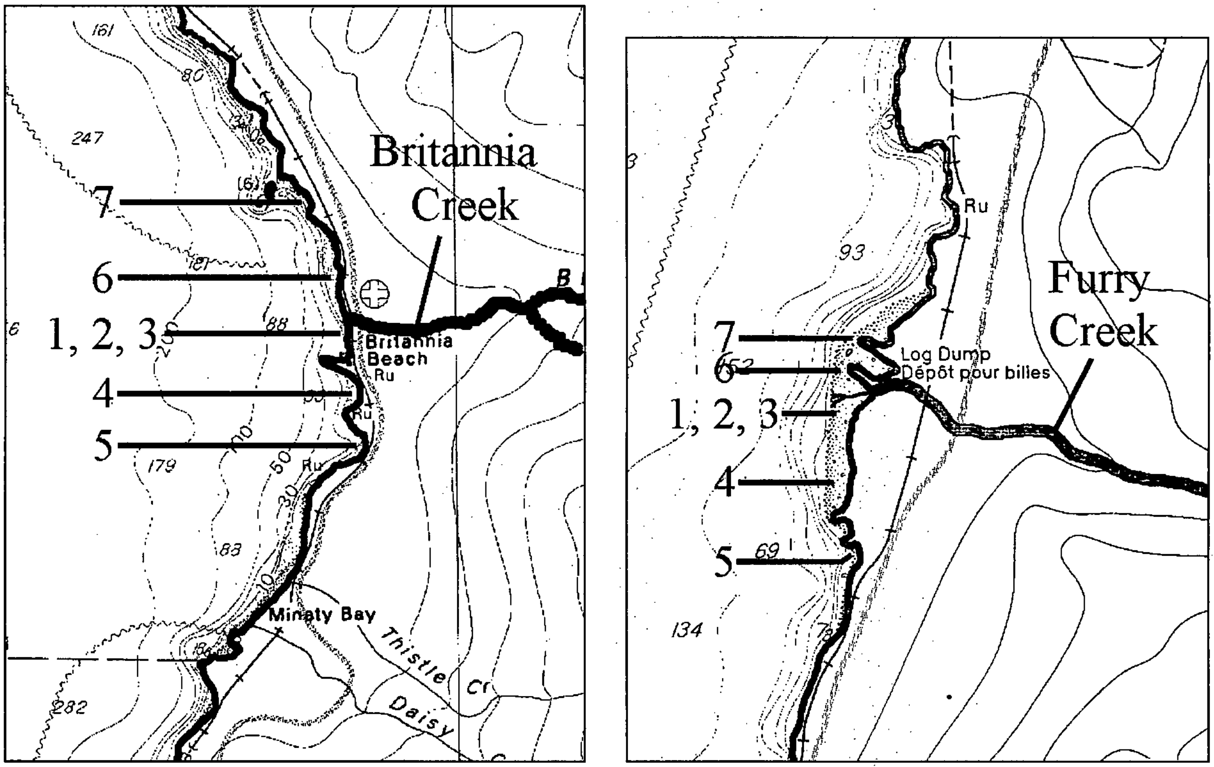

Figure 3.1. Transplant sites at Britannia Beach (left) and matching sites at Furry Creek (right). See Figure 1.1 for locations of creeks in Howe Sound. 1 and 2: November 1997; 3: February 1998; 4 and 5: June 1998; 6 and 7: August 1998. Sites BB-1 and FC-1 were ~50 m from the mouths of Britannia and Furry Creeks, respectively. Sites BB-2, BB-3, FC-2 and FC-3 were all ~100 m from their respective creek mouths. 1 cm = 350 m. From Canadian Hydrographic Service Chart #3526.

alone, which helped to prevent movement and loss of the transplants. The pail also served to elevate the rock somewhat from the substratum to minimize the effect of sand scouring. A possible drawback of digging holes in which to place pails is that this may expose copper-containing sediments. Metals in the these deeper sediments may be highly bioavailable due to the anoxic state of the sediment. However, the pails likely shield the plants from most of this metal, and the deep sediments are re-covered by surface sediments after the first tidal inundation. Rocks and pails were placed in a group at the site, with the greatest horizontal distance between any two rocks being 5 m.

3.2.2. Measurements

Plants were monitored for several parameters at varying intervals. A series of measurements were taken on each rock during each data collection. Percent cover of *F. gardneri* was measured using a 25 cm x 25 cm quadrat. The quadrat was pre-strung with nylon string in a grid pattern (with squares 1.5 cm x 1.5 cm), and 20 of the intersection points had been marked with pieces of wire. After haphazardly placing the quadrat on a rock, the object immediately under each point was recorded as *F. gardneri* or "other." Percent cover measurements were taken only on rocks from which no plants were taken for copper content analysis. Survivorship of *F. gardneri* was determined by monitoring tagged plants. Six plants were tagged on each rock during the first data collection, and their presence or absence was scored at each subsequent data collection. Growth rate of *F. gardneri* was estimated by measuring the length of the six tagged plants from the holdfast to the end of the longest frond. This provided an estimate of the average rate of growth over the entire interval between measurements.

3.2.3. Copper body burden

Copper body burden of copper in *F. gardneri* thalli was measured in two or three plants from each site. The plants were plucked from the rock, placed into plastic bags and returned to the laboratory. They were rinsed three times with seawater from the West Vancouver Laboratory system and frozen at -20°C. When all samples had been collected they were dried in a fumehood at ~40°C for ~4 hours and sent to the Analytical Chemistry Laboratories of the Geological Survey of Canada (Ottawa, Ontario). They were digested in 20 mL concentrated nitric acid and 2 mL perchloric acid, reduced to near dryness and then additionally digested with 10 mL concentrated hydrochloric acid, 10 mL concentrated hydrofluoric acid and 2 mL concentrated perchloric acid. Metal analysis was conducted by inductively-coupled plasma mass spectrometry (ICP-MS).

3.2.4. Data manipulation and statistical analysis

Survivorship scores estimated the proportion of plants surviving on each rock. Growth rate was averaged over all plants on a given rock. Individual plants could not be counted as replicates for either growth or survivorship because they are not independent of each other; growth and survival of any given plant may be correlated with that of others due to biological interactions or genetic relatedness. Percent cover, proportion of tagged plants surviving and growth rates were then compared by paired or unpaired one-tailed Student's t-tests, as noted in the results. Copper body burden was compared using unpaired one-tailed Student's t-tests. Direction of one-tailed hypotheses was determined by the predictions made in section 1.3.

The end point for the first four transplants was determined by mortality of *F. gardneri* plants; almost all plants at one or both of the Britannia Beach and Furry Creek sites had died and detached by the final time point shown in the results. The end of the August 1998 transplant occurred when most of the rocks at all sites could not be located, apparently due to a combination of wave action and shifting of the substratum.

3.3. Results

Several difficulties were encountered during the June 1997 experiment. Plants were moved to the north and south sides of Britannia Creek, but within two weeks the transplants on the north side of the Creek were completely destroyed by human disturbance or some other physical disturbance. These samples therefore provided no useful data. Furthermore, control plants at Furry Creek were not transplanted in a manner similar to those at Britannia Beach, but rather were picked up and replaced in their original location. This presents serious difficulties in separating transplant effects from those of AMD. The data from this transplant are therefore not presented here. It should be said, however, that the results observed were quite similar to those seen in the November 1997 transplant.

3.3.1. Percent Cover

Results of percent cover measurements for transplanted *F. gardneri* are shown in Figures 3.2 through Figure 3.5. Results of statistical comparisons are shown in Table 3.1. The November 1997 and February 1998 experiments show similar trends of a rapid loss of *F. gardneri* cover on rocks transplanted to Britannia Beach. This decrease in percent cover becomes evident about 30 days after the transplant. In contrast, the June and August 1998 experiments show no significant differences between cover of *F. gardneri* on rocks transplanted to Britannia Beach and that on rocks moved to Furry Creek; percent cover decreased on rocks at both sites. At site FC-5, percent cover of *F. gardneri* appears to be lower than that at site BB-5. This difference is not detected by the statistical tests, however, as one-tailed t-tests were used.

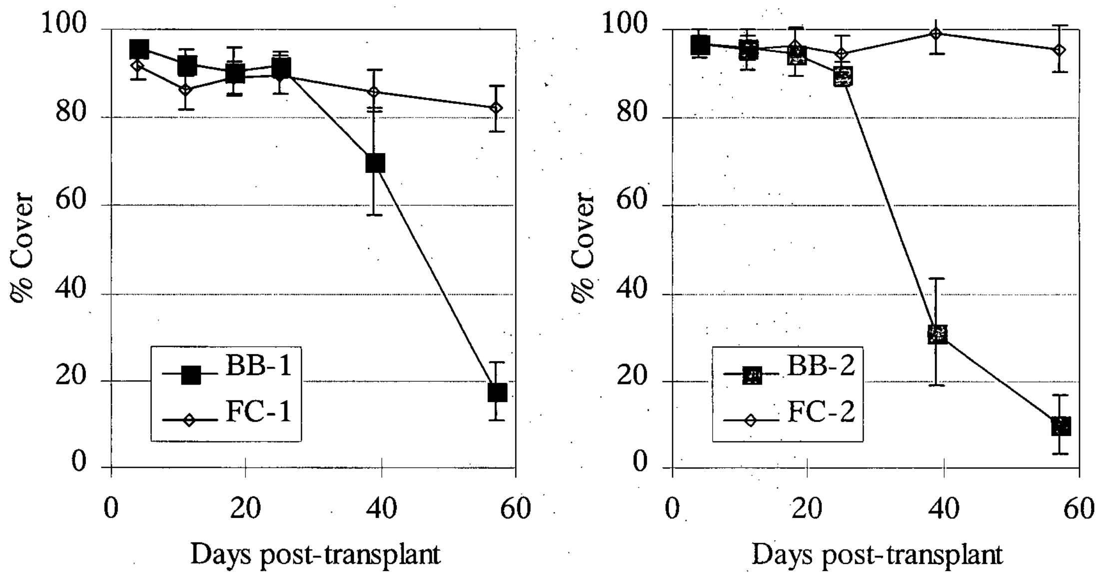

Figure 3.2. Percent cover of *Fucus gardneri* on rocks transplanted November 1997. BB = Britannia Beach. FC = Furry Creek. See Figure 3.1 for locations of sampling sites. Data are mean ± 1 standard error. n = 7 rocks.

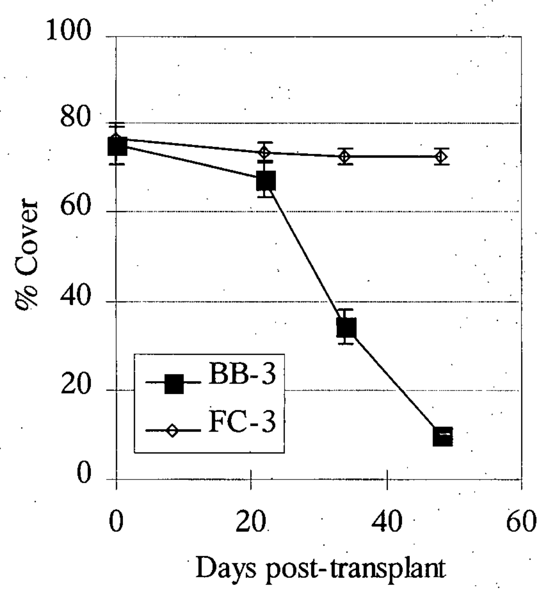

Figure 3.3. Percent cover of *Fucus gardneri* on rocks transplanted February 1998. BB = Britannia Beach. FC = Furry Creek. See Figure 3.1 for locations of sampling sites. Data are mean ± 1 standard error. n = 6 rocks.

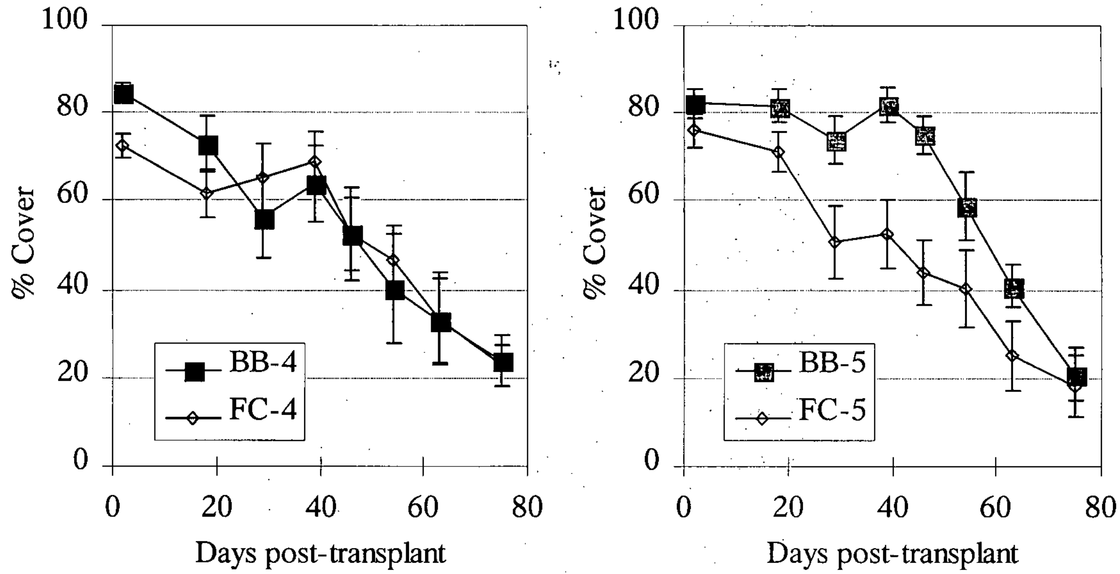

Figure 3.4. Percent cover of *Fucus gardneri* on rocks transplanted June 1998. BB = Britannia Beach. FC = Furry Creek. See Figure 3.1 for locations of sampling sites. Data are mean ± 1 standard error. n = 8 rocks except day 75, when n = 7 rocks at site 4.

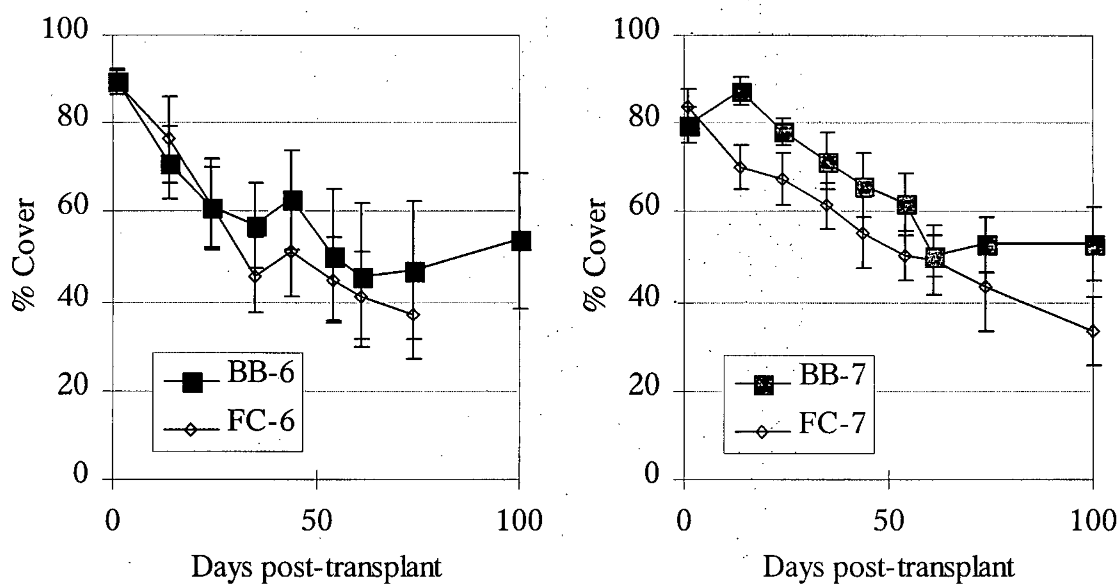

Figure 3.5. Percent cover of *Fucus gardneri* on rocks transplanted August 1998. BB = Britannia Beach. FC = Furry Creek. See Figure 3.1 for locations of sampling sites. Data are mean ± 1 standard error. n = 8 rocks until day 35, n = 7 thereafter at site 6. All rocks but one lost at FC-6 on day 100.

Table 3.1. Statistical analyses of percent cover results from all transplants. All analyses use one-tailed, paired Student's t-tests to compare percent cover of *Fucus gardneri* on rocks transplanted to Britannia Beach with that on rocks transplanted to Furry Creek. See Figure 3.1 for site locations. Time is days after transplant. $\alpha = 0.05$ in all tests. Significant differences are in bold type.

November 1997			**Feb 1998**		**June 1998**			**August 1998**		
Time	Site 1	Site 2	Time	Site 3	Time	Site 4	Site 5	Time	Site 6	Site 7
4	>0.500	>0.500	0	0.388	2	>0.500	>0.500	1	>0.500	0.292
11	>0.500	>0.500	22	0.128	18	>0.500	>0.500	14	0.366	>0.500
18	>0.500	0.339	34	**<0.001**	29	0.270	>0.500	24	0.483	>0.500
25	>0.500	0.291	48	**<0.001**	39	0.313	>0.500	35	>0.500	>0.500
39	0.167	**<0.001**			46	0.500	>0.500	44	>0.500	>0.500
57	**<0.001**	**<0.001**			54	0.358	>0.500	54	0.482	>0.500
					63	0.476	>0.500	61	0.384	>0.500
					75	0.380	>0.500	74	>0.500	>0.500
								100		>0.500

3.3.2. Survivorship

Results of survivorship measurements for transplanted *F. gardneri* are shown in Figures 3.6 through 3.9. Results of statistical comparisons are shown in Table 3.2. During the August 1998 transplant, tagging strings were poorly attached to the base of the plants and were observed to be falling from the plants, resulting in excessively high mortality estimates. Plants were therefore re-tagged on day 24 and previous data were disregarded.

The same general trends are seen in survivorship data as in the percent cover data. Plants at sites BB-1, BB-2 and BB-3 begin to detach after approximately 30 days during the November 1997 and February 1998 experiments, while plants at the control sites maintain survivorship >75%. During the June and October 1998 experiments, plants at all sites sustain heavy mortality so that survivorship is <25% and <40% during June and October, respectively.

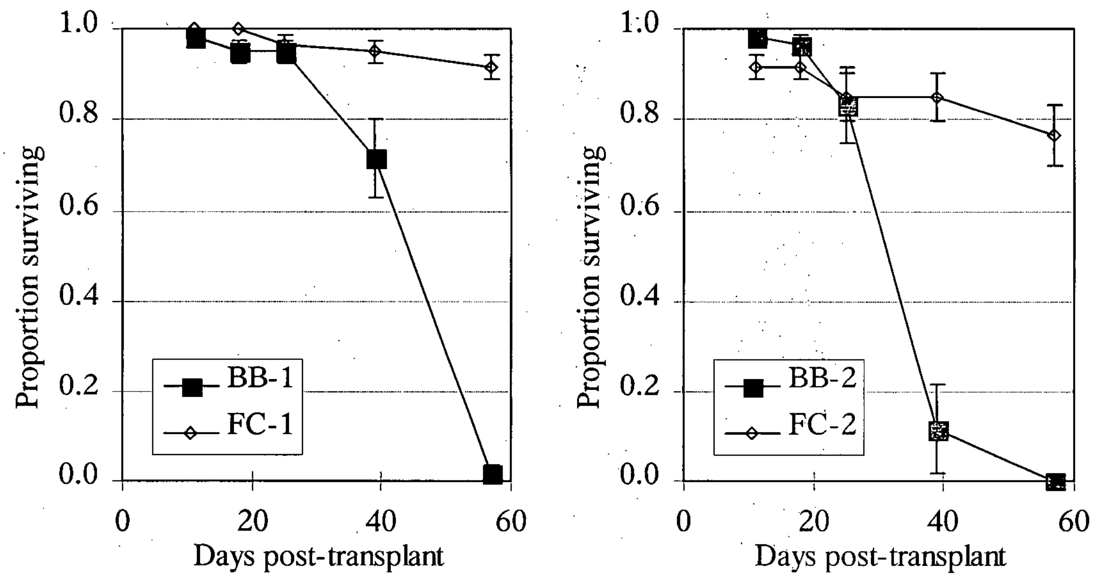

Figure 3.6. Survivorship of *Fucus gardneri* on rocks transplanted November 1997. BB = Britannia Beach. FC = Furry Creek. See Figure 3.1 for locations of sampling sites. Data are mean ± 1 standard error. n = 10 rocks.

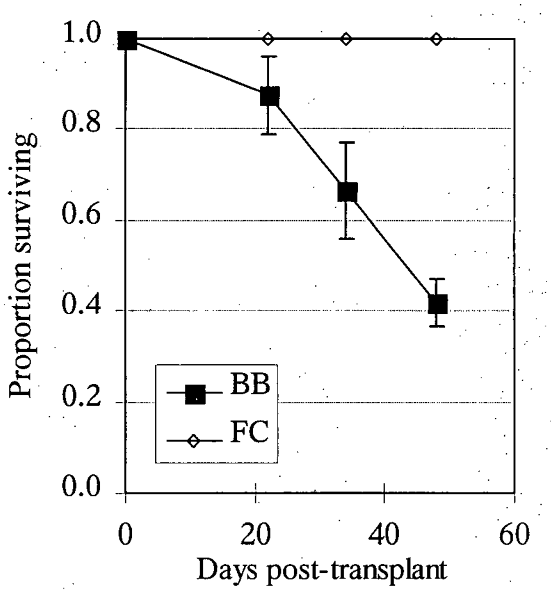

Figure 3.7. Survivorship of *Fucus gardneri* on rocks transplanted February 1998. BB = Britannia Beach. FC = Furry Creek. See Figure 3.1 for locations of sampling sites. Data are mean ± 1 standard error. n = 6 rocks.

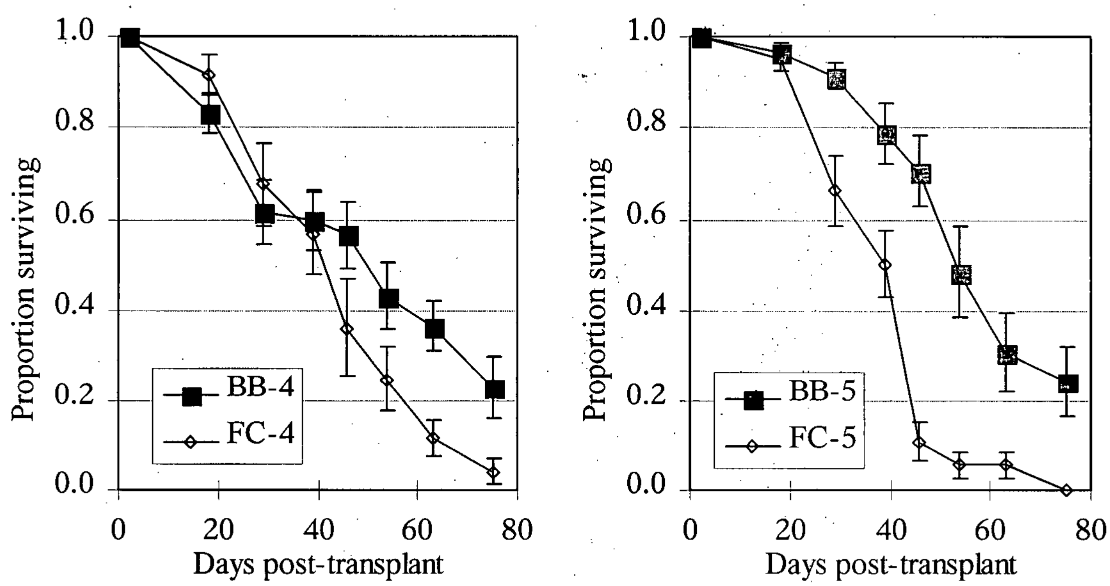

Figure 3.8. Survivorship of *Fucus gardneri* on rocks transplanted June 1998. BB = Britannia Beach. FC = Furry Creek. See Figure 3.1 for locations of sampling sites. Data are mean ± 1 standard error. n = 10 rocks except day 75, when n = 9 at site 4.

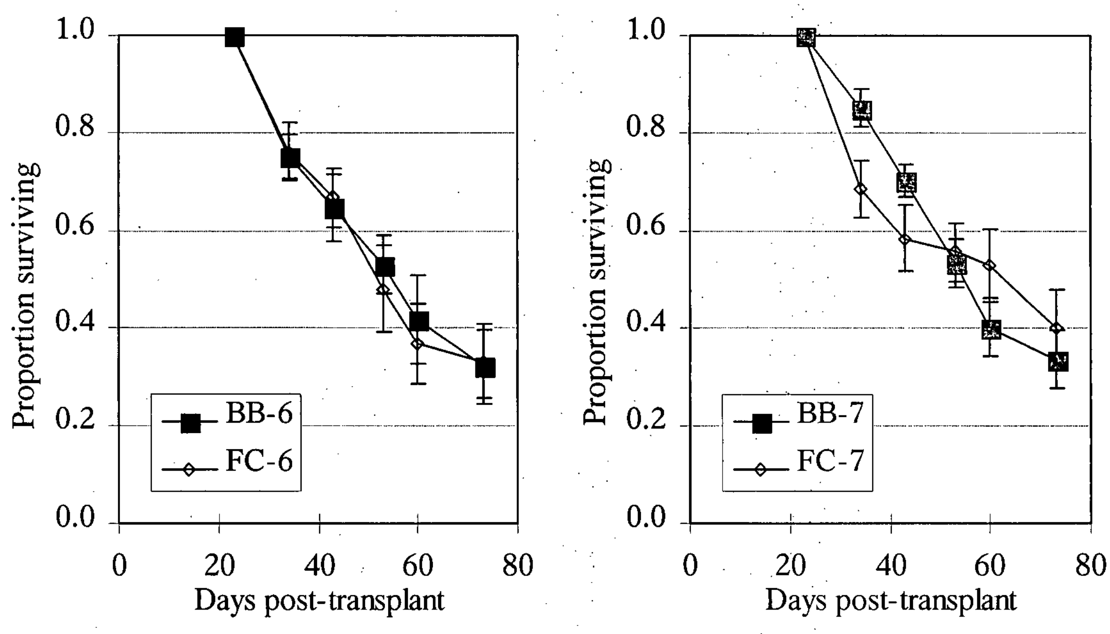

Figure 3.9. Survivorship of *Fucus gardneri* on rocks transplanted August 1998. BB = Britannia Beach. FC = Furry Creek. See Figure 3.1 for locations of sampling sites. Data are mean ± 1 standard error. n = 10 rocks.

Table 3.2. Statistical analyses of survivorship results from all transplants. All analyses use one-tailed, paired Student's t-tests to compare survivorship of *Fucus gardneri* on rocks transplanted to Britannia Beach with that of individuals transplanted to Furry Creek. See Figure 3.1 for site locations. Time is days after transplant. $\alpha = 0.05$ in all tests. Significant differences are in bold type.

November 1997			**Feb 1998**		**June 1998**			**August 1998**		
Time	Site 1	Site 2	Time	Site 3	Time	Site 4	Site 5	Time	Site 6	Site 7
11	0.172	>.500	22	0.093	18	0.065	>0.500	35	>0.500	>0.500
18	**0.041**	>.500	34	**0.005**	29	>0.500	>0.500	44	0.486	>0.500
25	0.296	>.500	48	**<0.001**	39	0.453	>0.500	54	>0.500	0.380
39	**0.024**	**<0.001**			46	>0.500	>0.500	61	>0.500	0.071
57	**<0.001**	**<0.001**			54	>0.500	>0.500	74	0.463	0.167
					63	>0.500	>0.500			
					75	>0.500	>0.500			

3.3.3. Growth

Results of growth rate measurements for transplanted *F. gardneri* are shown in Figures 3.10 through 3.12. Results of statistical comparisons are shown in Table 3.3. Time points are expressed as the mid-point of the interval over which the growth rate is calculated (see Appendix II for further explanation). Growth rates were not measured during the February 1998 transplant.

Growth rates of *F. gardneri* transplanted to BB-1 and BB-2 during November 1997 were significantly lower than those of control plants moved to FC-1 and FC-2 during all measurement intervals except the last interval at site 2. Plants transplanted to BB-4 had lower growth rates than control plants during 4 of 7 measurement intervals, while plants moved to BB-5 (farther from Britannia Creek) grew slower during 2 of 6 measurement intervals. Only one difference was detected between growth rates at the two Creeks in the August 1998 transplant, with growth being faster at FC-6 than at BB-6 during the fifth interval.

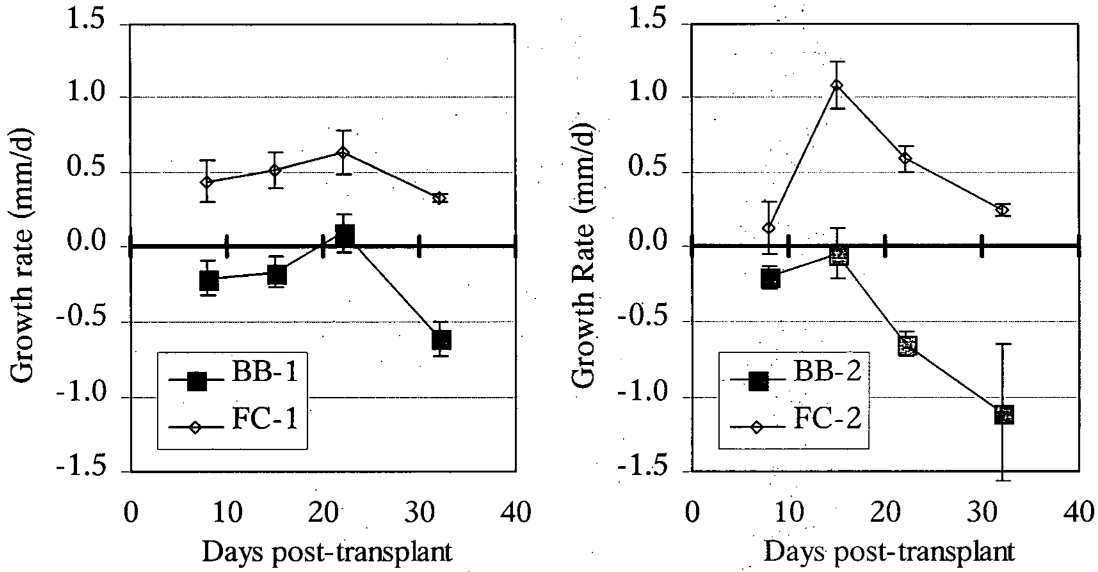

Figure 3.10. Growth rates of *Fucus gardneri* on rocks transplanted November 1997. BB = Britannia Beach. FC = Furry Creek. See Figure 3.1 for locations of sampling sites. Data are mean ± 1 standard error. n = 10 rocks.

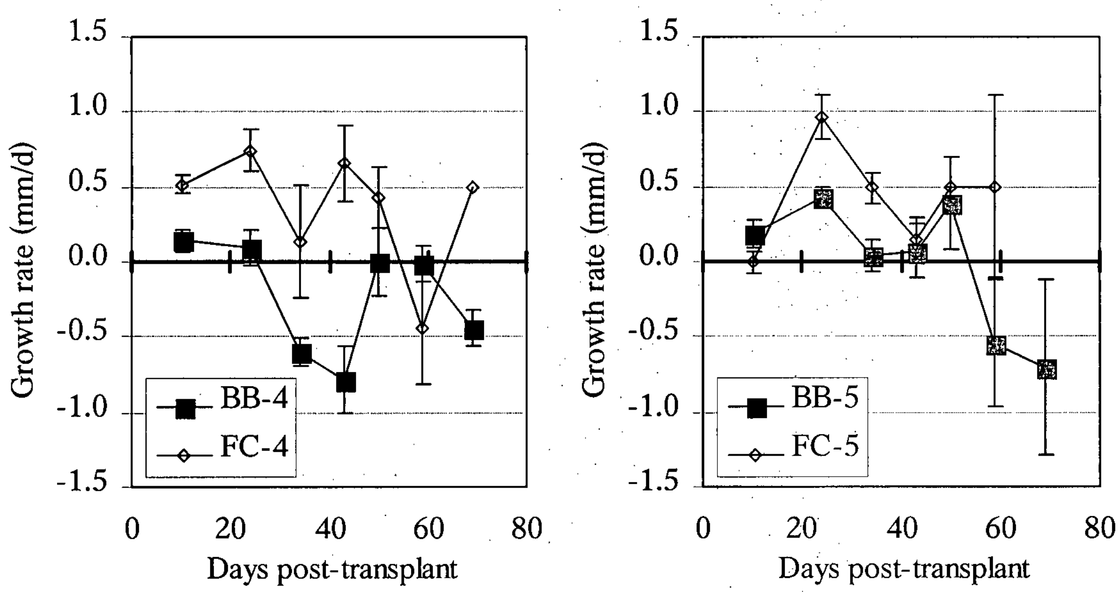

Figure 3.11. Growth rates of *Fucus gardneri* on rocks transplanted June 1998. BB = Britannia Beach. FC = Furry Creek. See Figure 3.1 for locations of sampling sites. Data are mean ± 1 standard error. n = 10 rocks except day 75, when n = 9 at site 4.

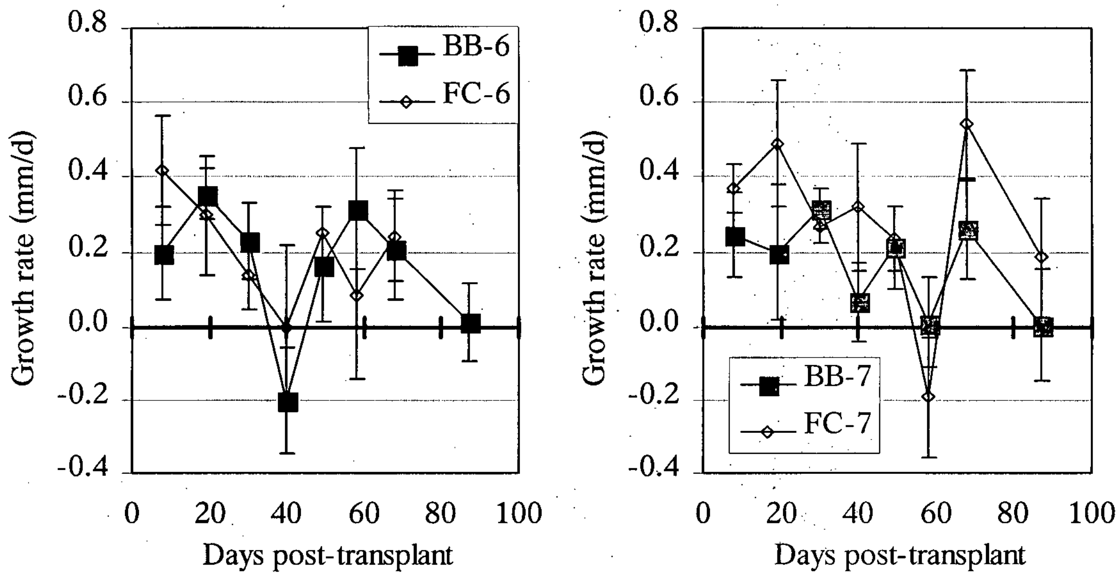

Figure 3.12. Growth rates of *Fucus gardneri* on rocks transplanted August 1998. BB = Britannia Beach. FC = Furry Creek. See Figure 3.1 for locations of sampling sites. Data are mean ± 1 standard error. n = 10 rocks.

Table 3.3. Statistical analyses of growth rate results from all transplants. All analyses use one-tailed Student's t-tests to compare growth rates of *Fucus gardneri* on rocks transplanted to Britannia Beach with that of individuals transplanted to Furry Creek. See Figure 3.1 for site locations. Time is days after transplant. $\alpha = 0.05$ in all tests. Significant differences are in bold type. Tests marked with * were conducted using unpaired t-tests. All other tests were paired t-tests.

November 1997			June 1998			August 1998		
Time	Site 1	Site 2	Time	Site 4	Site 5	Time	Site 6	Site 7
8	**<0.001**	**0.039**	10	**0.001**	>0.500	8	0.094	0.217
15	**0.001**	**0.001**	24	**0.003**	**0.006**	19	>0.500	0.269
22	**0.009**	**<0.001**	34	0.057	**0.001**	30	>0.500	>0.500
32	**<0.001**	0.141	43	**<0.001***	0.398*	40	0.295	0.084
			50	0.099*	0.434*	49	**0.018**	0.410
			59	>0.500*	0.136*	58	>0.500	>0.500
			69	**0.019***		68	>0.500	0.239
						87		>0.500

3.3.4. Copper body burden

Copper body burden measurements were done only during the November 1997 transplant (Figure 3.13). The results of statistical analyses are shown in Table 3.4. Body burden of copper increased very rapidly during the first two weeks after being transplanted to the mouth of Britannia Creek. The rate of uptake began to decrease at this point, but copper was still being taken up 39 days after the transplant, after which no plants were available to be sampled. There was no apparent change in the copper body burden of plants at Furry Creek.

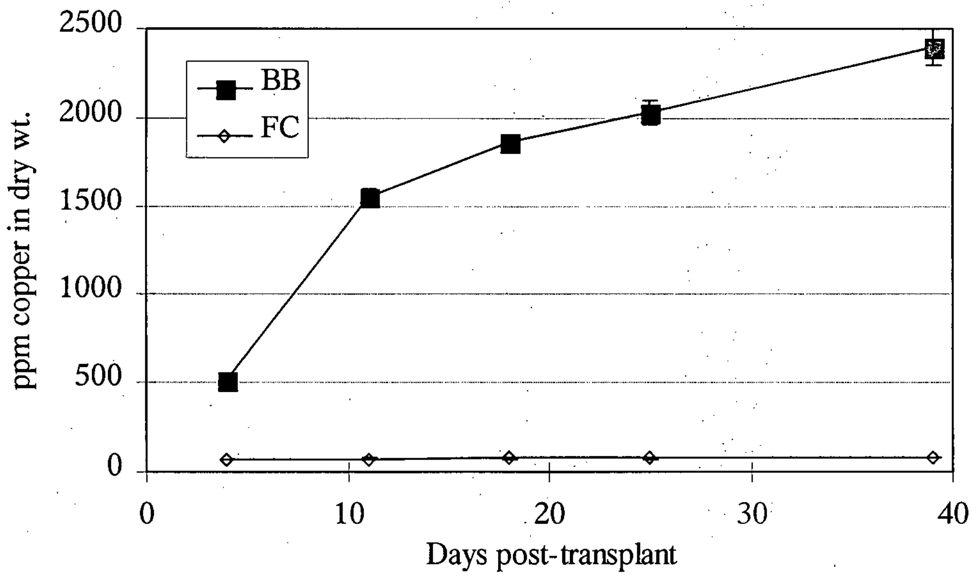

Figure 3.13. Copper body burden of *Fucus gardneri* on rocks transplanted November 1997 to BB-1 and FC-1. BB = Britannia Beach. FC = Furry Creek. Data are mean ± 1 standard error. n = 3 plants, except day 39, when n = 2.

Table 3.4. Statistical analyses of copper body burden from the November 1997 transplant. All analyses use one-tailed Student's t-tests to compare copper body burden of *Fucus gardneri* transplanted to Britannia Beach with that in plants transplanted to Furry Creek. See Figure 3.1 for site locations. Time is days after transplant. $\alpha = 0.05$ in all tests. Significant results are in bold type.

	Nov. 1997
Time	Site 1
11	**0.001**
18	**<0.001**
25	**<0.001**
39	**0.001**
57	**0.014**

3.3.5. General observations

Some changes in the condition of the plants became apparent after they were transplanted. The most obvious change occurred in the colour and texture of plants which were moved to the Britannia Beach area. After 2-30 days of exposure to AMD, the entire thallus took on a reddish brown colour which contrasted remarkably with the olive green colour of plants at Furry Creek and other sites. The plants at Britannia Beach also produced large amounts of exudates, resulting in a layer of slime on the outside of the plant. Concurrently, the thalli of plants at Britannia Beach had a very soft texture relative to plants at Furry Creek. These changes in plant appearance and texture became apparent at different times: 2 days post-transplant for all plants in the June 1997 experiment, 14 days for all plants in the November 1997 experiments and 30 days for the plants at site 4 for the June 1998 transplant. Plants at site 5, 6 and 7 showed no such changes at any time.

3.4. Discussion

The results of the transplant experiments showed two distinct patterns. The discussion is organized based on these patterns.

3.4.1. Severe Effects: November 1997 and February 1998

F. gardneri transplanted to the immediate vicinity of Britannia Creek in November 1997 showed no significant change in percent cover (Figure 3.2) or survivorship of tagged plants (Figure 3.6) for the first month after transplant. After this time, however, cover and survivorship drop off rapidly; by 57 days after the transplant almost all tagged plants had detached. The cover found on the last day was composed of holdfasts and stipes without fronds. These tissues are capable of neither reproduction nor growth. An identical pattern was seen in the cover (Figure 3.3) and survivorship (Figure 3.7) of the plants transplanted in February 1998. No differences between plants moved to Britannia Beach and Furry Creek are significant at $\alpha = 0.05$ until more than 30 days post-transplant.

Growth rates in the November 1997 transplant showed a more immediate onset of effects among the plants moved to Britannia Beach than is revealed in cover or survivorship. The first set of growth rate measurements, averaging growth from day 4 to day 11, showed that plants moved to Britannia Beach had significantly lower growth rates than those moved to Furry Creek (Figure 3.10; Table 3.3). While the growth rates are variable at different time points, the difference between growth at the two sites remains fairly consistent over the entire experiment. A notable feature of growth rates at both Britannia Beach sites in November 1997 is that they are negative or zero at all but one time point. This is not an artifact of plant breakage, as all detached plants were removed from the growth rate data set. Rather, the decrease in plant length appeared to be the result of plant erosion. Concurrent with the change in colour and texture of the plants (section 3.3.5), the tips of the receptacles were clearly being worn away, presumably due to a combination of poor plant health and wave action. The implication of this phenomenon for growth rate measurements is evident: the length of the plant will become shorter at each successive sampling date. Since *F. gardneri* grows from an apical meristem, removal of tissue from the plant's tips will dislodge the meristem, precluding further growth.

It appears that the growth rate of *F. gardneri* responds more rapidly to AMD than percent cover or survivorship. In particular, the use of tagged plants is a relatively conservative measure of their survivorship because a plant may die from toxicity quite quickly but remain attached to its substratum for a period of time before its holdfast or stipe gives way. Percent cover gives a very crude estimate of existing biomass, but like tagged plants, gives no information on the viability or health of this biomass.

Periodic collection of plants for copper content analysis provided an opportunity to examine the speed with which plants would take up the metal when exposed to high concentrations and how the levels of metal at these sites compared with concentrations in unmanipulated plants farther from Britannia Beach. The results (Figure 3.13) clearly showed large increases in the copper body burden of individuals transplanted to Britannia Beach. Furthermore, the uptake was very rapid in the first 11 days, after which it appeared to slow considerably. The concentration was still increasing up to day 39, after which no samples could be collected due to the death of all plants at Britannia Beach. When compared to copper levels in existing *F. gardneri* at sites near Britannia Creek (Figure 2.8; 500-700 ppm in dry wt. in the plants nearest the Creek), the transplants had 2-3 times more copper after just 11 days. Given that the levels of copper found in the extant plants nearest to Britannia Creek likely represents an approximate maximum that the plants can withstand, severe degradation of the plants' health at >2000 ppm copper is expected.

Some work has been done involving the transplantation of algae into areas with relatively high copper concentrations. Ho (1984) moved *Fucus vesiculosus* and *Ascophyllum nodosum*, two fucoid algae, from an unpolluted site in Cornwall, England, to Restronguet Creek, which was contaminated with zinc and copper from past mining activities. Ho (1984) observed copper concentrations of <20 ppm in control *F. vesiculosus*, while those moved to the polluted area contained 100, 150 and 230 ppm copper in dry weight after 15, 35 and 57 days, respectively. *A. nodosum* contained 60, 60 and 100 ppm copper at the same time intervals, while control plants contained <35 ppm copper. These amounts of copper are approximately one tenth of those seen in plants that were moved to Britannia Beach from Furry Creek, presumably due to lower concentrations of available copper (not reported) at Ho's (1984) site. However, interspecific differences are apparent within Ho's experiment; these differences may also be important when comparing Pacific *F. gardneri* with Atlantic *F. vesiculosus*. Forsberg *et al.* (1988) moved *F. vesiculosus* from Björkskär, an unpolluted site in Sweden, to Lördan, a relatively polluted site near Stockholm. After 12 months, there was no significant change in copper concentration in young tissues at Lördan relative to untransplanted controls, but there was significantly more copper in older tissues at the more polluted site (15.6 ± 1.0 ppm copper in dry weight at Lördan [mean ± standard deviation], 5.7 ± 4.1 ppm copper at Björkskär). Ambient concentrations of copper in the two areas were not reported.

The change in colour and texture of the plants soon after transplant to the mouth of Britannia Creek seemed to be an indication of the quickly declining health of the plants. The change in colour is consistent with Sorentino's (1979) finding that very high concentrations of copper cause degradation of chlorophyll and other pigments in some algae, which would lead to a change in colour. A change in plant texture may be a result of copper binding cell proteins such as those which maintain the plant's structure and which control the osmotic permeability of the cell (Sorentino 1979). The increased production of exudates may be one way the plant has of detoxifying the metals (Ragan *et al.* 1980; Schramm 1993).

3.4.2. No Detectable Effects: June and August 1998

Unlike the previous sets of transplant experiments, those conducted in June and August of 1998 to areas more distant (300-700 m) from Britannia Creek showed no consistent pattern of deleterious effects of AMD. In 33 comparisons using paired one-tailed t-tests, the null hypothesis of equal percent cover of Furry Creek and Britannia Beach transplants was never rejected (Table 3.1), while the null hypothesis of equal survivorship at Furry Creek and Britannia Beach was also never rejected (Table 3.2) in 24 comparisons. In fact, a quick glance at the graphical data suggests that percent cover and surviorship of *F. gardneri* may be lower at Furry Creek, at least at sites 4 through 7 for certain time points (Figures 3.4, 3.5, 3.8 and 3.9). This result is quite unexpected given the high cover and survivorship of plants at Furry Creek relative to those at Britannia Beach in all previous transplants. However, there are several possible explanations for the results observed.

An important consideration in the June 1998 and, to a lesser extent, the August 1998 transplant is physical factors such as desiccation. Howe Sound has a semi-diurnal tide pattern, and during the summer months the lowest tides occur at or near midday. The summer of 1998 was hot and sunny in upper Howe Sound, resulting in severe desiccation of *F. gardneri* thalli, sometimes on a daily basis (pers. obs.). This repeated desiccation is tolerated by most plants, but appears to result in high mortality rates in some populations. As well, the desiccation may have been aggravated by moving the plants into a different microclimate on a beach with less *F. gardneri* cover. This would likely have resulted in lower moisture levels in the immediate area of the plants. Combined with brisk, warm southerly winds on summer afternoons (Jackson & Steyn 1992; pers. obs.), these factors may have combined to cause severe desiccation of *F. gardneri*, especially at the Furry Creek sites, which had a more southerly aspect than the Britannia Beach sites. This might have contributed to greater overall mortality at Furry Creek than at Britannia Beach. Alternatively, the desiccation-induced mortality might have been about equal at Furry Creek and Britannia Beach, but very severe at both sites. This high rate of "background" mortality could then overshadow AMD-induced mortality at the Britannia Beach sites with the result that the latter would not be detected.

Another possible contributing factor is natural senescence. The population of *F. gardneri* at Furry Creek from which the June 1998 transplants were obtained sustained very high mortality in June-October 1998; the percent cover of *F. gardneri* declined from 70% to 15% over 4 months (Figure 2.4). If this mortality was caused by a natural senescence of this population, the mortality of the transplanted *F. gardneri* would be expected to be high regardless of any effect of AMD.

Yet another possibility was the relative amounts of dissolved copper in Howe Sound at different times of year. Assuming that the temporal pattern of loading from Britannia Creek into Howe Sound (Figures 1.2 and 1.3, respectively) is reasonably consistent from year to year, there might be relatively little dissolved copper present at sites BB-4 through BB-7 in June and August. If the experiments had been done during the peak in metal loadings, very different results may have been observed.

One observation which suggests some degree of AMD effects at one of the sites was the onset of the characteristic colour and texture changes after 30 days in plants at site BB-4 (see section 3.3.5). These changes were not evident at any of the other sites during the June or August 1998 transplants, at Furry Creek or at Britannia Beach. As well, the receptacles of *F. gardneri* at site BB-4 were clearly eroding, as those at sites BB-1, BB-2 and BB-3 had in previous experiments, while plants at all other sites showed no such tissue degradation. This erosion was evident in the growth rates observed in the June 1998 transplant, which were significantly lower at BB-4 than FC-4 at 4 of 7 intervals (Figure 3.11 and Table 3.3). This difference is not consistent among intervals, which may reflect the lower severity of AMD effects at greater distances from Britannia Creek.

The various explanations discussed above do not, however, address the possibility that AMD is having a minimal effect on adult *F. gardneri* at sites farther from the Creek. In fact none of the data from the June and August 1998 transplants, aside from qualitative observations of plant health, provide strong evidence that AMD affected adult *F. gardneri* growth or survivorship at the sites examined. This was not an entirely unexpected result, as copper concentrations at three of these sites (sites BB-5, BB-6 and BB-7 correspond to stations 6, 8 and 9 in Figures 2.2 and 2.3) are often <1-20% of those at the mouth of Britannia Creek (sites BB-1 through BB-3). However, the lack of transplant data from other seasons and the confounding factor of desiccation prevent any strong conclusions from being drawn from the results.

While there is no evidence that AMD can adversely affect adult *F. gardneri* at sites, this does not eliminate the pollution as a possible causative agent for the lack of *F. gardneri* near Britannia Creek (see Figures 2.1 and 2.4). The findings of many authors (Chung & Brinkhuis 1986; Maier & Müller 1986; Scanlan & Wilkinson 1987; Anderson *et al.* 1990) suggest that the microscopic reproductive stages of brown algae, including *Fucus* spp., may be much more susceptible than adult plants to toxins such as copper. Since *F. gardneri* zygotes must settle and germinate in an area to establish a viable population, any interference of AMD with this process may preclude the establishment of the algae in an area. Thus, AMD may be the major reason for the lack of *F. gardneri* in the entire area of absence near Britannia Creek despite the apparent lack of effects on adult plants at sites >300 m from the Creek mouth.

3.4.3. General Discussion of Transplant Experiments

Due to the high temporal and spatial variability in dissolved concentrations of copper at Britannia Beach, as well as the intricacies of copper speciation in the field and in the laboratory, it is difficult to associate the transplant data with any specific exposure to copper. However, it is useful to compare the above results with previous examinations of copper effects on algae.

While several authors (e.g., Ho 1984; Forsberg *et al.* 1988) have transplanted fucoids and measured copper content, there has apparently been no *in situ* work examining the effects on other biological parameters such as growth and survivorship. There have been numerous laboratory studies of copper effects on algae, however. Strömgren (1979) exposed *Ascophyllum nodosum* to a variety of concentrations of copper in a flowing seawater system and found that its growth rate was decreased to 80% of controls when exposed to 66 μg copper L^{-1} for 4 days, while growth rates of plants exposed to 340 μg copper L^{-1} were reduced to 20% of controls after 4 days. The same author also examined the effect of copper on other fucoid algae (Strömgren 1980). He saw significant reduction of growth rate of *Pelvetia canaliculata* and *Fucus spiralis* at 12 μg copper L^{-1}, of *F. serratus* at 25 μg copper L^{-1}, and of *F. vesiculosus* at 50 μg copper L^{-1}. Chung & Brinkhuis (1986) found that release of meiospores from *Laminaria saccharina* was reduced by ≥50 μg copper L^{-1}. Settlement and germination of the meiospores were not affected by any of the concentrations tested (≤500 μg copper L^{-1}). However, development of the microscopic gametophytes was delayed in ≥50 μg copper L^{-1}, and growth of sporophytes was inhibited at copper concentrations ≥10 μg L^{-1}. Munda & Hudnik (1986) found 2500 μg copper L^{-1} at a salinity of 31.5 to be lethal to *Fucus vesiculosus* within 20 days. Anderson *et al.* (1990) observed decreases in sporophyte production in *Macrocystis pyrifera* at 10 μg copper L^{-1}, in sporophyte growth at 32 μg copper L^{-1}, in germ-tube growth at 18 μg copper L^{-1} and in percent of spores germinated at 100 μg copper L^{-1}. Andersson & Kautsky (1996) studied the effects of copper on Baltic Sea *Fucus vesiculosus*. At salinities of 6 and 20, 20 μg copper L^{-1} caused a 70-80% decline in germination. At a salinity of 14, which the authors recognized as the optimum for this alga, no reduction in germination was observed. When ≤60 μg copper L^{-1} was added 24 hours after fertilization, the zygotes were much more resistant to copper toxicity.

Considering these previous studies, the results of transplant experiments at the mouth of Britannia Creek (sites BB-1, 2 and 3), where dissolved concentrations can locally exceed 1000 μg L^{-1}, are not surprising. The levels of copper at other sites (BB-4 through 7; <50-200 μg L^{-1}) are more in line with those examined in laboratory work. However, the bioavailability of copper in these laboratory studies is likely different from that at Britannia Beach; direct comparisons of data are therefore difficult. Andersson and Kautsky's (1996) findings that *F. vesiculosus* propagules are extremely susceptible to copper toxicity—especially at low salinities—lend support to the hypothesis that, while AMD at sites 300-500 m from Britannia Creek may not affect adult plants, it may completely preclude growth of juvenile plants.

3.4.4. Power Analysis

The calculation and implications of the power of statistical tests are discussed in section 1.2.6. The consequence of low power is that there is an inherent risk of not detecting serious environmental degradation. This does not appear to be a problem in the data from the November 1997 and February 1998 transplants, as effects were quite obvious after one month, and were verified by statistical tests. In the June and October 1998 experiments, however, there appeared to be some degradation of some plants that was not consistently detected by statistical tests. To gain some insight into these results, an *a posteriori* power analysis is conducted below on the growth rate analysis at BB-4 and BB-5 in June 1998.

An *a priori* power analysis was not used in this study for two reasons. First, there was little previous data which could be realistically used to estimate biologically significant effect sizes or variability in the population. Second, there was a practical limit on the number of samples which could be monitored to a sufficient degree to give meaningful results. Instead, an alternative approach is taken here, which is to measure in an *a posteriori* manner the power of tests already conducted. The analysis can be conducted with several different sample and effect sizes to look for weaknesses in the analyses.

To remain consistent with most current ecological work, α is set at 0.05, but 0.10 will also be considered. Assuming that 0.05 is an "acceptable" rate of error, a value of $\beta \leq 0.05$, and therefore a power ≥ 0.95, will also be deemed "acceptable." The standard deviation of growth rates in this experiment varied from 0.20 to 0.50 mm d^{-1}; a relatively conservative value of 0.40 mm d^{-1} will be used in this analysis. Sample sizes were 10 at each site, but $n = 20$ will also be considered. Three effect sizes (i.e., mean differences in growth rate between *F. gardneri* transplanted to Furry Creek and Britannia Beach), which are representative of those observed in the June 1998 experiments, will be used: 0.20, 0.35 and 0.50 mm d^{-1}.

Table 3.5. Power of the statistical analyses of growth rate measurements during the June 1998 transplant. Power values are calculated using equation 3.1, with s = 0.40 mm d^{-1} and the δ, n and α values shown. All results of the current experiments were analyzed with n = 10 and α = 0.05. Power analyses using other parameters are shown for comparison.

		δ (mm/d)		
n	α	0.20	0.35	0.50
10	0.05	<0.500	0.687	0.937
	0.10	<0.500	0.813	0.968
20	0.05	0.556	0.958	>0.999
	0.10	0.691	0.979	>0.999

It is clear that the statistical power of this particular set of tests was low. The effect size (the amount by which growth rates at Britannia Beach are less than those at Furry Creek) would have to be relatively large (>0.50 mm d^{-1}) before it would be reliably (power ≥ 0.95) detected using the methods described. Larger sample sizes would make smaller effect sizes (≥ 0.35 mm d^{-1}) apparent. Increasing α to 0.10 appears to have relatively little effect on power in this test, and is not a desirable option as it increases the chance of a Type I error. The ability of these experiments and statistics to detect subtle differences (0.20 mm d^{-1}) in growth rates of *F. gardneri* appears to be extremely low. The low statistical power of the methods used must be kept in mind when examining the results of these experiments; the lack of detectable differences in the June 1998 transplant may be more a function of the methods used than of an actual response of the algae. Furthermore, the lack of power may be even more important in the August 1998 experiment, where there is much more variability in the data (error bars in Figures 3.11 and 3.12).

3.5. Conclusions

All of Hypotheses 6, 7 and 8 (see section 1.3) are supported by experiments very close to Britannia Creek, but experiments farther from this creek do not support any of the hypotheses. The results of these experiments provide strong evidence for the deleterious effects of AMD on *F. gardneri* growth rates, cover and survivorship at the high concentrations within 100 m of the mouth of Britannia Creek. No effects are apparent at greater distances (≥300 m), but these latter observations are confounded by other effects which were unfortunately inherent in the timing and design of experiments. However, evidence from the literature suggests that AMD may affect reproductive stages of *F. gardneri* more severely than adult plants, resulting in exclusion of the plants from areas of high AMD concentrations.

The results of the transplant experiments build on the correlative evidence of AMD effects on *F. gardneri* provided by the measurements described in chapter 2. The use of experimental evidence adds weight to the hypothesis that AMD is at least partially responsible for the lack of *F. gardneri* near Britannia Creek. In terms of salmon productive capacity, AMD appears to be capable of severely limiting *F. gardneri* cover, survivorship and growth. Based on the assumption that salmon productivity is critically dependent on *F. gardneri* for the alga's associated fauna and contribution to the organic carbon pool, AMD would therefore also reduce salmon productive capacity.

4. GENERAL CONCLUSIONS

The overall objective of this thesis is to determine if acid mine drainage is responsible for the absence of *Fucus gardneri* Silva in the Britannia Beach area. The observations described in Chapter 2 showed a complete absence of *F. gardneri* from the shores 1000 m to the north of Britannia Creek and 600 m to the south of the Creek, despite the apparent suitability of abiotic and biotic conditions. However, there was no apparent difference between populations of *F. gardneri* at Britannia Beach which grow near this zone of absence and those which grow elsewhere in terms of percent cover, plant length or reproductive capacity. The plants near Britannia Creek, however, did contain up to 20 times more copper than those at Furry Creek. To examine the causative role of AMD in excluding *F. gardneri* near Britannia Creek, plants were transplanted into various areas near the Creek mouth and their health was monitored. In general, the health of plants transplanted to the immediate area near the mouth of Britannia Creek declined rapidly, but, when placed farther away, the plants fared no worse than controls. The results at greater distances from the Creek may be confounded, however, by the harshness of abiotic conditions (e.g., temperature, humidity) at the time of the experiment. Additionally, the statistical power of the experiments was low, raising the possibility that effects were not detectable with the sampling protocol used.

The above measurements and experiments provide strong correlative evidence for the suggestion that AMD is the major determinant of algal community structure within 600-1000 m of the Creek mouth. The absence of *F. gardneri* is not likely the result of unfavourable abiotic factors such as turbidity, salinity or temperature as the alga is found growing in equally or even more stressful areas in terms of all these factors (see Section 2.4.2). The transplant of *F. gardneri* into the area where it is absent examined one further possibility: that dispersal-related problems can exclude the alga. Dispersal ability is irrelevant at sites BB-1 through BB-3, as plants moved there died within two months; even if propagules settled at these sites they would not survive the extremely high concentrations of AMD. The possibility of dispersal ability limiting this alga's distribution is not, however, excluded farther from the Creek. While *F. gardneri* would not be expected to disperse rapidly given that most of its propagules settle within 1 m of the parent plant (Chapman 1995), other studies (Burrows & Lodge 1951; Paine *et al.* 1996) suggest that propagules can settle >1 km from the nearest population of adult *F. gardneri*. Given that the total shoreline length from which *F. gardneri* is absent covers only about 1600 m and the variety of circulation patterns which are observed, it seems very unlikely that propagules are not being carried to the AMD-affected shoreline by currents.

Acid mine drainage is the most probable feature of the Britannia Beach ecosystem which could bring about the observed distribution of algae; the combined weight of all the evidence points to AMD. The work in this thesis did not establish a model by which AMD may exclude *F. gardneri* in terms of life history stages. Work that attempted to elucidate this issue was unsuccessful because algal propagules could not be cultured. Given the lack of effects found in the June and August 1998 transplants, however, it seems that the peak in metal loadings in early spring (Figures 1.2 and 1.3; Chretien 1997; McCandless, unpublished data), possibly in combination with enhanced effects of AMD on juvenile *F. gardneri*, is necessary to explain the observed lack of the alga at Britannia Beach. Other seasonal characteristics of metal dispersion and toxicity which occur at Britannia Beach concurrently with the loading peak would likely aggravate the toxicity of the metal. The sharp density gradient in Howe Sound during the spring freshet of the Squamish River results in the majority of copper from Britannia Creek remaining in the surface layer of the Sound (Chretien 1997). This means that intertidal organisms such as

F. gardneri will be exposed to more copper than if the metal was dispersing into the entire water body. Additionally, the low salinities in this surface layer (often <5; Chretien 1997; this study, not presented) during the metal peak may increase the toxicity of copper to the algae (Betzer & Kott 1969).

However, it is important to recognize two important considerations. The first is that the effects seen cannot be attributed solely to the metals coming from Britannia Creek. There is also a submerged outfall at 30 m depth, approximately 50 m from the Creek mouth, which releases AMD and municipal sewage. The metal loadings in this outfall are 30-100% of those in the Creek, depending on the season (R. McCandless, unpublished data). During the spring freshet, the density gradient appears to keep this effluent below intertidal depths (Chretien 1997). However, at other times of the year, this water may rise to the surface and interact with biota. While diverting all AMD flow from the mine to the 4100 level and into the submerged outfall might partially mitigate the effects on intertidal organisms, there is no evidence for this in the present study.

A more fundamental issue in the above experiments involves the true separation of causation from correlation. This can be a problem in almost any ecological investigation, including the assessment of the effects of point-source pollution. The difficulty essentially rests in the fact that, while plants were moved to Britannia Beach and exposed to AMD, they were also subjected to all other biotic and abiotic elements which the Britannia Creek estuary ecosystem might impose on them. Thus, the absence of *F. gardneri* from the area near Britannia Creek might not be caused by AMD but by some other characteristic of the Creek's estuarine ecosystem. In this sense, all the evidence obtained from this study is simply correlative.

However, the prospect of indisputably establishing causation is quite daunting. One possibility would be to conduct laboratory experiments where various life stages of *F. gardneri* are subjected to different mixtures of AMD and seawater and the effects observed. Even if the various technical obstacles could be overcome, it is always difficult to generalize laboratory results to the field. Field experiments that eliminate the possibility of other Creek attributes confounding the results would be even more difficult. One could argue that the only way to remove the effects of Britannia Creek itself would be to add acid mine drainage from Britannia Creek to several other freshwater streams and investigate effects on biota in their estuaries. Even setting aside the obvious ethical prohibitions, such an experiment would be completely impracticable.

It was decided at the outset of this study to conduct field experiments as opposed to laboratory experiments. The inherent difficulty of mimicking field conditions in the laboratory was exacerbated in this study because of the very subtle nature of copper chemistry. Field experiments, by definition, exposed the plants to the natural conditions which may play a role in mitigating or intensifying the effects of AMD. An important sacrifice is made in terms of the conclusions, however, in that the results cannot be generalized outside of the Britannia Beach area. Furthermore, there is still a dependence on correlative evidence, however strong this correlation may be.

As a general summary in relation to the Department of Fisheries and Oceans' study, the results of this work provide strong evidence for the role of acid mine drainage from the Britannia Mine in causing the absence of *F. gardneri* from the shores of Howe Sound near Britannia Creek. While the experiments described here did not unequivocally establish AMD as the sole cause of *F. gardneri*'s absence, there is strong correlative evidence for this hypothesis. More definitive results could be obtained if steps were taken to abate the AMD from Britannia Mine.

It would be quite informative to monitor any changes in algal communities which might result from such an operation. It would be even more ideal to periodically transplant *F. gardneri* into the area and compare their progress to the results in this study. Experiments of this sort could largely alleviate the shortcomings of the current results.

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Appendix I — Raw Data from Chapter 2

This appendix presents a portion of the raw data from the transect studies conducted from June to December 1998: (1) percent cover of all items, and (2) oocyte release from *Fucus gardneri*.

Percent Cover Data

The methods for the collection of these data are described in section 2.2.2 and the results for *F. gardneri* and green algal cover are summarized, statisically analyzed and discussed in sections 2.3.2, 2.3.3, 2.4.2 and 2.4.3. Locations of sampling sites are shown in Figure 2.2. Abbreviations used in the data tables: Q # = quadrat number. Mus. = Mussel. Barn. = Barnacle. Gr.Al. = Filamentous green algae. S.E. = Standard error of the mean. The values presented are the percent cover of the specific organism or substratum type in a single quadrat. Data were collected at all stations in August - December, but stations BB-B and FC-B were not monitored in June or July.

Oocyte Release Data

The methods for the collection of these data are described in section 2.2.3 and the results are summarized, statistically analyzed and discussed in sections 2.3.5 and 2.4.5. Locations of sampling sites are shown in Figure 2.2. Abbreviations used in the data tables: S # = sample number. S.E. = Standard error of the mean. Data were collected from July to December, but samples in July and August yielded very low quantities of oocytes. Therefore, only October and December data are presented.

CANOPY COVER — JUNE 1998

Station BB-C

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	0	35	10	55
2	0	0	0	10	0	90
3	0	0	0	20	0	80
4	0	0	0	10	0	90
5	0	0	0	45	0	55
6	0	0	0	15	0	85
7	0	0	5	20	10	65
8	0	0	0	30	0	70
9	0	0	0	25	0	75
MEAN	0.0	0.0	0.6	23.3	2.2	73.9
S.E.	0.0	0.0	0.6	3.9	1.5	4.5

Station BB-D

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	0	50	0	50
2	0	0	0	40	0	60
3	0	0	0	80	5	15
4	0	0	0	75	15	10
5	0	0	0	80	15	5
6	0	0	0	0	0	100
7	0	0	0	95	5	0
8	0	0	0	70	20	10
9	0	0	0	95	0	5
MEAN	0.0	0.0	0.0	65.0	6.7	28.3
S.E.	0.0	0.0	0.0	10.2	2.6	11.4

Station BB-E

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	0	70	10	15
2	0	0	0	80	0	0
3	0	0	0	70	5	10
4	0	0	0	65	35	0
5	0	0	0	15	0	0
6	0	0	0	75	0	0
7	0	0	0	15	85	0
8	0	0	0	60	0	0
9	0	0	0	60	0	0
MEAN	0.0	0.0	0.0	56.7	15.0	2.8
S.E.	0.0	0.0	0.0	8.2	9.5	1.9

CANOPY COVER — JUNE 1998

Station BB-F

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	0	20	0	80
2	0	0	0	45	0	55
3	0	0	0	45	0	55
4	0	0	0	35	0	65
5	0	0	0	5	0	95
6	0	0	0	0	0	100
7	0	0	0	20	0	80
8	0	0	0	95	0	0
9	0	0	0	85	0	0
MEAN	0.0	0.0	0.0	38.9	0.0	58.9
S.E.	0.0	0.0	0.0	11.0	0.0	12.3

Station BB-G

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	40	40	0	20
2	15	0	45	0	0	40
3	0	10	80	10	0	0
4	40	0	60	0	0	0
5	10	0	45	10	5	30
6	30	5	5	35	0	25
7	45	0	5	45	0	5
8	60	0	5	35	0	0
9	5	0	5	70	20	0
MEAN	22.8	1.7	32.2	27.2	2.8	13.3
S.E.	7.3	1.2	9.4	7.9	2.2	5.2

Station BB-H

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	25	10	45	20	0
2	10	5	35	35	0	15
3	5	0	0	55	5	35
4	35	5	15	40	5	0
5	5	0	10	45	20	20
6	5	0	30	30	0	35
7	15	0	25	45	15	0
8	0	0	10	5	0	85
9	0	0	0	95	0	5
MEAN	8.3	3.9	15.0	43.9	7.2	21.7
S.E.	3.7	2.7	4.2	7.9	2.9	9.2

CANOPY COVER — JUNE 1998

Station FC-C

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	60	25	10	5	0	0
2	20	60	20	0	0	0
3	65	25	5	5	0	0
4	55	20	25	0	0	0
5	95	5	0	0	0	0
6	35	50	5	10	0	0
7	20	0	0	20	60	0
8	20	75	5	0	0	0
9	40	60	0	0	0	0
MEAN	45.6	35.6	7.8	4.4	6.7	0.0
S.E.	8.5	8.8	3.0	2.3	6.7	0.0

Station FC-D

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	20	70	10	0
2	80	5	15	0	0	0
3	0	0	25	40	10	25
4	0	30	25	40	0	5
5	5	10	30	55	0	0
6	0	0	25	35	10	30
7	35	0	0	65	0	0
8	70	0	10	20	0	0
9	60	5	35	0	0	0
MEAN	27.8	5.6	20.6	36.1	3.3	6.7
S.E.	11.3	3.3	3.6	8.5	1.7	4.0

Station FC-E

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	55	0	15	10	0	20
2	90	0	10	0	0	0
3	15	0	15	45	20	5
4	20	0	40	25	10	5
5	80	5	15	0	0	0
6	85	10	5	0	0	0
7	30	20	50	0	0	0
8	100	0	0	0	0	0
9	20	0	0	35	45	0
MEAN	55.0	3.9	16.7	12.8	8.3	3.3
S.E.	11.5	2.3	5.8	5.9	5.1	2.2

CANOPY COVER — JUNE 1998

Station FC-F

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	5	25	5	65	0	0
2	45	20	10	25	0	0
3	80	0	0	20	0	0
4	90	0	5	5	0	0
5	60	0	0	5	35	0
6	95	0	5	0	0	0
7	90	0	5	5	0	0
8	95	0	5	0	0	0
9	55	0	25	20	0	0
MEAN	68.3	5.0	6.7	16.1	3.9	0.0
S.E.	10.1	3.3	2.5	6.9	3.9	0.0

Station FC-G

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	85	5	0	5	0	5
2	0	70	30	0	0	0
3	0	25	30	30	0	15
4	70	20	10	0	0	0
5	0	85	15	0	0	0
6	25	20	20	35	0	0
7	0	0	20	60	0	20
8	20	10	15	30	0	25
9	35	20	40	5	0	0
MEAN	26.1	28.3	20.0	18.3	0.0	7.2
S.E.	10.7	9.8	4.0	7.1	0.0	3.3

SURFACE COVER — JUNE 1998

Station BB-C

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	35	10	55
2	0	0	10	0	90
3	0	0	20	0	80
4	0	0	10	0	90
5	0	0	45	0	55
6	0	0	15	0	85
7	0	5	20	10	65
8	0	0	30	0	70
9	0	0	25	0	75
MEAN	0.0	0.6	23.3	2.2	73.9
S.E.	0.0	0.6	3.9	1.5	4.5

Station BB-D

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	50	0	50
2	0	0	40	0	60
3	0	0	80	5	15
4	0	0	75	15	10
5	0	0	80	15	5
6	0	0	0	0	100
7	0	0	95	5	0
8	0	0	70	20	10
9	0	0	95	0	5
MEAN	0.0	0.0	65.0	6.7	28.3
S.E.	0.0	0.0	10.2	2.6	11.4

Station BB-E

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	70	10	15
2	0	0	80	0	0
3	0	0	70	5	10
4	0	0	65	35	0
5	0	0	15	0	0
6	0	0	75	0	0
7	0	0	15	85	0
8	0	0	60	0	0
9	0	0	60	0	0
MEAN	0.0	0.0	56.7	15.0	2.8
S.E.	0.0	0.0	8.2	9.5	1.9

SURFACE COVER — JUNE 1998

Station BB-F

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	20	0	80
2	0	0	45	0	55
3	0	0	45	0	55
4	0	0	35	0	65
5	0	0	5	0	95
6	0	0	0	0	100
7	0	0	20	0	80
8	0	0	95	0	0
9	0	0	85	0	0
MEAN	0.0	0.0	38.9	0.0	58.9
S.E.	0.0	0.0	11.0	0.0	12.3

Station BB-G

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	40	40	0	20
2	0	50	10	0	40
3	10	80	10	0	0
4	0	90	10	0	0
5	0	50	15	5	30
6	5	15	55	0	25
7	0	35	60	0	5
8	0	50	50	0	0
9	0	5	75	20	0
MEAN	1.7	46.1	36.1	2.8	13.3
S.E.	1.2	9.1	8.4	2.2	5.2

Station BB-H

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	40	40	0	20
2	0	50	10	0	40
3	10	80	10	0	0
4	0	90	10	0	0
5	0	50	15	5	30
6	5	15	55	0	25
7	0	35	60	0	5
8	0	50	50	0	0
9	0	5	75	20	0
MEAN	1.7	46.1	36.1	2.8	13.3
S.E.	1.2	9.1	8.4	2.2	5.2

SURFACE COVER — JUNE 1998

Station FC-C

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	35	25	40	0	0
2	80	20	0	0	0
3	80	20	0	0	0
4	55	45	0	0	0
5	70	30	0	0	0
6	95	0	5	0	0
7	5	0	20	75	0
8	95	5	0	0	0
9	90	0	10	0	0
MEAN	67.2	16.1	8.3	8.3	0.0
S.E.	10.2	5.3	4.6	8.3	0.0

Station FC-D

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	20	70	10	0
2	30	50	20	0	0
3	0	25	40	10	25
4	30	25	40	0	5
5	15	30	55	0	0
6	0	25	35	10	30
7	0	5	95	0	0
8	10	35	55	0	0
9	30	55	15	0	0
MEAN	12.8	30.0	47.2	3.3	6.7
S.E.	4.6	5.1	8.3	1.7	4.0

Station FC-E

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	5	20	60	15	0
2	15	20	60	5	0
3	0	25	50	20	5
4	0	45	30	20	5
5	40	60	0	0	0
6	75	0	25	0	0
7	40	60	0	0	0
8	30	15	20	35	0
9	0	0	35	65	0
MEAN	22.8	27.2	31.1	17.8	1.1
S.E.	8.6	7.6	7.6	7.1	0.7

SURFACE COVER — JUNE 1998

Station FC-F

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	25	5	65	5	0
2	20	30	40	10	0
3	10	20	70	0	0
4	40	30	25	5	0
5	0	15	5	80	0
6	10	15	35	40	0
7	60	25	15	0	0
8	35	45	10	10	0
9	15	55	30	0	0
MEAN	23.9	26.7	32.8	16.7	0.0
S.E.	6.2	5.2	7.6	8.9	0.0

Station FC-G

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	65	20	10	0	5
2	70	30	0	0	0
3	25	30	30	0	15
4	75	25	0	0	0
5	85	15	0	0	0
6	20	20	60	0	0
7	0	20	60	0	20
8	10	30	35	0	25
9	70	30	0	0	0
MEAN	46.7	24.4	21.7	0.0	7.2
S.E.	10.8	1.9	8.5	0.0	3.3

CANOPY COVER — JULY 1998

Station BB-C

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	0	40	0	60
2	0	0	0	5	0	95
3	0	0	0	0	0	100
4	0	0	0	55	0	45
5	0	0	0	0	0	100
6	0	0	0	20	0	80
7	0	0	0	5	0	95
8	0	0	0	5	0	95
9	0	0	0	15	0	85
MEAN	0.0	0.0	0.0	16.1	0.0	83.9
S.E.	0.0	0.0	0.0	6.4	0.0	6.4

Station BB-D

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	0	45	0	55
2	0	0	0	80	5	15
3	0	0	0	70	10	20
4	0	0	0	95	0	5
5	0	0	0	100	0	0
6	0	0	0	80	5	15
7	0	0	0	65	5	30
8	0	0	0	100	0	0
9	0	0	0	80	5	15
MEAN	0.0	0.0	0.0	79.4	3.3	17.2
S.E.	0.0	0.0	0.0	6.0	1.2	5.7

Station BB-E

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	0	100	0	0
2	0	0	0	100	0	0
3	0	0	0	100	0	0
4	0	0	0	100	0	0
5	0	0	0	100	0	0
6	0	0	0	100	0	0
7	0	0	0	95	5	0
8	0	0	0	100	0	0
9	0	0	0	100	0	0
MEAN	0.0	0.0	0.0	99.4	0.6	0.0
S.E.	0.0	0.0	0.0	0.6	0.6	0.0

CANOPY COVER — JULY 1998

Station BB-F

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	0	100	0	0
2	0	0	0	65	0	35
3	0	0	0	15	0	85
4	0	0	0	5	0	95
5	0	0	0	25	0	75
6	0	0	0	0	0	100
7	0	0	0	60	0	40
8	0	0	0	5	0	95
9	0	0	0	90	0	10
MEAN	0.0	0.0	0.0	40.6	0.0	59.4
S.E.	0.0	0.0	0.0	12.9	0.0	12.9

Station BB-G

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	5	0	20	35	0	40
2	25	25	40	10	0	0
3	55	5	10	0	0	30
4	40	0	20	25	0	15
5	30	0	30	20	0	20
6	5	10	30	55	0	0
7	20	0	5	50	0	25
8	25	0	50	5	0	20
9	0	30	65	5	0	0
MEAN	22.8	7.8	30.0	22.8	0.0	16.7
S.E.	6.0	3.9	6.4	6.7	0.0	4.8

Station BB-H

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	0	35	0	65
2	40	0	5	40	0	15
3	25	5	20	45	0	5
4	60	15	25	0	0	0
5	15	5	50	20	0	10
6	0	0	5	80	15	0
7	5	0	0	65	15	15
8	10	0	0	60	10	20
9	5	0	20	45	5	25
MEAN	17.8	2.8	13.9	43.3	5.0	17.2
S.E.	6.8	1.7	5.6	8.0	2.2	6.6

CANOPY COVER — JULY 1998

Station FC-C

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	30	40	15	15	0	0
2	90	0	5	5	0	0
3	35	50	0	15	0	0
4	30	40	15	5	10	0
5	90	0	5	5	0	0
6	50	25	0	10	15	0
7	55	20	25	0	0	0
8	55	20	25	0	0	0
9	25	30	0	20	25	0
MEAN	51.1	25.0	10.0	8.3	5.6	0.0
S.E.	8.2	5.8	3.4	2.4	3.1	0.0

Station FC-D

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	25	5	45	25	0	0
2	0	15	40	40	0	5
3	30	30	25	15	0	0
4	50	0	25	25	0	0
5	90	0	5	5	0	0
6	0	0	10	65	0	25
7	100	0	0	0	0	0
8	100	0	0	0	0	0
9	25	10	20	25	10	10
MEAN	46.7	6.7	18.9	22.2	1.1	4.4
S.E.	13.5	3.4	5.5	7.0	1.1	2.8

Station FC-E

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	10	60	5	25
2	20	0	0	35	15	30
3	30	0	0	40	15	15
4	100	0	0	0	0	0
5	100	0	0	0	0	0
6	85	0	0	10	5	0
7	0	0	10	75	15	0
8	0	5	5	55	35	0
9	10	0	40	35	15	0
MEAN	38.3	0.6	7.2	34.4	11.7	7.8
S.E.	14.6	0.6	4.3	8.9	3.6	4.1

CANOPY COVER — JULY 1998

Station FC-F

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	90	0	5	5	0	0
2	80	0	10	10	0	0
3	25	25	0	30	15	5
4	45	30	10	15	0	0
5	75	5	0	5	15	0
6	35	5	0	30	30	0
7	85	0	0	15	0	0
8	10	0	0	40	50	0
9	70	10	0	20	0	0
MEAN	57.2	8.3	2.8	18.9	12.2	0.6
S.E.	9.7	3.8	1.5	4.1	5.9	0.6

Station FC-G

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	25	0	30	35	0	10
2	35	15	20	30	0	0
3	15	0	30	55	0	0
4	55	0	25	20	0	0
5	40	15	0	45	0	0
6	60	5	15	20	0	0
7	0	0	0	100	0	0
8	25	45	20	10	0	0
9	15	0	5	80	0	0
MEAN	30.0	8.9	16.1	43.9	0.0	1.1
S.E.	6.5	5.0	4.0	10.0	0.0	1.1

SURFACE COVER — JULY 1998

Station BB-C

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	40	0	60
2	0	0	5	0	95
3	0	0	0	0	100
4	0	0	55	0	45
5	0	0	0	0	100
6	0	0	20	0	80
7	0	0	5	0	95
8	0	0	5	0	95
9	0	0	15	0	85
MEAN	0.0	0.0	16.1	0.0	83.9
S.E.	0.0	0.0	6.4	0.0	6.4

Station BB-D

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	45	0	55
2	0	0	80	5	15
3	0	0	70	10	20
4	0	0	95	0	5
5	0	0	100	0	0
6	0	0	80	5	15
7	0	0	65	5	30
8	0	0	100	0	0
9	0	0	80	5	15
MEAN	0.0	0.0	79.4	3.3	17.2
S.E.	0.0	0.0	6.0	1.2	5.7

Station BB-E

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	100	0	0
2	0	0	100	0	0
3	0	0	100	0	0
4	0	0	100	0	0
5	0	0	100	0	0
6	0	0	100	0	0
7	0	0	95	5	0
8	0	0	100	0	0
9	0	0	100	0	0
MEAN	0.0	0.0	99.4	0.6	0.0
S.E.	0.0	0.0	0.6	0.6	0.0

SURFACE COVER — JULY 1998

Station BB-F

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	100	0	0
2	0	0	65	0	35
3	0	0	15	0	85
4	0	0	5	0	95
5	0	0	25	0	75
6	0	0	0	0	100
7	0	0	60	0	40
8	0	0	5	0	95
9	0	0	90	0	10
MEAN	0.0	0.0	40.6	0.0	59.4
S.E.	0.0	0.0	12.9	0.0	12.9

Station BB-G

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	20	35	0	45
2	45	45	10	0	0
3	20	50	10	0	20
4	0	30	45	0	25
5	0	30	40	0	30
6	10	35	55	0	0
7	0	10	60	0	30
8	0	70	10	0	20
9	30	65	5	0	0
MEAN	11.7	39.4	30.0	0.0	18.9
S.E.	5.5	6.6	7.2	0.0	5.3

Station BB-H

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	35	0	65
2	0	5	85	0	10
3	5	20	70	0	5
4	65	30	0	0	5
5	5	65	20	0	10
6	0	5	80	15	0
7	0	0	70	15	15
8	0	0	65	15	20
9	0	20	50	5	25
MEAN	8.3	16.1	52.8	5.6	17.2
S.E.	7.1	7.1	9.7	2.4	6.5

SURFACE COVER — JULY 1998

Station FC-C

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	70	10	20	0	0
2	35	30	15	20	0
3	75	10	15	0	0
4	70	15	5	10	0
5	35	35	20	10	0
6	25	20	25	30	0
7	30	70	0	0	0
8	60	40	0	0	0
9	30	0	25	45	0
MEAN	47.8	25.6	13.9	12.8	0.0
S.E.	6.8	7.0	3.3	5.3	0.0

Station FC-D

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	5	60	35	0	0
2	15	40	40	0	5
3	55	25	20	0	0
4	25	35	40	0	0
5	15	75	10	0	0
6	0	10	65	0	25
7	30	30	40	0	0
8	10	50	40	0	0
9	10	30	35	15	10
MEAN	18.3	39.4	36.1	1.7	4.4
S.E.	5.5	6.5	5.1	1.7	2.8

Station FC-E

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	10	60	5	25
2	0	0	45	20	35
3	0	0	30	15	55
4	20	35	15	30	0
5	0	10	25	65	0
6	20	15	55	10	0
7	0	10	75	15	0
8	5	5	55	35	0
9	0	45	40	15	0
MEAN	5.0	14.4	44.4	23.3	12.8
S.E.	2.9	5.2	6.3	6.1	6.9

SURFACE COVER — JULY 1998

Station FC-F

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	40	20	35	5	0
2	30	50	20	0	0
3	15	0	55	30	0
4	45	25	25	5	0
5	10	30	30	30	0
6	0	5	50	45	0
7	10	10	70	10	0
8	0	0	45	55	0
9	5	10	60	25	0
MEAN	17.2	16.7	43.3	22.8	0.0
S.E.	5.7	5.5	5.7	6.4	0.0

Station FC-G

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	45	50	0	5
2	15	55	30	0	0
3	0	40	60	0	0
4	0	75	25	0	0
5	25	25	50	0	0
6	5	25	70	0	0
7	0	0	100	0	0
8	40	55	5	0	0
9	0	20	80	0	0
MEAN	9.4	37.8	52.2	0.0	0.6
S.E.	4.8	7.6	9.8	0.0	0.6

CANOPY COVER — AUGUST 1998

Station BB-B

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	20	55	0	25
2	25	5	35	25	0	10
3	0	0	25	0	0	75
4	15	5	45	10	0	25
5	25	5	35	25	0	10
6	20	0	55	25	0	0
7	10	0	40	50	0	0
8	0	0	25	25	0	50
9	5	0	15	10	0	70
MEAN	11.1	1.7	32.8	25.0	0.0	29.4
S.E.	3.5	0.8	4.3	6.0	0.0	9.6

Station BB-C

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	10	35	5	50
2	0	0	0	30	5	65
3	0	0	0	45	30	25
4	0	0	0	30	0	70
5	0	0	5	15	0	80
6	0	0	0	35	55	10
7	0	0	0	5	0	95
8	0	0	0	5	10	85
9	0	0	0	40	15	45
MEAN	0.0	0.0	1.7	26.7	13.3	58.3
S.E.	0.0	0.0	1.2	4.9	6.1	9.4

Station BB-D

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	0	100	0	0
2	0	0	0	75	5	20
3	0	0	0	60	0	40
4	0	0	0	80	20	0
5	0	0	0	85	0	15
6	0	0	0	65	0	35
7	0	0	0	85	0	15
8	0	0	0	70	30	0
9	0	0	0	85	10	5
MEAN	0.0	0.0	0.0	78.3	7.2	14.4
S.E.	0.0	0.0	0.0	4.1	3.6	5.0

CANOPY COVER — AUGUST 1998

Station BB-E

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	0	55	45	0
2	0	0	0	100	0	0
3	0	0	0	100	0	0
4	0	0	0	55	45	0
5	0	0	0	90	10	0
6	0	0	0	55	45	0
7	0	0	0	100	0	0
8	0	0	0	90	10	0
9	0	0	0	90	10	0
MEAN	0.0	0.0	0.0	81.7	18.3	0.0
S.E.	0.0	0.0	0.0	6.8	6.8	0.0

Station BB-F

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	0	10	0	90
2	0	0	0	0	0	100
3	0	0	0	90	0	10
4	0	0	0	55	0	45
5	0	0	0	10	0	90
6	0	0	0	15	0	85
7	0	0	0	10	0	90
8	0	0	0	25	0	75
9	0	0	0	100	0	0
MEAN	0.0	0.0	0.0	35.0	0.0	65.0
S.E.	0.0	0.0	0.0	12.5	0.0	12.5

Station BB-G

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	25	60	10	0	5
2	0	0	5	15	0	80
3	0	0	5	10	0	85
4	0	0	0	0	0	100
5	20	20	40	10	0	10
6	70	0	5	20	0	5
7	0	0	10	90	0	0
8	55	0	10	10	25	0
9	15	5	55	25	0	0
MEAN	17.8	5.6	21.1	21.1	2.8	31.7
S.E.	8.9	3.3	7.9	8.9	2.8	14.3

CANOPY COVER — AUGUST 1998
Station BB-H

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	0	45	15	40
2	10	0	5	55	15	15
3	5	0	0	90	0	5
4	10	10	50	10	15	5
5	0	10	15	55	10	10
6	0	0	0	80	5	15
7	0	0	10	90	0	0
8	25	0	10	65	0	0
9	30	0	0	70	0	0
MEAN	8.9	2.2	10.0	62.2	6.7	10.0
S.E.	3.8	1.5	5.3	8.4	2.4	4.2

CANOPY COVER — AUGUST 1998

Station FC-B

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	40	0	10	50	0	0
2	50	15	10	25	0	0
3	10	0	15	75	0	0
4	5	0	10	85	0	0
5	25	20	10	40	5	0
6	85	0	5	10	0	0
7	0	20	35	45	0	0
8	45	0	15	40	0	0
9	5	5	60	30	0	0
MEAN	29.4	6.7	18.9	44.4	0.6	0.0
S.E.	9.4	3.0	5.9	7.8	0.6	0.0

Station FC-C

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	45	30	15	5	5	0
2	75	25	0	0	0	0
3	40	40	5	0	15	0
4	30	60	10	0	0	0
5	40	20	5	10	25	0
6	30	35	30	5	0	0
7	75	20	5	0	0	0
8	30	55	0	0	15	0
9	85	0	15	0	0	0
MEAN	50.0	31.7	9.4	2.2	6.7	0.0
S.E.	7.4	6.2	3.2	1.2	3.1	0.0

Station FC-D

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	65	5	5	15	0	10
2	85	5	0	10	0	0
3	40	5	35	20	0	0
4	0	5	5	80	10	0
5	0	15	30	50	5	0
6	60	35	5	0	0	0
7	60	15	5	20	0	0
8	0	15	10	70	5	0
9	70	5	15	10	0	0
MEAN	42.2	11.7	12.2	30.6	2.2	1.1
S.E.	11.2	3.3	4.1	9.6	1.2	1.1

CANOPY COVER — AUGUST 1998

Station FC-E

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	35	15	10	20	20	0
2	20	20	0	45	15	0
3	5	15	20	50	10	0
4	45	0	0	20	35	0
5	30	5	0	50	15	0
6	0	0	5	45	45	5
7	0	10	0	55	35	0
8	60	10	0	25	5	0
9	95	0	5	0	0	0
MEAN	32.2	8.3	4.4	34.4	20.0	0.6
S.E.	10.4	2.5	2.3	6.3	5.1	0.6

Station FC-F

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	40	0	5	55	0	0
2	70	0	0	30	0	0
3	50	15	5	25	5	0
4	70	0	10	20	0	0
5	60	15	25	0	0	0
6	40	0	5	40	15	0
7	75	5	15	5	0	0
8	0	20	10	30	40	0
9	0	20	20	45	15	0
MEAN	45.0	8.3	10.6	27.8	8.3	0.0
S.E.	9.5	3.0	2.7	6.0	4.5	0.0

Station FC-G

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	20	80	0	0
2	10	25	10	55	0	0
3	70	25	0	5	0	0
4	45	25	30	0	0	0
5	45	5	35	15	0	0
6	0	0	25	75	0	0
7	80	15	5	0	0	0
8	10	10	55	20	0	5
9	0	65	35	0	0	0
MEAN	28.9	18.9	23.9	27.8	0.0	0.6
S.E.	10.6	6.7	5.8	11.0	0.0	0.6

SURFACE COVER — AUGUST 1998

Station BB-B

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	20	55	0	25
2	5	55	30	0	10
3	0	25	0	0	75
4	5	55	10	0	30
5	5	60	30	0	5
6	0	65	35	0	0
7	0	45	55	0	0
8	0	25	25	0	50
9	0	15	15	0	70
MEAN	1.7	40.6	28.3	0.0	29.4
S.E.	0.8	6.4	6.2	0.0	9.8

Station BB-C

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	10	35	5	50
2	0	0	30	5	65
3	0	0	45	30	25
4	0	0	30	0	70
5	0	5	15	0	80
6	0	0	35	55	10
7	0	0	5	0	95
8	0	0	5	10	85
9	0	0	40	15	45
MEAN	0.0	1.7	26.7	13.3	58.3
S.E.	0.0	1.2	4.9	6.1	9.4

Station BB-D

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	100	0	0
2	0	0	75	5	20
3	0	0	60	0	40
4	0	0	80	20	0
5	0	0	85	0	15
6	0	0	65	0	35
7	0	0	85	0	15
8	0	0	70	30	0
9	0	0	85	10	5
MEAN	0.0	0.0	78.3	7.2	14.4
S.E.	0.0	0.0	4.1	3.6	5.0

SURFACE COVER — AUGUST 1998

Station BB-E

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	55	45	0
2	0	0	100	0	0
3	0	0	100	0	0
4	0	0	55	45	0
5	0	0	90	10	0
6	0	0	55	45	0
7	0	0	100	0	0
8	0	0	90	10	0
9	0	0	90	10	0
MEAN	0.0	0.0	81.7	18.3	0.0
S.E.	0.0	0.0	6.8	6.8	0.0

Station BB-F

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	10	0	90
2	0	0	0	0	100
3	0	0	90	0	10
4	0	0	55	0	45
5	0	0	10	0	90
6	0	0	15	0	85
7	0	0	10	0	90
8	0	0	25	0	75
9	0	0	100	0	0
MEAN	0.0	0.0	35.0	0.0	65.0
S.E.	0.0	0.0	12.5	0.0	12.5

Station BB-G

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	25	60	10	0	5
2	0	5	15	0	80
3	0	5	10	0	85
4	0	0	0	0	100
5	30	50	10	0	10
6	0	25	70	0	5
7	5	20	65	0	10
8	5	20	65	0	10
9	5	70	25	0	0
MEAN	7.8	28.3	30.0	0.0	33.9
S.E.	3.8	8.5	9.4	0.0	13.8

SURFACE COVER — AUGUST 1998
Station BB-H

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	45	15	40
2	0	10	55	20	15
3	0	0	95	0	5
4	10	60	10	15	5
5	10	15	55	10	10
6	0	0	80	5	15
7	0	10	90	0	0
8	25	20	55	0	0
9	0	0	100	0	0
MEAN	5.0	12.8	65.0	7.2	10.0
S.E.	2.9	6.4	9.6	2.6	4.2

SURFACE COVER — AUGUST 1998

Station FC-B

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	25	75	0	0
2	35	10	55	0	0
3	0	15	85	0	0
4	0	10	90	0	0
5	40	10	45	5	0
6	25	50	25	0	0
7	20	35	45	0	0
8	0	45	55	0	0
9	5	65	30	0	0
MEAN	13.9	29.4	56.1	0.6	0.0
S.E.	5.5	6.8	7.7	0.6	0.0

Station FC-C

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	40	35	25	0	0
2	75	15	10	0	0
3	45	30	5	20	0
4	75	25	0	0	0
5	40	15	20	25	0
6	40	55	5	0	0
7	60	35	5	0	0
8	85	10	0	5	0
9	25	35	30	10	0
MEAN	53.9	28.3	11.1	6.7	0.0
S.E.	6.9	4.6	3.7	3.2	0.0

Station FC-D

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	10	25	50	0	15
2	15	45	40	0	0
3	10	60	30	0	0
4	5	5	80	10	0
5	15	30	50	5	0
6	85	15	0	0	0
7	25	25	50	0	0
8	15	10	70	5	0
9	50	10	40	0	0
MEAN	25.6	25.0	45.6	2.2	1.7
S.E.	8.6	6.0	7.7	1.2	1.7

SURFACE COVER — AUGUST 1998

Station FC-E

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	10	0	60	30	0
2	20	5	50	25	0
3	15	20	55	10	0
4	0	0	40	60	0
5	5	0	60	35	0
6	10	0	55	35	0
7	10	0	55	35	0
8	25	0	60	15	0
9	25	5	35	35	0
MEAN	13.3	3.3	52.2	31.1	0.0
S.E.	2.9	2.2	3.0	4.8	0.0

Station FC-F

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	5	70	25	0
2	0	15	65	20	0
3	30	0	45	25	0
4	20	20	60	0	0
5	25	70	5	0	0
6	5	10	60	25	0
7	15	55	25	5	0
8	20	10	30	40	0
9	20	20	45	15	0
MEAN	15.0	22.8	45.0	17.2	0.0
S.E.	3.6	7.9	7.2	4.5	0.0

Station FC-G

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	20	80	0	0
2	30	10	60	0	0
3	70	25	5	0	0
4	45	50	5	0	0
5	15	75	10	0	0
6	0	25	75	0	0
7	70	20	10	0	0
8	10	55	30	0	5
9	65	35	0	0	0
MEAN	33.9	35.0	30.6	0.0	0.6
S.E.	9.8	7.0	10.8	0.0	0.6

CANOPY COVER — OCTOBER 1998

Station BB-B

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	0	100	0	0
2	25	0	55	20	0	0
3	0	0	35	65	0	0
4	5	0	40	55	0	0
5	10	0	45	45	0	0
6	15	0	45	40	0	0
7	0	0	10	90	0	0
8	25	5	55	15	0	0
9	0	0	15	85	0	0
MEAN	8.9	0.6	33.3	57.2	0.0	0.0
S.E.	3.5	0.6	6.7	10.1	0.0	0.0

Station BB-C

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	10	45	0	45
2	0	0	0	65	35	0
3	0	0	0	45	55	0
4	0	0	0	75	25	0
5	0	0	30	70	0	0
6	0	0	0	90	10	0
7	0	0	5	95	0	0
8	0	0	0	35	0	65
9	0	0	5	50	0	45
MEAN	0.0	0.0	5.6	63.3	13.9	17.2
S.E.	0.0	0.0	3.3	7.0	6.7	8.8

Station BB-D

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	0	100	0	0
2	0	0	0	5	95	0
3	0	0	0	45	0	55
4	0	0	0	80	20	0
5	0	0	0	40	50	10
6	0	0	0	85	0	15
7	0	0	0	85	0	15
8	0	0	0	90	10	0
9	0	0	0	65	5	30
MEAN	0.0	0.0	0.0	66.1	20.0	13.9
S.E.	0.0	0.0	0.0	10.2	10.8	6.2

CANOPY COVER — OCTOBER 1998

Station BB-E

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	0	90	0	10
2	0	0	0	100	0	0
3	0	0	0	95	0	5
4	0	0	0	30	0	70
5	0	0	0	100	0	0
6	0	0	0	80	0	20
7	0	0	0	100	0	0
8	0	0	0	0	20	80
9	0	0	0	80	20	0
MEAN	0.0	0.0	0.0	75.0	4.4	20.6
S.E.	0.0	0.0	0.0	11.9	2.9	10.6

Station BB-F

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	0	100	0	0
2	0	0	0	20	0	80
3	0	0	0	70	0	30
4	0	0	0	100	0	0
5	0	0	0	0	0	100
6	0	0	0	0	0	100
7	0	0	0	100	0	0
8	0	0	0	100	0	0
9	0	0	0	100	0	0
MEAN	0.0	0.0	0.0	65.6	0.0	34.4
S.E.	0.0	0.0	0.0	15.2	0.0	15.2

Station BB-G

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	45	0	15	40	0	0
2	5	10	85	0	0	0
3	50	5	5	40	0	0
4	5	25	70	0	0	0
5	5	0	50	45	0	0
6	30	0	25	40	0	5
7	0	0	25	75	0	0
8	0	0	0	100	0	0
9	25	0	25	50	0	0
MEAN	18.3	4.4	33.3	43.3	0.0	0.6
S.E.	6.6	2.8	9.7	10.6	0.0	0.6

CANOPY COVER — OCTOBER 1998
Station BB-H

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	70	0	0	30	0	0
2	5	0	0	95	0	0
3	0	0	5	95	0	0
4	80	0	0	20	0	0
5	40	0	25	20	15	0
6	0	0	5	95	0	0
7	60	10	15	15	0	0
8	10	0	10	80	0	0
9	0	0	0	100	0	0
MEAN	29.4	1.1	6.7	61.1	1.7	0.0
S.E.	11.1	1.1	2.9	12.8	1.7	0.0

CANOPY COVER — OCTOBER 1998

Station FC-B

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	0	100	0	0
2	5	5	0	90	0	0
3	0	0	10	90	0	0
4	0	0	10	90	0	0
5	0	0	50	50	0	0
6	0	5	45	50	0	0
7	5	0	60	35	0	0
8	50	0	25	25	0	0
9	45	15	5	35	0	0
MEAN	11.7	2.8	22.8	62.8	0.0	0.0
S.E.	6.8	1.7	7.7	9.8	0.0	0.0

Station FC-C

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	15	20	35	25	5	0
2	20	70	10	0	0	0
3	0	60	10	30	0	0
4	50	10	20	20	0	0
5	70	25	5	0	0	0
6	0	15	20	60	5	0
7	20	65	15	0	0	0
8	15	50	10	20	5	0
9	0	65	15	20	0	0
MEAN	21.1	42.2	15.6	19.4	1.7	0.0
S.E.	8.0	8.1	2.9	6.4	0.8	0.0

Station FC-D

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	15	70	10	5	0	0
2	0	5	5	90	0	0
3	0	15	10	75	0	0
4	90	5	0	5	0	0
5	0	40	0	50	10	0
6	35	0	25	40	0	0
7	50	10	25	15	0	0
8	50	5	20	25	0	0
9	65	5	10	20	0	0
MEAN	33.9	17.2	11.7	36.1	1.1	0.0
S.E.	10.8	7.7	3.2	10.1	1.1	0.0

CANOPY COVER — OCTOBER 1998

Station FC-E

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	15	10	10	65	0	0
2	70	0	0	15	15	0
3	65	0	0	35	0	0
4	25	20	20	35	0	0
5	95	5	0	0	0	0
6	80	0	20	0	0	0
7	60	20	0	20	0	0
8	75	0	10	15	0	0
9	75	0	5	20	0	0
MEAN	62.2	6.1	7.2	22.8	1.7	0.0
S.E.	8.7	2.9	2.8	6.7	1.7	0.0

Station FC-F

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	5	10	5	65	15	0
2	0	30	40	30	0	0
3	5	25	25	30	15	0
4	5	30	10	40	15	0
5	0	10	45	45	0	0
6	0	15	25	55	5	0
7	5	10	45	40	0	0
8	5	5	0	75	15	0
9	30	15	10	40	5	0
MEAN	6.1	16.7	22.8	46.7	7.8	0.0
S.E.	3.1	3.1	5.8	5.1	2.4	0.0

Station FC-G

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.
1	100	0	0	0	0	0
2	65	0	10	20	0	5
3	20	0	65	10	0	5
4	55	0	15	0	0	30
5	10	15	20	55	0	0
6	40	0	20	20	0	20
7	15	0	25	45	0	15
8	10	0	85	5	0	0
9	0	15	20	65	0	0
MEAN	35.0	3.3	28.9	24.4	0.0	8.3
S.E.	11.0	2.2	9.2	8.2	0.0	3.6

SURFACE COVER — OCTOBER 1998

Station BB-B

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	100	0	0
2	0	60	40	0	0
3	0	35	65	0	0
4	0	45	55	0	0
5	0	55	45	0	0
6	0	55	45	0	0
7	0	10	90	0	0
8	5	50	45	0	0
9	0	15	85	0	0
MEAN	0.6	36.1	63.3	0.0	0.0
S.E.	0.6	7.4	7.6	0.0	0.0

Station BB-C

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	10	45	0	45
2	0	0	65	35	0
3	0	0	45	55	0
4	0	0	75	25	0
5	0	30	70	0	0
6	0	0	90	10	0
7	0	5	95	0	0
8	0	0	35	0	65
9	0	5	50	0	45
MEAN	0.0	5.6	63.3	13.9	17.2
S.E.	0.0	3.3	7.0	6.7	8.8

Station BB-D

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	100	0	0
2	0	0	5	95	0
3	0	0	45	0	55
4	0	0	80	20	0
5	0	0	40	50	10
6	0	0	85	0	15
7	0	0	85	0	15
8	0	0	90	10	0
9	0	0	65	5	30
MEAN	0.0	0.0	66.1	20.0	13.9
S.E.	0.0	0.0	10.2	10.8	6.2

SURFACE COVER — OCTOBER 1998

Station BB-E

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	90	0	10
2	0	0	100	0	0
3	0	0	95	0	5
4	0	0	30	0	70
5	0	0	100	0	0
6	0	0	80	0	20
7	0	0	100	0	0
8	0	0	0	20	80
9	0	0	80	20	0
MEAN	0.0	0.0	75.0	4.4	20.6
S.E.	0.0	0.0	11.9	2.9	10.6

Station BB-F

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	100	0	0
2	0	0	20	0	80
3	0	0	70	0	30
4	0	0	100	0	0
5	0	0	0	0	100
6	0	0	0	0	100
7	0	0	100	0	0
8	0	0	100	0	0
9	0	0	100	0	0
MEAN	0.0	0.0	65.6	0.0	34.4
S.E.	0.0	0.0	15.2	0.0	15.2

Station BB-G

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	30	70	0	0
2	10	90	0	0	0
3	5	15	80	0	0
4	25	75	0	0	0
5	0	50	50	0	0
6	0	40	55	0	5
7	0	25	75	0	0
8	0	0	100	0	0
9	0	35	65	0	0
MEAN	4.4	40.0	55.0	0.0	0.6
S.E.	2.8	9.4	11.5	0.0	0.6

SURFACE COVER — OCTOBER 1998
Station BB-H

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	5	95	0	0
2	0	0	100	0	0
3	0	5	95	0	0
4	0	40	60	0	0
5	0	30	45	25	0
6	0	5	95	0	0
7	20	30	50	0	0
8	0	10	90	0	0
9	0	0	100	0	0
MEAN	2.2	13.9	81.1	2.8	0.0
S.E.	2.2	5.1	7.5	2.8	0.0

SURFACE COVER — OCTOBER 1998

Station FC-B

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	0	0	100	0	0
2	5	0	95	0	0
3	0	10	90	0	0
4	0	10	90	0	0
5	0	50	50	0	0
6	5	45	50	0	0
7	0	65	35	0	0
8	0	70	30	0	0
9	35	35	30	0	0
MEAN	5.0	31.7	63.3	0.0	0.0
S.E.	3.8	9.2	10.0	0.0	0.0

Station FC-C

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	30	40	25	5	0
2	85	15	0	0	0
3	60	10	30	0	0
4	20	60	20	0	0
5	55	35	10	0	0
6	15	20	60	5	0
7	70	25	5	0	0
8	50	20	25	5	0
9	65	15	20	0	0
MEAN	50.0	26.7	21.7	1.7	0.0
S.E.	7.9	5.3	5.8	0.8	0.0

Station FC-D

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	80	10	10	0	0
2	5	5	90	0	0
3	15	10	75	0	0
4	25	45	30	0	0
5	40	0	50	10	0
6	5	45	50	0	0
7	25	30	45	0	0
8	15	50	35	0	0
9	25	20	55	0	0
MEAN	26.1	23.9	48.9	1.1	0.0
S.E.	7.7	6.4	7.9	1.1	0.0

SURFACE COVER — OCTOBER 1998

Station FC-E

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	10	10	80	0	0
2	5	5	80	10	0
3	5	30	60	5	0
4	40	20	40	0	0
5	40	40	20	0	0
6	10	80	10	0	0
7	30	15	55	0	0
8	15	20	65	0	0
9	15	20	45	20	0
MEAN	18.9	26.7	50.6	3.9	0.0
S.E.	4.7	7.5	8.1	2.3	0.0

Station FC-F

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.
1	10	5	70	15	0
2	30	40	30	0	0
3	25	25	35	15	0
4	30	10	45	15	0
5	10	45	45	0	0
6	15	25	55	5	0
7	10	50	40	0	0
8	5	5	75	15	0
9	20	30	45	5	0
MEAN	17.2	26.1	48.9	7.8	0.0
S.E.	3.1	5.6	5.1	2.4	0.0

Station FC-G

Q #	Mus.	Barn.	Rumpus	Sand	Gr.Al.
1	15	40	45	0	0
2	0	45	45	0	10
3	0	75	20	0	5
4	0	50	0	0	50
5	15	20	65	0	0
6	0	30	45	0	25
7	0	40	45	0	15
8	0	95	5	0	0
9	15	20	65	0	0
MEAN	5.0	46.1	37.2	0.0	11.7
S.E.	2.5	8.3	7.9	0.0	5.6

CANOPY COVER — DECEMBER 1998

Station BB-B

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.	Other*
1	0	0	0	100	0	0	0
2	0	0	0	100	0	0	0
3	0	0	0	100	0	0	0
4	0	0	0	100	0	0	0
5	0	0	0	100	0	0	0
6	0	0	0	100	0	0	0
7	0	0	0	100	0	0	0
8	0	0	0	100	0	0	0
9	0	0	0	100	0	0	0
MEAN	0.0	0.0	0.0	100.0	0.0	0.0	0.0
S.E.	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Station BB-C

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.	Other*
1	0	0	20	80	0	0	0
2	0	0	0	100	0	0	0
3	0	0	0	100	0	0	0
4	0	0	0	90	10	0	0
5	0	0	0	95	5	0	0
6	0	0	0	95	5	0	0
7	0	0	10	90	0	0	0
8	0	0	0	100	0	0	0
9	0	0	0	100	0	0	0
MEAN	0.0	0.0	3.3	94.4	2.2	0.0	0.0
S.E.	0.0	0.0	2.4	2.3	1.2	0.0	0.0

Station BB-D

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.	Other*
1	0	0	0	100	0	0	0
2	0	0	0	100	0	0	0
3	0	0	0	100	0	0	0
4	0	0	0	100	0	0	0
5	0	0	0	100	0	0	0
6	0	0	0	100	0	0	0
7	0	0	0	100	0	0	0
8	0	0	0	100	0	0	0
9	0	0	0	100	0	0	0
MEAN	0.0	0.0	0.0	100.0	0.0	0.0	0.0
S.E.	0.0	0.0	0.0	0.0	0.0	0.0	0.0

*** Other = *Porphyra* spp.**

CANOPY COVER — DECEMBER 1998

Station BB-E

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.	Other*
1	0	0	0	100	0	0	0
2	0	0	0	100	0	0	0
3	0	0	0	100	0	0	0
4	0	0	0	100	0	0	0
5	0	0	0	100	0	0	0
6	0	0	0	100	0	0	0
7	0	0	0	100	0	0	0
8	0	0	0	100	0	0	0
9	0	0	0	100	0	0	0
MEAN	0.0	0.0	0.0	100.0	0.0	0.0	0.0
S.E.	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Station BB-F

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.	Other*
1	0	0	0	100	0	0	0
2	0	0	0	70	0	30	0
3	0	0	0	65	0	35	0
4	0	0	0	100	0	0	0
5	0	0	0	55	0	45	0
6	0	0	0	100	0	0	0
7	0	0	0	85	0	15	0
8	0	0	0	95	0	5	0
9	0	0	0	70	0	30	0
MEAN	0.0	0.0	0.0	82.2	0.0	17.8	0.0
S.E.	0.0	0.0	0.0	5.8	0.0	5.8	0.0

Station BB-G

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.	Other*
1	10	0	5	85	0	0	0
2	20	0	0	80	0	0	0
3	0	0	70	30	0	0	0
4	20	0	35	45	0	0	0
5	0	0	40	60	0	0	0
6	5	0	0	95	0	0	0
7	20	0	50	30	0	0	0
8	15	0	15	70	0	0	0
9	20	10	35	35	0	0	0
MEAN	12.2	1.1	27.8	58.9	0.0	0.0	0.0
S.E.	2.9	1.1	8.1	8.3	0.0	0.0	0.0

*** Other = *Porphyra* spp.**

CANOPY COVER — DECEMBER 1998
Station BB-H

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.	Other*
1	0	0	0	100	0	0	0
2	5	0	5	90	0	0	0
3	0	0	0	0	100	0	0
4	5	5	20	70	0	0	0
5	0	0	5	95	0	0	0
6	5	0	0	80	15	0	0
7	60	0	0	40	0	0	0
8	15	0	0	75	10	0	0
9	0	0	0	15	85	0	0
MEAN	10.0	0.6	3.3	62.8	23.3	0.0	0.0
S.E.	6.5	0.6	2.2	12.0	13.3	0.0	0.0

*** Other = *Porphyra* spp.**

CANOPY COVER — DECEMBER 1998

Station FC-B

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.	Other*
1	60	0	0	40	0	0	0
2	0	0	0	100	0	0	0
3	0	0	50	35	0	0	15
4	0	0	10	90	0	0	0
5	0	0	0	100	0	0	0
6	0	0	0	95	0	0	5
7	0	0	50	45	0	0	5
8	15	0	0	85	0	0	0
9	0	0	55	30	0	0	15
MEAN	8.3	0.0	18.3	68.9	0.0	0.0	4.4
S.E.	6.7	0.0	8.4	10.1	0.0	0.0	2.1

Station FC-C

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.	Other*
1	35	30	30	5	0	0	0
2	15	65	10	10	0	0	0
3	50	10	10	25	5	0	0
4	20	55	20	5	0	0	0
5	25	50	15	10	0	0	0
6	0	55	20	25	0	0	0
7	0	90	10	0	0	0	0
8	20	45	25	10	0	0	0
9	0	35	5	60	0	0	0
MEAN	18.3	48.3	16.1	16.7	0.6	0.0	0.0
S.E.	5.7	7.5	2.7	6.1	0.6	0.0	0.0

Station FC-D

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.	Other*
1	0	0	5	95	0	0	0
2	0	10	15	75	0	0	0
3	35	15	5	45	0	0	0
4	0	10	5	85	0	0	0
5	0	20	5	70	5	0	0
6	0	5	0	95	0	0	0
7	0	5	0	45	50	0	0
8	0	5	15	80	0	0	0
9	5	5	5	65	20	0	0
MEAN	4.4	8.3	6.1	72.8	8.3	0.0	0.0
S.E.	3.9	2.0	1.8	6.2	5.7	0.0	0.0

*** Other = *Porphyra* spp.**

CANOPY COVER — DECEMBER 1998

Station FC-E

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.	Other*
1	70	0	5	25	0	0	0
2	10	0	0	25	65	0	0
3	40	25	10	5	20	0	0
4	15	5	0	75	5	0	0
5	0	0	0	100	0	0	0
6	10	30	0	45	15	0	0
7	5	5	5	80	5	0	0
8	65	0	10	0	25	0	0
9	20	0	5	55	20	0	0
MEAN	26.1	7.2	3.9	45.6	17.2	0.0	0.0
S.E.	8.7	3.9	1.4	11.6	6.7	0.0	0.0

Station FC-F

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.	Other*
1	0	20	0	45	35	0	0
2	50	0	10	40	0	0	0
3	30	0	0	40	25	5	0
4	55	0	0	35	10	0	0
5	0	0	0	70	30	0	0
6	0	10	10	45	35	0	0
7	5	5	5	85	0	0	0
8	0	0	5	95	0	0	0
9	0	0	15	85	0	0	0
MEAN	15.6	3.9	5.0	60.0	15.0	0.6	0.0
S.E.	7.7	2.3	1.9	7.9	5.3	0.6	0.0

Station FC-G

Q #	*Fucus*	Mus.	Barn.	Rock	Sand	Gr.Al.	Other*
1	20	0	10	70	0	0	0
2	0	0	0	100	0	0	0
3	50	0	0	50	0	0	0
4	10	0	30	55	0	0	5
5	0	0	10	85	0	0	5
6	0	0	0	95	0	5	0
7	0	15	20	65	0	0	0
8	0	0	55	45	0	0	0
9	0	0	25	75	0	0	0
MEAN	8.9	1.7	16.7	71.1	0.0	0.6	1.1
S.E.	5.6	1.7	6.1	6.5	0.0	0.6	0.7

*** Other = *Porphyra* spp.**

SURFACE COVER — DECEMBER 1998

Station BB-B

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.	Other*
1	0	0	100	0	0	0
2	0	0	100	0	0	0
3	0	0	100	0	0	0
4	0	0	100	0	0	0
5	0	0	100	0	0	0
6	0	0	100	0	0	0
7	0	0	100	0	0	0
8	0	0	100	0	0	0
9	0	0	100	0	0	0
MEAN	0.0	0.0	100.0	0.0	0.0	0.0
S.E.	0.0	0.0	0.0	0.0	0.0	0.0

Station BB-C

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.	Other*
1	0	20	80	0	0	0
2	0	0	100	0	0	0
3	0	0	100	0	0	0
4	0	0	90	10	0	0
5	0	0	95	5	0	0
6	0	0	95	5	0	0
7	0	10	90	0	0	0
8	0	0	100	0	0	0
9	0	0	100	0	0	0
MEAN	0.0	3.3	94.4	2.2	0.0	0.0
S.E.	0.0	2.4	2.3	1.2	0.0	0.0

Station BB-D

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.	Other*
1	0	0	100	0	0	0
2	0	0	100	0	0	0
3	0	0	100	0	0	0
4	0	0	100	0	0	0
5	0	0	100	0	0	0
6	0	0	100	0	0	0
7	0	0	100	0	0	0
8	0	0	100	0	0	0
9	0	0	100	0	0	0
MEAN	0.0	0.0	100.0	0.0	0.0	0.0
S.E.	0.0	0.0	0.0	0.0	0.0	0.0

*** Other = *Porphyra* spp.**

SURFACE COVER — DECEMBER 1998

Station BB-E

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.	Other*
1	0	0	100	0	0	0
2	0	0	100	0	0	0
3	0	0	100	0	0	0
4	0	0	100	0	0	0
5	0	0	100	0	0	0
6	0	0	100	0	0	0
7	0	0	100	0	0	0
8	0	0	100	0	0	0
9	0	0	100	0	0	0
MEAN	0.0	0.0	100.0	0.0	0.0	0.0
S.E.	0.0	0.0	0.0	0.0	0.0	0.0

Station BB-F

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.	Other*
1	0	0	100	0	0	0
2	0	0	70	0	30	0
3	0	0	65	0	35	0
4	0	0	100	0	0	0
5	0	0	55	0	45	0
6	0	0	100	0	0	0
7	0	0	85	0	15	0
8	0	0	95	0	5	0
9	0	0	70	0	30	0
MEAN	0.0	0.0	82.2	0.0	17.8	0.0
S.E.	0.0	0.0	5.8	0.0	5.8	0.0

Station BB-G

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.	Other*
1	0	5	95	0	0	0
2	0	0	100	0	0	0
3	0	70	30	0	0	0
4	0	50	50	0	0	0
5	0	40	60	0	0	0
6	0	0	100	0	0	0
7	0	60	40	0	0	0
8	0	15	85	0	0	0
9	10	55	35	0	0	0
MEAN	1.1	32.8	66.1	0.0	0.0	0.0
S.E.	1.1	9.3	9.7	0.0	0.0	0.0

*** Other = *Porphyra* spp.**

SURFACE COVER — DECEMBER 1998
Station BB-H

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.	Other*
1	0	0	100	0	0	0
2	0	5	95	0	0	0
3	0	0	0	100	0	0
4	5	20	75	0	0	0
5	0	5	95	0	0	0
6	0	0	85	15	0	0
7	0	0	100	0	0	0
8	0	0	85	15	0	0
9	0	0	15	85	0	0
MEAN	0.6	3.3	72.2	23.9	0.0	0.0
S.E.	0.6	2.2	12.6	13.2	0.0	0.0

*** Other = *Porphyra* spp.**

SURFACE COVER — DECEMBER 1998

Station FC-B

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.	Other*
1	0	10	90	0	0	0
2	0	0	100	0	0	0
3	0	50	35	0	0	15
4	0	10	90	0	0	0
5	0	0	100	0	0	0
6	0	0	95	0	0	5
7	0	50	45	0	0	5
8	0	0	100	0	0	0
9	0	55	30	0	0	15
MEAN	0.0	19.4	76.1	0.0	0.0	4.4
S.E.	0.0	8.2	10.0	0.0	0.0	2.1

Station FC-C

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.	Other*
1	50	40	10	0	0	0
2	80	10	10	0	0	0
3	35	20	45	0	0	0
4	60	35	5	0	0	0
5	60	25	15	0	0	0
6	55	20	25	0	0	0
7	90	10	0	0	0	0
8	55	35	10	0	0	0
9	35	5	60	0	0	0
MEAN	57.8	22.2	20.0	0.0	0.0	0.0
S.E.	6.1	4.2	6.7	0.0	0.0	0.0

Station FC-D

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.	Other*
1	0	5	95	0	0	0
2	10	15	75	0	0	0
3	35	5	60	0	0	0
4	10	5	85	0	0	0
5	20	5	70	5	0	0
6	5	0	95	0	0	0
7	5	0	45	50	0	0
8	5	15	80	0	0	0
9	5	5	70	20	0	0
MEAN	10.6	6.1	75.0	8.3	0.0	0.0
S.E.	3.6	1.8	5.4	5.7	0.0	0.0

*** Other = *Porphyra* spp.**

SURFACE COVER — DECEMBER 1998

Station FC-E

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.	Other*
1	15	20	65	0	0	0
2	5	0	30	65	0	0
3	30	10	40	20	0	0
4	5	5	85	5	0	0
5	0	0	100	0	0	0
6	30	5	45	20	0	0
7	10	5	80	5	0	0
8	0	25	30	45	0	0
9	0	10	70	20	0	0
MEAN	10.6	8.9	60.6	20.0	0.0	0.0
S.E.	4.0	2.9	8.5	7.4	0.0	0.0

Station FC-F

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.	Other*
1	20	0	45	35	0	0
2	0	10	55	35	0	0
3	0	0	55	40	5	0
4	0	0	85	15	0	0
5	0	0	70	30	0	0
6	10	10	45	35	0	0
7	5	5	90	0	0	0
8	0	5	95	0	0	0
9	0	15	85	0	0	0
MEAN	3.9	5.0	69.4	21.1	0.6	0.0
S.E.	2.3	1.9	6.6	5.8	0.6	0.0

Station FC-G

Q #	Mus.	Barn.	Rock	Sand	Gr.Al.	Other*
1	0	20	80	0	0	0
2	0	0	100	0	0	0
3	0	15	85	0	0	0
4	0	40	55	0	0	5
5	0	10	85	0	0	5
6	0	0	95	0	5	0
7	15	20	65	0	0	0
8	0	55	45	0	0	0
9	0	25	75	0	0	0
MEAN	1.7	20.6	76.1	0.0	0.6	1.1
S.E.	1.7	6.0	6.1	0.0	0.6	0.7

*** Other = *Porphyra* spp.**

FUCUS GARDNERI OOCYTE RELEASE — OCTOBER 1998

Station BB-B		Plant surface	
S #	Oocytes	area (cm^2)	Oocytes cm^{-2}
1	660	88.9	7.42
2	864	62.4	13.85
3	1356	87.0	15.59
MEAN	960	79.4	12.29
S.E.	207	8.5	2.48

Station BB-G		Plant surface	
S #	Oocytes	area (cm^2)	Oocytes cm^{-2}
1	732	110.4	6.63
2	336	174.4	1.93
3	386	130.2	2.96
MEAN	485	138.3	3.84
S.E.	125	18.9	1.43

Station BB-H		Plant surface	
S #	Oocytes	area (cm^2)	Oocytes cm^{-2}
1	252	155.8	1.62
2	324	176.2	1.84
3	60	158.7	0.38
MEAN	212	163.6	1.28
S.E.	79	6.4	0.45

Station FC-B		Plant surface	
S #	Oocytes	area (cm^2)	Oocytes cm^{-2}
1	60	203.3	0.30
2	60	174.1	0.34
3	900	167.9	5.36
MEAN	340	181.8	2.00
S.E.	280	10.9	1.68

Station FC-C		Plant surface	
S #	Oocytes	area (cm^2)	Oocytes cm^{-2}
1	996	215.5	4.62
2	180	187.2	0.96
3	1212	217.4	5.57
MEAN	796	206.7	3.72
S.E.	314	9.8	1.41

Station FC-D		Plant surface	
S #	Oocytes	area (cm^2)	Oocytes cm^{-2}
1	1896	213.6	8.88
2	792	215.1	3.68
3	804	184.9	4.35
MEAN	1164	204.5	5.64
S.E.	366	9.8	1.63

Station FC-E		Plant surface	
S #	Oocytes	area (cm^2)	Oocytes cm^{-2}
1	1200	222.6	5.39
2	372	186.5	1.99
3	72	203.8	0.35
MEAN	548	204.3	2.58
S.E.	337	10.4	1.48

Station FC-F		Plant surface	
S #	Oocytes	area (cm^2)	Oocytes cm^{-2}
1	204	171.2	1.19
2	1164	217.0	5.36
3	1380	238.1	5.80
MEAN	916	208.8	4.12
S.E.	361	19.7	1.47

Station FC-G		Plant surface	
S #	Oocytes	area (cm^2)	Oocytes cm^{-2}
1	720	156.0	4.62
2	720	133.9	5.38
3	2040	189.8	10.75
MEAN	1160	159.9	6.91
S.E.	440	16.3	1.93

FUCUS GARDNERI OOCYTE RELEASE — DECEMBER 1998

Station BB-G		Plant surface	
S #	Oocytes	area (cm^2)	Oocytes cm^{-2}
1	400	49.2	8.13
2	240	38.4	6.25
3	112	66.3	1.69
4	—	—	—
5	—	—	—
MEAN	251	51.3	5.36
S.E.	83	8.1	1.91

Station BB-H		Plant surface	
S #	Oocytes	area (cm^2)	Oocytes cm^{-2}
1	64	30.0	2.13
2	16	70.6	0.23
3	24	91.9	0.26
4	64	131.4	0.49
5	72	81.0	0.89
MEAN	48	81.0	0.80
S.E.	15	21.2	0.46

Station FC-B		Plant surface	
S #	Oocytes	area (cm^2)	Oocytes cm^{-2}
1	136	98.3	1.38
2	16	48.2	0.33
3	128	55.9	2.29
4	136	80.0	1.70
5	32	72.8	0.44
MEAN	90	71.0	1.23
S.E.	35	11.5	0.48

Station FC-C		Plant surface	
S #	Oocytes	area (cm^2)	Oocytes cm^{-2}
1	152	68.4	2.22
2	544	76.6	7.10
3	—	—	—
4	160	57.0	2.81
5	48	104.0	0.46
MEAN	226	76.5	3.15
S.E.	126	11.6	1.63

Station FC-D		Plant surface	
S #	Oocytes	area (cm^2)	Oocytes cm^{-2}
1	128	72.5	1.77
2	136	80.6	1.69
3	32	58.3	0.55
4	656	93.4	7.02
5	16	59.0	0.27
MEAN	194	72.8	2.26
S.E.	153	8.6	1.59

Station FC-E		Plant surface	
S #	Oocytes	area (cm^2)	Oocytes cm^{-2}
1	496	181.5	2.73
2	56	79.7	0.70
3	392	89.0	4.40
4	208	89.0	2.34
5	168	87.3	1.92
MEAN	264	105.3	2.42
S.E.	102	24.7	0.78

Station FC-F		Plant surface	
S #	Oocytes	area (cm^2)	Oocytes cm^{-2}
1	152	108.7	1.40
2	208	80.7	2.58
3	288	130.7	2.20
4	552	95.1	5.80
5	104	58.3	1.78
MEAN	261	94.7	2.75
S.E.	102	15.8	1.02

Station FC-G		Plant surface	
S #	Oocytes	area (cm^2)	Oocytes cm^{-2}
1	448	116.4	3.85
2	112	40.9	2.74
3	208	71.4	2.91
4	—	—	—
5	—	—	—
MEAN	256	76.2	3.17
S.E.	100	21.9	0.34

Appendix II — Raw Data from Chapter 3

This appendix presents a portion of the raw data from the transplant experiments conducted from November 1997 to November 1998: (1) survivorship of *Fucus gardneri*, and (2) growth rates of *F. gardneri*.

Survivorship Data

The methods for the collection of these data are described in section 3.2.2 and the results are summarized, statisically analyzed and discussed in sections 3.3.2, 3.4.1, 3.4.2 and 3.4.3. Locations of sampling sites are shown in Figure 3.1. Abbreviations used in the data tables: R # = rock number. S.E. = Standard error of the mean. Dates are abbreviated as DDMMYY. e.g., 131197 = 13 November 1997. The values presented are the proportion of plants on a given rock which survived to that data collection.

Growth Rate Data

The methods for the collection of these data are described in section 3.2.2 and the results are summarized, statistically analyzed and discussed in sections 3.3.3, 3.4.1, 3.4.2 and 3.4.3. Locations of sampling sites are shown in Figure 3.1. Abbreviations used in the data tables: R # = rock number. S.E. = Standard error of the mean. Dates are abbreviated as DDMMYY. e.g., 131197 = 13 November 1997. The values presented are the mean growth rate of all plants on a given rock. These rates are calculated as:

$$GR = (L_t - L_{t-1})/T$$

where GR is the growth rate in mm d^{-1}, L_t is the length of the plant at the time of data collection, L_{t-1} is the length of the plant at the last data collection, and T is the number of days between the two data collections.

FUCUS GARDNERI SURVIVORSHIP — NOVEMBER 1997 TRANSPLANT

BB-1

R #	131197	201197	271197	111297	080198
1	1.00	1.00	1.00	0.83	0.00
4	1.00	1.00	1.00	0.50	0.00
9	1.00	1.00	1.00	1.00	0.00
10	1.00	1.00	1.00	1.00	0.17
13	0.83	0.83	0.83	0.50	0.00
15	1.00	0.83	0.83	0.33	0.00
16	1.00	1.00	1.00	0.83	0.00
18	1.00	0.83	0.83	0.33	0.00
19	1.00	1.00	1.00	0.83	0.00
20	1.00	1.00	1.00	1.00	0.00
Mean	0.983	0.950	0.950	0.717	0.017
S.E.	0.017	0.025	0.025	0.086	0.017

FC-1

R #	131197	201197	271197	111297	080198
1	1.00	1.00	1.00	1.00	1.00
4	1.00	1.00	1.00	1.00	0.83
9	1.00	1.00	1.00	1.00	1.00
10	1.00	1.00	0.83	0.83	0.83
13	1.00	1.00	1.00	1.00	1.00
15	1.00	1.00	1.00	1.00	1.00
16	1.00	1.00	1.00	1.00	1.00
18	1.00	1.00	0.83	0.83	0.83
19	1.00	1.00	1.00	1.00	0.83
20	1.00	1.00	1.00	0.83	0.83
Mean	1.000	1.000	0.967	0.950	0.917
S.E.	0.000	0.000	0.022	0.025	0.028

BB-2

R #	131197	201197	271197	111297	080198
2	0.83	0.83	0.83	0.00	0.00
3	1.00	1.00	1.00	0.00	0.00
5	1.00	1.00	0.17	0.00	0.00
6	1.00	1.00	0.83	0.00	0.00
7	1.00	1.00	1.00	0.00	0.00
8	1.00	1.00	1.00	0.00	0.00
11	1.00	1.00	0.83	0.00	0.00
12	1.00	0.83	0.67	0.00	0.00
14	1.00	1.00	1.00	0.17	0.00
17	1.00	1.00	1.00	1.00	0.00
Mean	0.983	0.967	0.833	0.117	0.000
S.E.	0.017	0.022	0.082	0.100	0.000

FC-2

R #	131197	201197	271197	111297	080198
2	1.00	1.00	1.00	1.00	1.00
3	0.83	0.83	0.50	0.50	0.50
5	0.83	0.83	0.83	0.83	0.83
6	1.00	1.00	1.00	1.00	1.00
7	1.00	1.00	0.83	0.83	0.50
8	0.83	0.83	0.67	0.67	0.67
11	0.83	0.83	0.83	0.83	0.83
12	1.00	1.00	1.00	1.00	1.00
14	1.00	1.00	1.00	1.00	0.50
17	0.83	0.83	0.83	0.83	0.83
Mean	0.917	0.917	0.850	0.850	0.767
S.E.	0.028	0.028	0.052	0.052	0.067

FUCUS GARDNERI SURVIVORSHIP — FEBRUARY 1998 TRANSPLANT

BB-3

R #	090398	210398	040498
1	1.00	0.75	0.50
2	1.00	1.00	0.50
3	0.50	0.25	0.25
4	1.00	0.50	0.25
5	0.75	0.75	0.50
6	1.00	0.75	0.50
Mean	0.875	0.667	0.417
S.E.	0.085	0.105	0.053

FC-3

R #	090398	210398	040498
1	1.00	1.00	1.00
2	1.00	1.00	1.00
3	1.00	1.00	1.00
4	1.00	1.00	1.00
5	1.00	1.00	1.00
6	1.00	1.00	1.00
Mean	1.000	1.000	1.000
S.E.	0.000	0.000	0.000

FUCUS GARDNERI SURVIVORSHIP — JUNE 1998 TRANSPLANT

BB-4

R #	290698	100798	200798	270798	040898	130898	250898
2	0.83	0.33	0.33	0.33	0.17	0.17	0.00
6	0.67	0.67	0.67	0.67	0.50	0.33	*
8	1.00	0.83	0.67	0.67	0.50	0.33	0.17
9	1.00	0.33	0.33	0.17	0.17	0.17	0.00
10	0.67	0.33	0.33	0.33	0.17	0.17	0.00
12	1.00	0.83	0.83	0.83	0.83	0.67	0.50
14	0.83	0.83	0.83	0.67	0.50	0.50	0.50
15	0.83	0.83	0.83	0.83	0.67	0.50	0.33
16	0.83	0.50	0.50	0.50	0.33	0.33	*
17	0.67	0.67	0.67	0.67	0.50	0.50	0.33
Mean	0.833	0.617	0.600	0.567	0.433	0.367	0.229
S.E.	0.043	0.070	0.067	0.071	0.071	0.054	0.069

(Date)

FC-4

R #	290698	100798	200798	270798	040898	130898	250898
2	1.00	1.00	1.00	0.83	0.50	0.17	0.00
6	0.83	0.33	0.17	0.00	0.00	0.00	0.00
8	1.00	0.40	0.40	0.20	0.00	0.00	0.00
9	0.67	0.40	0.40	0.00	0.00	0.00	0.00
10	0.67	0.33	0.33	0.00	0.00	0.00	0.00
12	1.00	0.83	0.80	0.80	0.40	0.20	0.00
14	1.00	0.67	0.50	0.25	0.25	0.25	0.25
15	1.00	1.00	1.00	0.80	0.60	0.20	0.00
16	1.00	0.80	0.60	0.40	0.40	0.00	0.00
17	1.00	1.00	0.50	0.33	0.33	0.33	0.17
Mean	0.917	0.677	0.570	0.362	0.248	0.115	0.042
S.E.	0.045	0.091	0.089	0.107	0.074	0.041	0.028

(Date)

* data were not collected — there was a large log on top of these two rocks

FUCUS GARDNERI SURVIVORSHIP — JUNE 1998 TRANSPLANT

BB-5

R #	Date: 290698	100798	200798	270798	040898	130898	250898
1	0.83	0.83	0.83	0.83	0.67	0.67	0.33
3	1.00	0.83	0.67	0.60	0.00	0.00	0.00
4	1.00	1.00	1.00	1.00	1.00	0.75	0.75
5	1.00	0.80	0.60	0.60	0.20	0.20	0.20
7	1.00	0.83	0.83	0.60	0.50	0.00	0.00
11	1.00	1.00	0.33	0.20	0.17	0.00	0.00
13	0.83	0.83	0.83	0.83	0.83	0.33	0.17
18	1.00	1.00	1.00	0.80	0.50	0.33	0.17
19	1.00	1.00	0.80	0.60	0.40	0.20	0.20
20	1.00	1.00	1.00	1.00	0.60	0.60	0.60
Mean	0.967	0.913	0.790	0.707	0.487	0.308	0.242
S.E.	0.022	0.029	0.066	0.076	0.098	0.089	0.081

FC-5

R #	Date: 290698	100798	200798	270798	040898	130898	250898
1	1.00	0.83	0.50	0.17	0.17	0.17	0.00
3	1.00	0.83	0.80	0.17	0.00	0.00	0.00
4	0.83	0.50	0.50	0.17	0.00	0.00	0.00
5	1.00	0.83	0.60	0.00	0.00	0.00	0.00
7	0.83	0.17	0.00	0.00	0.00	0.00	0.00
11	1.00	0.50	0.33	0.00	0.00	0.00	0.00
13	0.83	0.50	0.50	0.17	0.20	0.20	0.00
18	1.00	1.00	0.50	0.00	0.00	0.00	0.00
19	1.00	0.80	0.80	0.40	0.20	0.20	0.00
20	1.00	0.67	0.50	0.00	0.00	0.00	0.00
Mean	0.950	0.663	0.503	0.107	0.057	0.057	0.000
S.E.	0.025	0.078	0.072	0.042	0.029	0.029	0.000

FUCUS GARDNERI SURVIVORSHIP — AUGUST 1998 TRANSPLANT

BB-6

R #	Date: 140998	230998	031098	101098	231098
2	0.83	0.83	0.83	0.83	0.67
3	0.67	0.33	0.33	0.33	0.00
4	0.67	0.33	0.33	0.17	0.17
7	0.83	0.83	0.50	—	—
8	0.50	0.50	0.50	0.50	0.33
9	0.83	0.67	0.67	0.00	0.33
13	0.83	0.83	0.40	0.40	0.40
15	0.67	0.50	0.50	0.50	0.33
16	1.00	0.83	0.83	0.83	0.67
17	0.67	0.80	0.40	0.20	0.00
Mean	0.750	0.647	0.530	0.419	0.322
S.E.	0.045	0.067	0.059	0.090	0.077

FC-6

R #	Date: 140998	230998	031098	101098	231098
2	0.83	0.83	0.50	0.50	0.50
3	0.67	0.67	0.33	0.00	0.00
4	0.83	0.83	0.83	0.67	0.50
7	1.00	0.83	0.83	0.33	0.33
8	—	—	—	—	—
9	0.83	0.67	0.50	0.50	0.33
13	1.00	0.83	0.67	0.67	0.67
15	0.50	0.50	0.17	0.17	0.17
16	0.50	0.33	0.00	0.00	0.00
17	0.67	0.50	0.50	0.50	0.50
Mean	0.759	0.667	0.481	0.370	0.333
S.E.	0.060	0.059	0.089	0.082	0.075

— : no data due to complete mortality of plants on these rocks

FUCUS GARDNERI SURVIVORSHIP — AUGUST 1998 TRANSPLANT

BB-7

	Date				
R #	140998	230998	031098	101098	231098
1	0.67	0.67	0.67	0.50	0.50
5	1.00	0.83	0.33	0.33	0.17
6	0.83	0.67	0.33	0.17	0.17
10	1.00	0.67	0.50	0.33	0.33
11	0.67	0.50	0.33	0.17	0.17
12	0.83	0.67	0.67	0.67	0.67
14	0.83	0.83	0.67	0.20	0.20
18	1.00	0.67	0.50	0.50	0.50
19	0.83	0.83	0.67	0.67	0.50
20	0.83	0.67	0.67	0.50	0.17
Mean	0.850	0.700	0.533	0.403	0.337
S.E.	0.039	0.033	0.048	0.061	0.060

FC-7

	Date				
R #	140998	230998	031098	101098	231098
1	0.83	0.83	0.50	0.33	0.33
5	0.33	0.33	0.33	0.17	0.17
6	0.50	0.33	0.33	0.33	0.33
10	0.83	0.83	0.83	0.83	0.67
11	0.83	0.67	0.67	0.60	0.60
12	0.83	0.67	0.67	0.80	0.60
14	0.67	0.33	0.40	0.40	0.00
18	0.83	0.83	0.83	0.83	0.67
19	0.50	0.50	0.50	0.50	0.50
20	0.67	0.50	0.50	0.50	0.17
Mean	0.683	0.583	0.557	0.530	0.403
S.E.	0.058	0.067	0.059	0.074	0.075

FUCUS GARDNERI GROWTH RATE — NOVEMBER 1997 TRANSPLANT

BB-1

R #	131197	201197	271197	111297
1	0.12	-0.36	0.12	-0.30
4	-0.98	0.26	-0.17	-0.46
9	-0.43	0.00	-0.43	0.07
10	0.02	-0.57	0.95	-0.39
13	0.11	0.26	-0.26	-0.54
15	-0.26	-0.49	0.11	-0.64
16	0.07	-0.60	0.31	-0.79
18	0.02	-0.26	0.43	-1.21
19	-0.19	0.19	0.10	-0.96
20	-0.60	-0.12	-0.24	-0.86
Mean	-0.210	-0.168	0.093	-0.609
S.E.	0.115	0.106	0.128	0.116

FC-1

R #	131197	201197	271197	111297
1	1.10	0.81	1.21	0.29
4	-0.07	0.40	0.81	0.31
9	-0.29	1.31	0.71	0.48
10	0.86	0.33	0.54	0.31
13	0.71	-0.05	-0.17	0.38
15	-0.02	0.69	0.00	0.35
16	0.45	0.12	1.36	0.27
18	0.69	0.57	0.43	0.43
19	0.43	0.69	0.64	0.25
20	0.45	0.23	0.74	0.17
Mean	0.431	0.511	0.628	0.324
S.E.	0.139	0.124	0.149	0.028

BB-2

R #	131197	201197	271197	111297
2	0.17	-0.09	-0.76	—
3	0.02	0.14	-0.76	—
5	-0.24	0.05	-0.52	—
6	0.00	-0.14	-0.37	—
7	-0.43	-0.19	-0.86	—
8	-0.29	0.40	-0.74	—
11	-0.40	0.37	-0.36	—
12	-0.45	0.52	-0.80	—
14	-0.43	-0.20	-0.23	-0.64
17	-0.02	-1.38	-1.00	-1.57
Mean	-0.207	-0.052	-0.640	-1.107
S.E.	0.073	0.169	0.080	0.464

FC-2

R #	131197	201197	271197	111297
2	1.07	0.81	0.86	0.43
3	0.00	1.20	0.86	0.24
5	0.71	0.77	0.46	0.17
6	-0.52	1.83	0.74	0.13
7	-0.79	1.68	0.49	0.33
8	0.40	0.51	0.57	0.11
11	0.21	1.57	0.71	0.39
12	-0.02	0.90	0.83	0.30
14	0.23	0.26	0.26	0.01
17	-0.06	1.29	0.09	0.27
Mean	0.124	1.083	0.586	0.237
S.E.	0.172	0.163	0.084	0.042

— : no data due to complete mortality of plants on these rocks

FUCUS GARDNERI GROWTH RATE — JUNE 1998 TRANSPLANT

BB-4

R #	290698	100798	200798	270798	040898	130898	250898
	Date						
2	0.25	0.14	-0.60	-0.36	-0.38	0.22	—
6	0.18	0.50	-0.23	-0.64	-0.29	0.72	—
8	0.14	-0.04	-0.88	-0.54	0.00	-0.28	-0.58
9	-0.04	-0.14	0.05	-1.71	-0.38	0.33	—
10	0.26	-0.18	-0.80	-0.43	-0.38	-0.44	—
12	0.03	-0.16	-0.56	-0.34	-0.50	-0.31	-0.86
14	0.38	-0.42	-0.88	-0.29	-0.46	0.15	-0.14
15	-0.25	0.25	-0.80	-0.29	0.22	-0.07	-0.33
16	0.55	0.06	-0.80	-2.33	1.88	-0.17	—
17	-0.07	0.91	-0.58	-0.96	0.25	-0.30	-0.29
Mean	0.142	0.092	-0.607	-0.789	-0.003	-0.014	-0.442
S.E.	0.074	0.122	0.097	0.221	0.226	0.115	0.127

FC-4

R #	290698	100798	200798	270798	040898	130898	250898
	Date						
2	0.50	0.77	0.25	0.43	0.50	0.78	—
6	0.78	0.32	-3.10	—	—	—	—
8	0.73	1.82	0.50	2.14	-0.63	—	—
9	0.68	0.55	0.65	—	—	—	—
10	0.16	1.00	0.65	—	—	—	—
12	0.42	0.62	0.72	0.25	0.50	-0.89	—
14	0.48	0.36	0.97	0.57	0.63	0.00	—
15	0.32	0.45	0.22	0.62	0.79	-1.22	—
16	0.65	0.58	0.50	0.36	0.19	—	—
17	0.43	0.94	-0.03	0.21	1.00	-0.89	0.50
Mean	0.514	0.741	0.133	0.655	0.426	-0.444	0.500
S.E.	0.061	0.139	0.371	0.254	0.200	0.367	n/a

— : no data due to complete mortality of plants on these rocks

FUCUS GARDNERI GROWTH RATE — JUNE 1998 TRANSPLANT

BB-5

R #	Date: 290698	100798	200798	270798	040898	130898	250898
1	0.17	0.47	-0.08	0.40	-0.03	0.47	0.33
3	0.07	0.25	0.12	0.29	—	—	—
4	0.52	0.24	0.22	-1.32	0.44	-0.89	0.50
5	0.57	0.18	0.43	0.05	-0.25	0.67	0.08
7	0.20	0.44	0.22	-0.11	0.29	—	—
11	-0.54	0.80	-0.60	0.57	2.75	—	—
13	0.07	0.65	0.00	-0.21	-0.10	-1.94	-3.67
18	0.30	0.24	0.45	0.09	0.29	0.00	0.17
19	0.23	0.50	-0.20	0.67	0.25	-2.11	-1.92
20	0.29	0.55	-0.18	0.29	-0.19	0.00	-0.44
Mean	0.189	0.432	0.039	0.070	0.384	-0.544	-0.706
S.E.	0.096	0.064	0.102	0.178	0.307	0.426	0.582

FC-5

R #	Date: 290698	100798	200798	270798	040898	130898	250898
1	0.11	1.16	0.53	0.43	0.50	-0.11	—
3	0.07	0.71	0.33	-0.14	—	—	—
4	-0.20	1.15	0.73	0.43	—	—	—
5	0.10	0.49	0.73	—	—	—	—
7	0.17	0.82		—	—	—	—
11	0.30	0.82	-0.05	—	—	—	—
13	0.03	0.21	0.70	-0.29	0.50	1.11	—
18	-0.46	1.43	0.80	—	—	—	—
19	0.01	0.95	0.13	0.29	—	—	—
20	-0.18	1.84	0.53	—	—	—	—
Mean	-0.006	0.958	0.493	0.143	0.500	0.500	n/a
S.E.	0.069	0.148	0.100	0.150	0.000	0.611	n/a

— : no data due to complete mortality of plants on these rocks

FUCUS GARDNERI GROWTH RATE — AUGUST 1998 TRANSPLANT

BB-6

R #	240898	030998	140998	230998	031098	101098	231098	181198
	Date							
2	0.18	0.23	0.36	0.16	0.48	0.29	0.42	0.26
3	0.29	0.50	0.50	-0.50	-0.15	0.07	—	—
4	0.11	0.35	0.48	-1.22	0.25	0.43	0.69	0.19
7	0.03	0.50	-0.16	0.16	-0.37	—	—	—
8	0.50	0.40	0.48	-0.41	1.00	0.05	0.31	-0.23
9	-0.01	0.25	0.44	-0.08	0.45	—	0.05	-0.15
13	0.58	0.65	-0.27	0.11	-0.25	0.79	-0.46	0.19
15	0.50	0.58	-0.20	-0.52	-0.30	1.05	0.15	-0.42
16	-0.72	0.10	0.42	0.11	0.75	0.30	0.29	0.25
17	0.50	0.00	0.25	0.18	-0.20	-0.43	—	—
Mean	0.196	0.356	0.230	-0.202	0.166	0.317	0.208	0.012
S.E.	0.123	0.067	0.100	0.145	0.154	0.161	0.136	0.105

FC-6

R #	240898	030998	140998	230998	031098	101098	231098	181198
	Date							
2	0.31	0.10	0.18	-0.04	0.33	-1.00	-0.21	—
3	0.27	-0.80	-0.14	-0.11	0.20	—	—	—
4	0.70	0.83	0.15	0.49	0.60	-0.43	0.41	—
7	0.81	0.70	0.23	0.13	0.24	0.14	0.62	—
8	0.35	0.45	—	—	—	—	—	—
9	0.13	0.37	0.33	0.53	0.30	0.67	0.08	0.54
13	1.25	—	0.67	0.09	0.33	0.36	0.40	-4.02
15	-0.25	0.55	0.12	0.30	0.00	0.57	0.15	—
16	0.18	0.07	-0.24	0.28	—	—	—	—
17	—	0.40	-0.05	-1.67	0.00	0.29	—	—
Mean	0.417	0.297	0.138	-0.001	0.250	0.085	0.243	-1.740
S.E.	0.146	0.160	0.090	0.220	0.069	0.225	0.120	2.279

— : no data due to complete mortality of plants on these rocks.

FUCUS GARDNERI GROWTH RATE — AUGUST 1998 TRANSPLANT

BB-7

	Date							
R #	240898	030998	140998	230998	031098	101098	231098	181198
1	-0.14	1.25	0.09	0.17	0.07	0.00	0.10	0.23
5	0.79	-0.50	0.23	0.02	0.33	0.33	—	—
6	0.44	0.00	0.49	0.28	-0.10	0.00	0.15	
10	0.21	-0.05	0.23	0.19	0.63	-0.86	-0.04	-0.75
11	0.19	-0.43	0.23	0.17	0.65	0.29	0.85	0.42
12	0.00	—	0.36	0.39	0.68	0.07	1.06	0.18
14	-0.04	0.50	0.29	-0.29	-0.05	0.00	-0.15	0.15
18	-0.08	0.53	0.15	-0.47	0.20	0.43	0.08	—
19	0.21	0.20	0.40	-0.33	-0.35	-0.38	0.23	-0.33
20	0.89	0.30	0.67	0.53	0.05	0.24	0.08	0.12
Mean	0.247	0.199	0.314	0.066	0.212	0.012	0.261	0.003
S.E.	0.113	0.179	0.055	0.104	0.112	0.121	0.137	0.152

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	Date							
R #	240898	030998	140998	230998	031098	101098	231098	181198
1	0.38	-0.30	0.02	0.58	-0.20	0.14	0.50	—
5	0.08	1.30	0.41	-0.61	0.20	-1.43	1.00	-0.19
6	0.36	-0.10	0.18	1.17	-0.15	-0.71	1.00	—
10	0.54	0.95	0.44	0.29	0.34	-0.17	0.38	—
11	0.80	0.27	0.51	0.42	0.63	0.33	0.97	0.44
12	0.27	0.75	0.22	0.14	0.27	-0.22	-0.03	-0.21
14	0.30	0.30	0.18	-0.39	0.45	-0.14	—	—
18	0.46	—	0.20	0.76	0.42	0.23	0.63	0.42
19	0.28	0.77	0.33	0.11	-0.03	0.00	-0.23	—
20	0.23	0.47	0.20	0.74	0.43	0.05	0.62	0.46
Mean	0.370	0.489	0.269	0.320	0.235	-0.193	0.539	0.185
S.E.	0.062	0.170	0.047	0.170	0.088	0.165	0.147	0.158

— : no data due to complete mortality of plants on these rocks.