EFFECT OF GRAZING BY *BRANTA CANADENSIS* (CANADA GEESE) ON THE FITNESS OF *CAREX LYNGBYEI* (LYNGBY'S SEDGE) AT A RESTORED WETLAND IN THE DUWAMISH RIVER ESTUARY

by

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This is to certify that I have examined this copy of a master's thesis by

CAREN JANE CRANDELL

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Date: June 9, 2000

Master's Thesis

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Abstract

Effect of Grazing by *Branta canadensis* (Canada Geese) on the Fitness of *Carex lyngbyei* (Lyngby's Sedge) at a Restored Wetland in the Duwamish River Estuary

by Caren Jane Crandell

Chairperson of the Supervisory Committee: Professor Kern Ewing
College of Forest Resources

Estuarine restoration efforts are increasing in the Pacific Northwest at a time when local and global populations of geese are on the rise. In order to determine the effect of grazing by geese on an intertidal sedge, bare root shoots of *C. lyngbyei* were planted at an estuarine wetland restoration site frequented by *Branta canadensis* (Canada geese) in the Duwamish River estuary in April, 1996. It was hypothesized that grazing would have a negative effect on the fitness of the *C. lyngbyei* as measured by a number of attributes, especially belowground (BG) biomass and percent total non-structural carbohydrates (TNC). The effectiveness of exclosures on increasing plant survival was evaluated by protecting plants in 30 experimental plots with chicken wire fencing and exposing three plots to goose herbivory. Three plants from half of the protected plots were sampled in October, 1996, and aboveground (AG) and BG attributes were measured. One year later, plants in 15 of the experimental plots were protected for a second growing season; and plants in the remaining 15 plots were exposed to grazing by geese beginning in April. In October 1997, three plants from every plot were sampled and the same attributes measured. Volunteer species appeared within exclosures during the first growing season and within all experimental plots during the second growing season. The presence of all volunteer species was recorded in 25 of 30 plots in August 1996, after which time the recruits were removed in order to maintain constant conditions in all experimental plots.

All species present within quadrats surrounding the sampled *C. lyngbyei* plants were recorded during the second growing season. The data from both years were analyzed with two-way-species-indicator analysis (TWINSPAN) and detrended correspondence analysis (DCA). From April through June of the second growing season, goose behavior was recorded using a combination of scanning and sequential techniques. Grazing intensity was calculated by relating the time geese spent grazing on *C. lyngbyei* on site to the amount of available *C. lyngbyei*. In order to test the effect of grazing on reference sites, exclosures were constructed in nearby established native stands of *C. lyngbyei*. Grazed and protected reference plots were sampled on 1 November 1997. All AG and BG attributes, except total non-structural carbohydrates (TNC), were measured for these samples.

Survival of newly planted *C. lyngbyei* shoots was dependent on protection from the geese in the form of a physical barrier since none of the planted shoots survived in unfenced areas. During the second growing season, grazing by Canada geese at the level of 0.0006 geese day^{-1} m^{-2} available *C. lyngbyei* (or 330 goose-days ha^{-1} available *C. lyngbyei*) had a negative effect on the fitness of 2-year-old *C. lyngbyei* plants, as measured by AG biomass, shoot height and number, and BG biomass and rhizome number. The percent of energy reserves TNC in BG tissue was not affected by grazing, although TNC in the second year dropped to half of the levels of the first year. Plants grazed during the second growing season probably regressed to a fitness lower than that established at the end of the first growing season, as measured by BG biomass, thus underscoring the importance of a second year of protection. Protection for two growing seasons resulted in *C. lyngbyei* plants that had 58% of the BG biomass of the grazed established stands that served as a target state.

Results of the multivariate analysis suggest that site conditions and the size of the *C. lyngbyei* plant affect the diversity and weediness of volunteering plant communities. In general, *C. lyngbyei* grew larger in the portions of the site with unconsolidated mixed sediment, slightly lower salinities, and lower average elevation. Fewer weedy (early successional and aggressive vegetatively reproducing) species grew in these areas with larger *C. lyngbyei*. Grazing appeared to cause a convergence of species assemblages independent of site conditions, while protection appeared to allow a more diverse array of assemblages to establish across all site conditions. *C. lyngbyei* may not require management of non-target species if it is planted in conditions for which it is well suited and then is protected from grazing by geese.

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CHAPTER 1: INTRODUCTION

A dominant high-intertidal plant of the brackish marshes of the Pacific Northwest, *Carex lyngbyei* (Cyperaceae) is a perennial sedge that performs a number of important functions in these estuarine systems: it provides habitat and food for mammals, birds, and invertebrates and is a source of macrophytic primary production that serves as the foundation for the detrital food web (Ewing 1982, 1983, and 1986; Seliskar and Gallagher 1983; Simenstad 1983; Hutchinson 1988). As a result, estuarine restoration efforts in the region frequently include plantings of *C. lyngbyei*. Especially in urban areas, these efforts are regularly thwarted by resident (non-migrating) populations of western Canada geese (*Branta canadensis moffitti*). The short-term impact of Canada geese on these projects can include removal and consumption of the entire planted unit. Canada geese also intensely graze established *C. lyngbyei* populations in such urban systems as the Duwamish River, although these populations currently seem to be able to withstand some level of grazing pressure. The longer-term effects of grazing on the sedge species are not known.

Monitoring of restoration and reference sites usually includes measurements of primary productivity as indicators of the health or level of functioning of a restored or created wetland (Frenkel and Morlan 1991). The monitoring of a restored urban wetland in the Puyallup River in Tacoma, Washington, revealed that above- (AG) and below-ground (BG) biomass for *C. lyngbyei* varied greatly both between the experimental and reference sites and from year to year over a 5-year period (Simenstad and Thom 1996). Although there was evidence of heavy grazing at this restored wetland site, the methodology for measuring *C. lyngbyei* peak biomass production did not account for AG tissue that was consumed. Nor was grazing pressure directly addressed in the comparison of stressed (urban) and reference (non-urban) sites in Puget Sound (Wenger 1995; Simenstad, pers. comm.); in fact, a grazed site was dropped from the statistical analysis because of unknown impacts.

The assumption that removal of photosynthesizing plant tissue would have a negative impact on plants possesses apparent logic; but the effect of grazing on plants has been hotly debated by ecologists, botanists, conservationists, and range-managers for decades (Belsky *et al.* 1993, Painter and Belsky 1993). McNaughton (1979, 1983) and Owen and Weigart (1981) cited increased net aboveground primary productivity in populations of grazed plants as evidence that herbivores optimize plant- and community-productivity and that mutualism exists between plants and their grazers. But Belsky (1986), in a review of the literature, and Painter and Belsky (1993), in a position paper, stated that there is no credible evidence from which one can generalize that plants benefit from grazing or that plants "need" grazers as much as grazers need them. Belsky (1987) stated that much of the misinterpretation of data has come from a focus on the community- and ecosystem-levels rather than on the fitness of the individual plant.

The fitness of an organism is usually defined in terms of the competitive ability of a genotype to contribute to the next generation (Lincoln *et al.* 1982). When the concept of fitness is applied to clonal organisms, the emphasis is on the "continued reduplication of discrete modular units, the sum of these units representing the product of a single zygote. . . . A single genotype of a clonal plant displays its fitness as a more or less fragmented phenotype" (Noble *et al.* 1979: 983-984). The site of vegetative reproduction of *C. lyngbyei* is below ground, and the fates of vegetatively produced shoots determine the persistence of *Carex* populations (Bedford *et al.* 1988). The importance of vegetative reproduction is underscored by the work of Ewing (1982), who saw no *C. lyngbyei* seedlings during three years of field work in the marshes of the Skagit River Delta, Washington, and found *C. lyngbyei* seed viability to be very low. In this study, therefore, the fitness of *C. lyngbyei* is defined in terms of the capacity for vegetative reproduction year after year.

BG biomass of *C. lyngbyei* performs other important functions that contribute to the success of the species. In their study of *C. lyngbyei* in a tidal marsh of the Fraser River, Kistritz *et al.* (1983) determined that BG organs constitute most of the biomass and control the growth and nutrient-dynamics of this perennial sedge. Gallagher and Kibby (1981) attributed increased productivity in *C. lyngbyei* stands in different portions of an Oregon marsh to their ability to mobilize BG reserves early in the growth season.

Emergent marsh plants, including *C. lyngbyei*, perform a number of habitat functions for fish and wildlife. Juvenile salmon, especially chinook (*Oncorhynchus tshawytscha*) and chum (*O. keta*), live in the tidal channels of river delta marshes before migrating to the Pacific Ocean (Levy and Northcote, 1982). Non-anadromous fish, such as three-spined stickleback (*Gasterosteus aculeatus*) and surf smelt (*Hypomesus pretiosus*) also spend time in the channels (Simenstad, 1983). Waterfowl use emergent marsh habitat for a number of life requirements: American coots (*Fulica americana*) use it for refuge and reproduction; American goldfinches (*Carduelis tristis*) use it for feeding and reproduction; American widgeon *Anas americana*) use it for feeding, refuge, and reproduction; black brant (*Branta bernicla*) use it for feeding and refuge; and Canada geese (*B. canadensis*) use it for feeding, refuge, and reproduction (Simenstad *et al.* 1991). Geese (various spp.), trumpeter swans (*Olor buccinator*) and grizzly bears (*Ursus arctos horribilis*) forage on young *C. lyngbyei* because it is high in protein early in the growing season (Pojar and MacKinnon, 1994). A perennial plant with aboveground stems that die back at the end of the growing season, *C. lyngbyei* is among the species that contributes carbon material to the system (Thom, 1981). The plant biomass is exported to the estuary and decomposes. The resulting detritus forms the basis of the entire estuarine food web (Simenstad, 1983).

In stating, "grazing is a whole plant experience," Painter and Belsky (1993: 5) called for more work on the BG portion of the grazing picture. Since this portion of the plant is not consumed during grazing and is so important to the success of perennials, it is surprising that very few grazing studies have considered the effect on BG attributes. Cargill and Jefferies (1984) found no difference in BG biomass between grazed and ungrazed swards of *C. subspathacea*, but the authors discussed the limitations of BG samples and urged caution in the interpretation of the results. Beaulieu *et al.* (1996) found that an arctic graminoid species (*Eriophorum scheuchzeri*) was able to compensate for leaves lost to grazing and to maintain AG production at a level similar to ungrazed plants, but did so at the expense of BG energy reserves (*i.e.*, total nonstructural carbohydrates (TNC)).

C. lyngbyei is an important component of healthy estuarine ecosystems in the Pacific Northwest. As a result, it is often selected for planting in estuarine restoration projects. Canada geese frequently inhabit the areas that are the subject of restoration efforts. Clarification of the effect of grazing on *C. lyngbyei* should lead to restoration techniques and management practices that improve the performance of restored marshes. In response to increasing populations of geese worldwide (Allan *et al.* 1995), a number of studies (Jefferies *et al.* 1979, Prins and Ydenberg 1985, Bedard, *et al.* 1986, Hik and Jefferies 1990 Percival and Houston 1992, Beaulieu *et al.* 1996) have been conducted on the effect of grazing by geese on plants. Although Jefferies and co-workers (Cargill and Jefferies 1984; Kotanen and Jefferies 1987; Hik *et al.* 1992) have investigated the effect of grazing by lesser snow geese on a sub-arctic species of *Carex*, neither *C. lyngbyei* nor Canada geese appear in the grazing literature. Further, only one other study examines the effects of grazing by waterfowl in the context of restoration (Clevering and Van Gulik 1997).

The turning basin at the upper end of the navigation channel in the Duwamish Waterway is the site of an ongoing restoration project. Removal by geese of *C. lyngbyei* shoots following planting in 1995 resulted in 0% survival of the plantings (Tanner, pers. comm.). The Coastal America partners identified the need to address the role of geese in the success or failure of *C. lyngbyei* establishment. The current study was designed to meet that need. The sedge was replanted at the site and quickly followed with some protection from geese in 1996. A grazing study conducted at this restoration site offered several advantages over those conducted in established stands of this clonal species: it provided an opportunity to look at the localized response to grazing on the scale of the individual plant, gain relatively easy access to the BG plant tissues, and examine the effects of grazing in a restoration context. The restoration context permitted consideration of naturally occurring—rather than artificially established—levels of grazing by geese and provided the potential for addressing the amount of time that new plants might require protection in order to become sufficiently established to withstand grazing.

Goals and Objectives

The goal of this study was to gain an understanding of both short-term and longer-term effects of goose grazing on the fitness of *C. lyngbyei.* The objectives of the study were the following: 1) to determine the effect of protection from geese for one growing season on the establishment and survival of planted *C. lyngbyei* at the restoration site; 2) to determine the effect of one season of grazing by Canada geese on the fitness of individual *C. lyngbyei* plants at a restoration site, as measured by AG and BG biomass, vegetative reproduction, and energy storage in BG tissues; 3) to determine the effect of goose grazing on similar aspects of established stands of *C. lyngbyei* at reference sites; and 4) to develop a means of quantifying goose-use of the restoration site.

Study Questions and Hypotheses

1. Does protection from geese for one growing season increase establishment of planted *C. lyngbyei* shoots at the Duwamish restoration site?

H_0: Protection does not affect the establishment of *C. lyngbyei* planted at the restoration site.

H_a: Protection increases the establishment of *C. lyngbyei* planted at the restoration site.

Canada geese may play a role in preventing bare-root shoots of *C. lyngbyei* from establishing after being planted. *C. lyngbyei* shoots were planted at the Duwamish Upper Turning Basin in April, 1994, and disappeared within a week. The geese in the area may have pulled out the shoots shortly after their planting. Protection with fencing is expected to increase the plants' survival and establishment as measured by percentage of plants remaining at the end of the growing season.

2. Will one season of grazing by Canada geese negatively affect the fitness of 1-year-old*C. lyngbyei* plants at a restoration site, as measured by AG and BG biomass, stem height, vegetative reproduction, and energy storage in belowground tissues?

> H_o: Grazing by Canada geese does not affect the fitness of 1-year-old *C. lyngbyei* plants at the Duwamish restoration site, as measured by AG and BG biomass, stem height, vegetative reproduction (stem density and rhizome number), and energy storage (total nonstructural carbohydrates) in belowground tissues.
>
> H_a: Grazing by Canada geese affects the fitness of 1-year-old *C. lyngbyei* plants at the Duwamish restoration site, as measured by AG and BG biomass, stem height, vegetative reproduction (stem density and rhizome number), and energy storage (total nonstructural carbohydrates) in belowground tissues.

Different plant species react to grazing in a variety of ways. Evidence exists for some effect (increase or decrease) or no effect of grazing on AG and BG biomass, but most of these mixed results have been on existing, established populations of plants. A practitioner in the restoration field has stated that one year of protection from goose grazing is enough to allow plants to establish to the point at which they can tolerate grazing, although there are no data to document or support this claim (Gary Jones, pers. comm.). The one study in the literature that has examined the effect of grazing by birds (swans) in a restoration context found that 3 years of grazing resulted in the disappearance of *Scirpus lacustris* transplants and that 3-year-old *S. lacustris* stands were able to withstand several grazing episodes during its fourth growing season. It is expected that one season of grazing will have a negative effect on the AG and BG biomass, stem height, and vegetative reproduction (stem density and rhizome number) of 1-year-old *C. lyngbyei* plants. BG biomass is particularly important to measure because it is not consumed during grazing activity and accurately reflects the below ground productivity of the plant over the growing season. It is also expected that grazed plants will store less energy below ground and will therefore have lower carbohydrate reserves in the roots and rhizomes than their protected counterparts.

3. Does grazing by Canada geese have a negative effect on similar aspects of established stands of *C. lyngbyei* at nearby reference sites on the Duwamish?

> H_0: Grazing by Canada geese does not affect the fitness of native established *C. lyngbyei* plants on the Duwamish River, as measured by AG and BG biomass, stem height, and vegetative reproduction (stem density and rhizome number).
>
> H_a: Grazing by Canada geese affects the fitness of *C. lyngbyei* plants on the Duwamish River, as measured by AG and BG biomass, stem height, and vegetative reproduction (stem density and rhizome number).

As stated for Question 2, the reactions of various plants species to grazing has been mixed. Some *C. lyngbyei* stands in the Duwamish River are grazed heavily. Areas that escape grazing behind such physical barriers as large woody debris are much taller than parts that are grazed. The decrease in height would be expected since the act of grazing involves the consumption of aboveground portions of plants, but the decrease in photosynthetic surface suggests that there may be a negative effect on the overall fitness of the plants as measured by other characteristics. With the effect of grazing assessed, a more accurate picture of the status of the *C. lyngbyei* stands on the Duwamish will be acquired. It is expected that one season of grazing will have a negative effect on the AG and BG biomass, stem height, and vegetative reproduction (stem density and rhizome number) of native established *C. lyngbyei* stands.

4. What is the goose-use of the restoration site and how can it be measured?

Grazed areas experience different levels of pressure depending on the frequency and duration of the grazing incidences. The manipulative studies that have quantified grazing pressure have exposed plots to captive geese for certain periods of time or until a certain amount of biomass is removed. Others have quantified grazing by relating fecal deposits in plots to consumption of biomass. The grazing treatment in the current study will involve naturally occurring populations of geese and natural levels of grazing. Natural grazing pressure must be quantified so that the pressure at this site can be described and so that any effect can be attributed to this level of grazing at this site. Work at other sites with similar populations of geese and new plants growing under similar conditions could then expect comparable effects.

5. How does goose grazing affect the plant community in areas occupied by 1-year-old *C. lyngbyei* and naturally recruiting species?

Grazing has long been documented to cause shifts in plant communities. Some species are preferentially eaten. Others have growth forms that facilitate their recovery from grazing. Others benefit from the increased light that is available when vegetation is continually cropped. Exclosures increased the survival of naturally recruiting species in addition to increasing the survival of the planted *C. lyngbyei* . Multivariate approaches will be used to determine how the species composition of the planted areas changes as a result of exposure to grazing. Graminoids (vegetatively reproducing perennials) and fast growing annuals are expected to dominate the areas exposed to grazing, whereas *C. lyngbyei* is expected to dominate those areas that remain protected.

CHAPTER 2: METHODS

Study Sites

The study site is located on the Duwamish River in Seattle, Washington, 9.6 km (6.0 miles) from the river mouth (Figure 1) on the west bank of the turning basin at the upper end of the navigation channel (Figure 2). The restoration project is the joint effort of the U.S. Fish and Wildlife Service, U.S. Environmental Protection Agency, U.S. Army Corps of Engineers, and the Port of Seattle, which formed a partnership through the federal Coastal America program. Established in 1992, the Coastal America program promotes partnerships among federal, state, and local entities working on coastal restoration projects. The original shoreline at the Upper Turning Basin was altered through decades of deposition of dredged spoils associated with the maintenance of the navigation channel (Cagney, pers. comm.). In 1992, a cove-like area was excavated down to intertidal elevations. In 1995, an attempt to revegetate the intertidal portions of this site with *Scirpus acutis* (hardstem bulrush) and *C. lyngbyei* (Lyngby's sedge) failed (Cordell, *et al.* 1996). Geese were thought to have something to do with the rapid (within one week) disappearance of the planted species (Tanner, pers. comm.).

Two established stands of *C. lyngbyei* located within 300 m of the restoration site were used as reference stands and as the sites of manipulation experiments on native stands (Figures 1 and 2). One reference stand was located on Boeing property on the west bank of the river just upriver from the Turning Basin and the Oxbow Bridge. This stand was approximately 50 m long and 4-5 m wide. The bottom of the river channel dropped steeply below this bench. The other stand was located on Port of Seattle property on the west bank of the river but downstream of the restoration site. It was approximately 20 m long and 1-2 m wide. There was no vegetation below this stand, but the river bottom sloped more gently down and away from this stand than it did at the upstream reference stand.

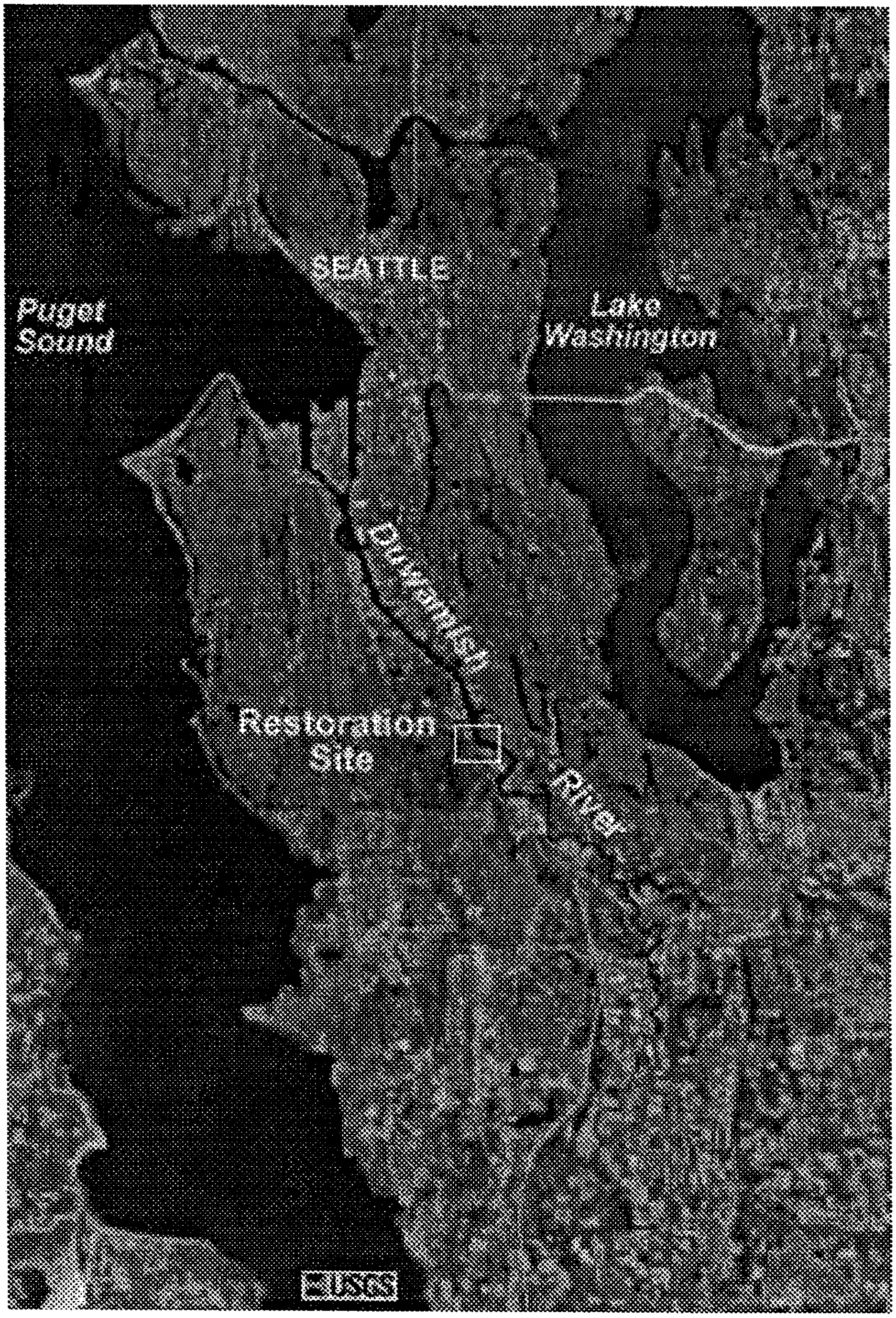


Figure 1. 1990 aerial photograph showing location of Coastal America restoration site in the Upper Turning Basin of the Duwamish River estuary, Seattle, Washington. See Figure 2 for inset. Scale: 1 centimeter = 1,900 meters (1 inch = 15,800 feet) Photograph courtesy of U. S. Geological Survey.

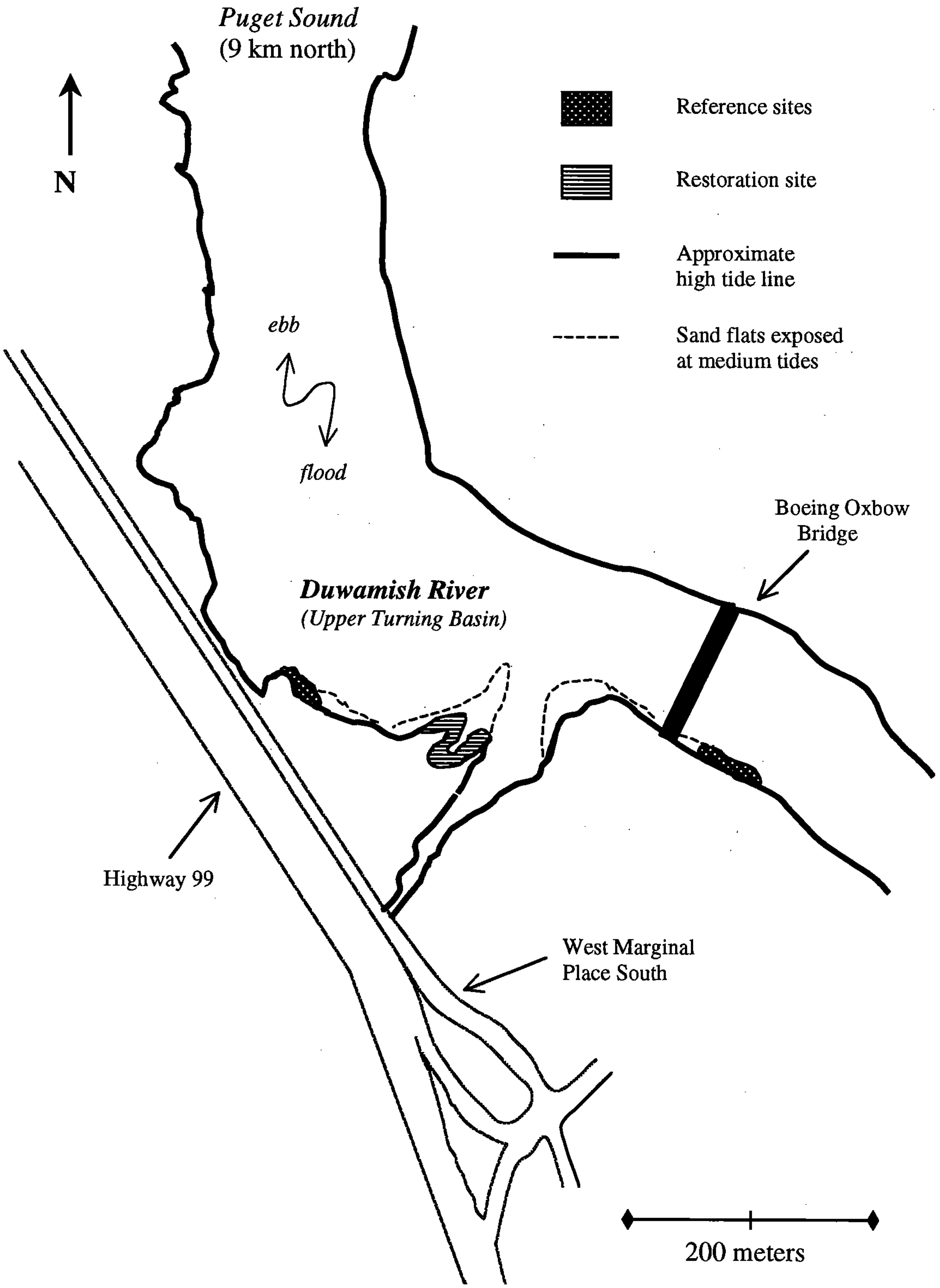


Figure 2. Coastal America restoration site (planted *Carex lyngbyei*) and nearby reference sites (established stands of *C. lyngbyei*), at which grazing experiments were conducted in 1997 on the Duwamish River, Seattle, Washington. Stands of *C. lyngbyei* are not to scale.

The portion of the river in which this study was conducted is oligo- to mesohaline; freshwater influences are greater in the fall than the summer months due to precipitation and increased flows released from the Howard Hansen Dam upstream. Between June and August, 1994, mean soil-pore-water salinities in this portion of the river ranged from 1 to 11 ppt (Wenger 1995); soil-pore water salinities measured at the restoration-site during the second growing season (1997) of this study ranged from 2 to 18 ppt in August, 4.5 to 13.5 ppt in September, 1 to 4 ppt in October, and 0 to 1 ppt in November.

Experimental Design—Restoration Site

On 17 April 1996, over 2,000 individual shoots of *C. lyngbyei* were planted on 30-cm (1-foot) centers in a band (approximately 80 m long and 4 m wide, totaling 330 m^2) along the shoreline, between the approximate elevations of 2.59 m (8.5 ft) and 3.20 m (10.5 ft) above mean lower low water (MLLW). This serpentine band curved along the inside of the excavated (and relatively protected) cove and then across a spit on the (relatively exposed) downstream side of the cove (Figures 2 and 3).

A randomized block design with within-cell replication was superimposed on the planted area (Figure 3). The planted area was divided into three blocks because of the possibility that differences in river energy would lead to different environmental conditions (*e.g.*, substrate particle-size, sedimentation rates) and plant growth. Each block was divided into 11 plots, which were exposed to the following three treatments: 1 plot was exposed to goose herbivory beginning the day that the shoots were planted; 5 plots were protected from geese for 1 year and exposed to grazing during the second year; and 5 plots were protected from grazing for two full growing seasons (18 months). The plots exposed from the time of planting were not expected to survive, so only 1 plot of this treatment per block was deemed necessary to provide statistical power to the study. Each plot contained between 40 and 100 plants, depending on the actual size of the plot permitted by its place in a curved planted area. The plants were 1 year old when the exclosures

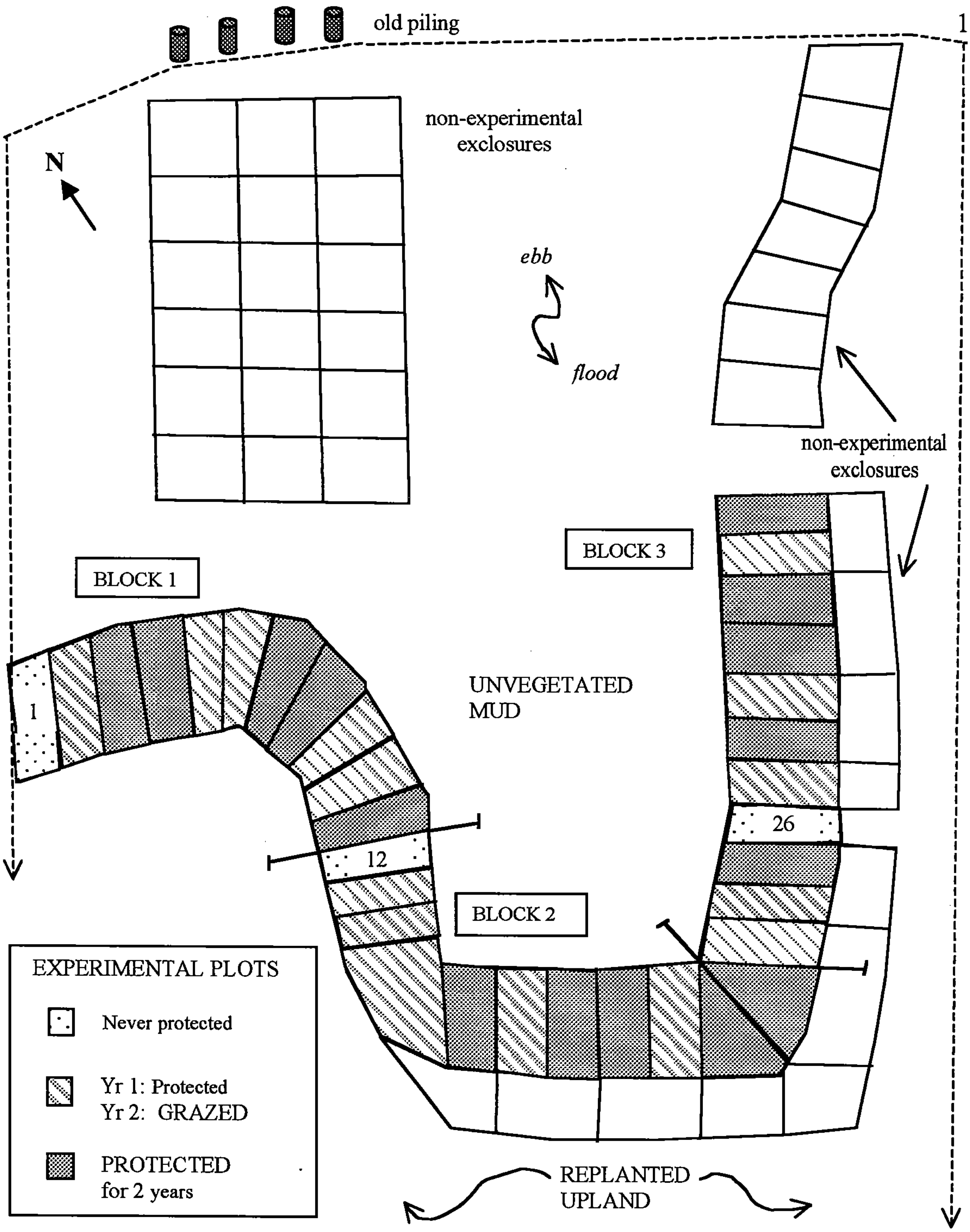


Figure 3. Map (not to scale) of restoration site at the Upper Turning of the Duwamish River, Seattle, Washington. Shaded and hatched areas are 33 experimental plots in a randomized block design. Each of the three blocks consists of 11 plots. Plots are approximately 2.5 m by 3.5-6 m; grazed plots were exposed on the waterward side. >2000 bare-root shoots of *Carex lyngbyei* were planted in a total experimental area of approximately 330 m^2. Outer dashed line indicates approximate boundaries of area within which goose observations were conducted.

were removed from half the plots. They were exposed to grazing beginning on 5 and 6 April 1997, at the beginning of the second growing season.

Experimental Design—Established **C. lyngbyei** *Stands*

A manipulation experiment was conducted on the two established stands of *C. lyngbyei* beginning on 23 and 27 March 1997 and coinciding with the second growing season of the experiment at the restoration site. Because of the small size of these established stands, very few plots could be established and few samples could be taken. The larger, upstream stand was divided into 6 plots, with the treatment of the first (upstream) plot assigned randomly and "grazed" and "protected" treatments alternately assigned to the remainder of the plots. The smaller, downstream stand was divided into 5 plots, and treatments were assigned in a manner similar to that of the other stand. At the time the plots were established, evidence of grazing existed in all plots, especially in the most accessible portions of the stand (*i.e.,* lowest elevation and nearest the water).

Between 1 and 15 November 1997, one sample was taken from each plot. The placement of the 22-cm core for sampling was determined randomly with the blind toss of a wired flag. These *C. lyngbyei* stands consisted of long-established clonal plants within which individual plants could not be distinguished. The 22-cm-diameter PVC core used in the restoration experiment was used for all sampling in this portion of the study in order to provide maximum potential for comparison to the samples from the restoration site. Acquisition and processing of samples otherwise followed the procedures described in the subsection entitled "Plant Sampling," with the following two exceptions: 1) because of the difficulty of keeping the BG biomass intact during its removal from the ground and the cleaning process and in order to avoid duplicate counts, rhizome totals were determined by subtracting the number of fragments in the sample from the number of points of rhizome-origin; and 2) no TNC analysis was conducted on the material from the native stands.

Goose Exclosures

Goose exclosures coincided with the boundaries of each protected plot, most of which were rectangular in shape and measured approximately 2.5 m by 4 m. During the first growing season, fencing was constructed of 0.61-m (2 ft) 0.05-m-mesh (2 in) chicken-wire secured to 1.52-m (5 ft) flanged fence-posts driven 0.45-0.61 m (1.5-2 ft) into the substrate. During the second growing season, 0.91-m (3-ft) fencing was used because geese had occasionally been observed to jump/fly over the shorter fencing at low tide and to swim over the top of the plots at high tide.

The fencing itself was a physical barrier intended to prevent geese from walking or swimming into the plots. The size of the exclosures was deemed small enough to deter geese from flying in because they avoid areas that are cage-like (Manuwal, pers. comm.). Since geese are also believed to avoid areas in which they may foul their wings (Manuwal, pers. comm.), nylon cord was strung diagonally across the top of the plot from opposite corners.

Plant Survival Assessment

Plant or shoot survival was assessed by analyzing photographs of each plot taken on the day of planting and then comparing the individuals identified in those photographs to the existing plants at the end of the first growing season (December 1996). Percent survival was determined for each plot.

Plant Sampling and Processing

Plant samples were collected at the end of the first growing season (between 19 and 28 October 1996) and at the end of the second growing season (between 5 October and 1 November 1997). At the end of the first growing season, one out of every two protected plots was sampled. (None of the original plants survived in the exposed plots.) Three randomly selected plants were sampled from each of 15 protected plots, for a total of 45 plants. At the end of the second growing season, three plants from every one of the 30 plots (15 protected and 15 exposed to grazing) were sampled, for a total of 90 plants. Plots were sampled in pairs (*i.e.*, one protected then one grazed from the same block), and pairs were selected from alternating blocks in order to minimize the effect that seasonal changes (*e.g.*, translocation of nutrients over the sampling period) or storage time of samples might have on carbohydrate levels in the BG biomass of the plants. In this manner, any effects would be experienced by plants in all blocks and both treatments and be less likely to confound the analysis.

A 22-cm-diameter section of PVC pipe was centered on a plant during sampling. This size proved to be an excellent match to the scale of a *C. lyngbyei* plant. Shoots were counted within the core, and the maximum shoot height was measured. To facilitate the pipe's passage through the belowground biomass, a root knife was used to create a vertical cut through the substrate and any root mass immediately below the edge of the core. The core was then driven 15 cm into the substrate with a rubber mallet. This depth captured the largest portion—but not all—of roots and rhizomes of the plants. Gallagher and Kibby (1981) found that 10-cm cores captured 72% of underground reserves (*i.e.*, carbohydrates) and 20-cm cores captured 100% of reserves in *C. lyngbyei* in an estuarine marsh in Oregon, so a 15-cm core might be expected to capture 86% or more of these reserves. However, in the spring in the Skagit River marsh, Ewing (1982) found that macro-organic matter (>1 mm) increased to a depth of 25 cm and then gradually decreased to the 40 cm depth sampled, so samples from established stands may not capture as high a percentage of the accumulated belowground biomass. In the current study, 15 cm often proved to be the practical limit to which the core could be driven with a mallet. All plant material and substrate within the core was removed and placed on a 6-mm mesh screen. The total area sampled for each plant was 380 cm^2 (0.038 m^2), and the total volume sampled was 5,702 cm^3 (0.0005702 m^3). The material was washed over the screen with river water. All visible *C. lyngbyei* root fragments were picked out of the sediment and bagged with the intact plant sample. In order to minimize the impact of the sampling, as much sediment as possible was recaptured in a bucket and returned to the hole created by the sampling method.

Plant samples were stored in sealed plastic bags at 11° C and/or frozen at 0° C until processed in the laboratory. Samples from the first season were stored for approximately 7 days before being washed and dried. Samples from the second growing season were stored in the refrigerator from 1 to 58 days before being processed. Those samples requiring storage of more than 58 days were frozen after that day until processed further.

Plant processing in the laboratory began with additional sediment removal and then separation of the biomass into the following categories:

1) *AG biomass* (*i.e.,* all green leaves and shoots removed at the soil level or as close to the base as possible, usually within 1 cm of the base proper);
2) *BG biomass* (*i.e.*, base, roots, and rhizomes), which was further separated into
    a) *attached BG biomass* (*i.e.,* biomass clearly attached to the AG biomass and therefore indisputably *C. lyngbyei*; used for counting rhizomes and for carbohydrate analysis),
    b) *BG live fragments* (*i.e.,* live BG material assessed to be separated during the sampling process from the *C. lyngbyei* plant),
    c) *BG dead fragments* (*i.e.,* dead BG material assessed to be *C. lyngbyei*); and
3) *other* (*i.e.,* unidentifiable organic matter).

Live and dead BG fragments were distinguished on the basis of color, texture, and buoyancy. Plant tissue that was white and firm and floated in water was categorized as live BG biomass; tissue that was more brown and flaccid and sank in water was categorized as dead BG biomass.

While the BG biomass for a given plant was still intact, points of origin of rhizomes were counted as measure of vegetative reproduction. A rhizome linking two shoots (*e.g.,* originating at the base of the plant and ending with a new shoot) had one point of origin. Each branching of the rhizome added a point of origin to the total. Following this count, the BG biomass was divided for more thorough cleaning if necessary. BG comparisons were made using the pooled data of attached BG biomass and BG live fragments, except for the analysis of TNC for which only the attached BG biomass was used.

After a final rinse with distilled water, the plant material was dried in a small drying oven at 100° C for 1 hour (a requirement of the analysis for TNC) and then in a convection oven at 70° C for at least 48 h (Smith 1969; Canham *et al.* 1999). Biomass measurements of dried plant material were made to the nearest 0.1 g.

For the purposes of comparing the restored and established stands to those of other *C. lyngbyei* in the Pacific Northwest, values for AG and BG biomass and shoot density were extrapolated from 0.038 m^2 22-cm core) to 1 m^2 and then multiplied by 60%. The *C. lyngbyei* shoots were planted 30-cm (1 foot) apart. Since the sampling was centered on randomly selected individual plants, no spaces between plants were sampled. Within 1 m^2 planted with 30-cm spacing, approximately 60% of the plot was never selected for sampling and was free of *C. lyngbyei* shoots through the two years of this study (pers. obs.). The 60% adjustment provides a more accurate assessment of growth across the plots and site than the simple extrapolation does.

Total Nonstructural Carbohydrate Analysis

TNCs are those carbohydrates that can be accumulated and then readily mobilized for metabolism or translocation to other plant parts. They provide an estimate of the carbohydrate energy readily available to the plant (Smith 1969). The TNC analysis employed enzymes to break starch molecules into simple sugars (Smith 1969, as modified by Canham *et al.* 1999 and Kobe, pers. comm.) and then a colorimetric process to establish the concentration of glucose in a given sample (Dubois *et al.* 1956). The procedure in Canham *et al.* (1999) was modified in two ways: the samples and buffer were mixed using a test-tube mixer rather than a sonicator, and the first hot water bath temperature was slightly lowered and the time lengthened to prevent excessive evaporation of the water bath. Only attached BG tissue was analyzed for TNC because there was no uncertainty about the origin or identity of the tissue. The dried plant material was ground to the consistency of whole wheat flour using a conventional coffee-bean grinder followed by mortar and pestle. Ground tissue was then stored at 0° C until chemical processing. Upon removal from the freezer, a portion of ground material from each plant was dried at 70° C to constant weight. From this material, three 0.1 g subsamples were obtained for each plant for further analysis. If the available plant material was less than 0.3 g, the sample was divided into three equal subsamples.

Each subsample of ground material was transferred to a 15-ml Nalgene® centrifuge tube to which 5 ml of acetic acid buffer (mixed from 2 parts 0.2 M acetic acid and 3 parts 0.2 M sodium acetate solutions for a pH of 4.8) were added. Samples in capped tubes were mixed on a small test-tube mixer for 3 min. Another 5 ml of buffer was added to each sample. Two controls were also established: 1) a positive control containing approximately 0.005 g of corn starch and 10 ml of buffer (2.8×10^{-3} M glucose equivalents) and 2) a negative control containing 10 ml of the buffer only.

One ml of alpha-amylase solution (Sigma; Type II-A from *Bacillus* spp., mixed at a concentration of 184 units/ml) was added to each sample and control. Samples were placed for 1.5 hour in a hot-water bath (75° C) placed on top of a shaker that was set at the highest speed (approximately 1 shake per second) that allowed the water to remain in the bath container. One ml of amyloglucosidase solution (Sigma; diluted to 120 units/ml) was added to each sample. The samples were placed for 8 h in a 50° C hot-water bath placed on the shaker.

The samples were then spun in a centrifuge for 10 min at 10,000 rpm. A 5-ml subsample of the supernatant fluid was removed and placed in a 60-ml Nalgene® storage bottle with 50 ml of de-ionized water (DI). The diluted sample was mixed on the test-tube mixer then frozen at 0° C until the colorimetric analysis.

For the colorimetric analysis, glucose standards ranging from 4 to 80 ppm were mixed from a stock dextrose solution of 200 ppm (1.11×10^{-3} M). Standard curves were developed with spectrophotometer readings from 2 ml of each standard at the beginning of the laboratory session, after every 20 samples, and at the end of the session. Two (2) ml of DI were used as the blank.

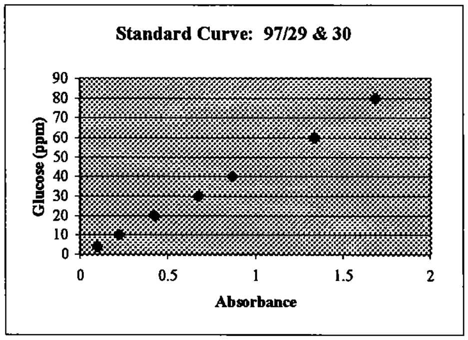
The thawed samples were re-mixed on the test-tube mixer, and a 0.5 ml subsample was placed in a 50 ml glass test tube. One and a half (1.5) ml DI was added, and the mixture was swirled. Under a ventilation hood, 0.15 ml phenol was added to the samples, enzyme controls, glucose standards and/or spectrophotometer blanks. Five ml of sulfuric acid were added to each test tube. The mixture was swirled. After the reaction was allowed to proceed for 10 min, a portion of each sample was poured into a 4-ml methyl-acetate spectrophotometer-cuvette; and the absorbance readings were recorded at a wavelength of 487 nm.

Standard curves relating optical density to glucose concentration were developed, and regression equations were used to convert spectrophotometer readings (absorbance (ABS)) to glucose concentrations for each plant subsample (Figure 4). Glucose concentration (ppm) of a sample was calculated from the following equation (Kobe, pers. comm.):

sample ppm = intercept + x-coefficient*(sample ABS)
where sample ABS = ABS of sample – ABS of blanks – ABS of negative control.

STANDARD SOLUTIONS (dextrose)

Standard ppm	Absorbance
4	0.097
10	0.223
20	0.422
30	0.673
40	0.867
60	1.338
80	1.687



Regression Statistics	
Multiple R	0.998969211
R Square	**0.997939485**
Adjusted R Sc	0.831272818
Standard Erro	1.244634546
Observations	7

ANOVA

	df
Regression	1
Residual	6
Total	7

	Coefficients
Intercept	0
Absorbance	**46.25955055**

Regression equation
for standard curve
y = 46.26x + 0
x = sample absorbance

PLOTS 29 & 30

Sample	Biomass (g)	Absorbance	Adj. Absorb.	Sample ppm	%TNC			
97/29-1A	0.1007	0.259	0.152	7.03152	**3.686834717**			
97/29-1B	0.1005	0.288	0.181	8.37306	**4.398980776**			
97/29-1C	0.1003	0.286	0.179	8.28054	**4.359047976**	**4.148287823**		
97/29-2A	0.1005	0.664	0.557	25.76682	**13.53719499**			
97/29-2B	0.101	0.748	0.641	29.65266	**15.50158859**			
97/29-2C	0.1005	0.76	0.653	30.20778	**15.87035606**	**14.96971321**	**7.32**	PLOT 97/29
97/29-3A	0.1015	0.203	0.096	4.44096	**2.310174266**			
97/29-3B	0.1014	0.235	0.128	5.92128	**3.083270059**			
97/29-3C	0.1008	0.238	0.131	6.06006	**3.174317143**	**2.855920489**		
97/30-1A	0.1003	0.382	0.263	12.16638	**6.404634736**			
97/30-1B	0.1011	0.445	0.326	15.08076	**7.876005223**			
97/30-1C	0.1011	0.424	0.305	14.1093	**7.368655193**	**7.216431717**		
97/30-2A	0.1009	0.353	0.234	10.82484	**5.664534708**			
97/30-2B	0.1006	0.348	0.229	10.59354	**5.560028946**			
97/30-2C	0.101	0.396	0.277	12.81402	**6.698814416**	**5.974459357**	**5.90**	PLOT 97/30
97/30-3A	0.1014	0.33	0.211	9.76086	**5.082577988**			
97/30-3B	0.1013	0.303	0.184	8.51184	**4.436576032**			
97/30-3C	0.1009	0.283	0.164	7.58664	**3.970015778**	**4.496389933**		

Plot 29 neg control	0.107
Plot 30 neg control	0.119

Adjusted absorbance = sample absorbance - absorbance of negative control
Sample ppm = y = 46.26x+0
%TNC = (sample ppm/dry wt)*0.000001*12*11*4 = (sample ppm/dry wt)*0.000528*100

Figure 4. Example of spread sheets and regression analysis used in a colorimetric assay to calculate percent total nonstructural carbohydrate (TNC) in belowground biomass samples of *Carex lyngbyei* that had been subjected to an enzymatic process that breaks down starch into glucose equivalents. % = percent of dry mass of belowground biomass. Three subsamples were processed for each of three plants in a given plot. The mean of three plant values was the plot value used in statistical analysis.

Percent TNC was calculated from the adjusted reading and the following equation, which accounted for dilutions and for initial plant-subsample biomass (Kobe, pers. comm.):

% TNC = A x B x C x D x E,
where A = sample ppm/dry weight of sample
B = 1 g/1,000,000 μg (conversion factor to make A a ratio)
C = 12/1 (the buffer and enzyme dilutions)
D = 55/5 or 11/1 (dilution in transferring to storage bottle)
E = 4/1 (dilution prior to phenol-sulfuric assay).

Volunteer Plant Species

Two methods were used for collecting data on plant species that naturally established themselves within the experimental plots. (*C. lyngbyei* and *S. acutus* were omitted from this analysis because they were planted at the site.) In August 1996, during the first growing season, the plant community was sampled using a technique that combined randomly placed quadrats and the point-intercept method (Tear, pers. comm.). A 0.0025 m^2 (5-cm on a side) quadrat was used to sample plant species. Presence/absence of plant species was determined for 25 randomly selected quadrats in each plot. Using randomly generated numbers, a sampling point was determined within the plot and marked with a meter-stick. The quadrat was slid vertically along the meter-stick, thereby creating a three-dimensional column of sampling space. All species within the sampling space were noted as present, even if they were not rooted inside the footprint of the quadrat. As a result, several layers of vegetation with different growth habits were sampled, and the three-dimensional quality of the marsh vegetation was captured. Twenty-five (25) quadrats were sampled in 25 of the 30 plots protected during the first growing season, for a total of 750 quadrats. To convert the presence data into a form useable within the analyses described below that rely on some measure of abundance, presence in plots was multiplied by a factor of 4. For example, if a species occurred in one quadrat out of 25 quadrats sampled in the plot, its abundance was converted to 4 percent for the given plot. Presence in 5 quadrats was converted to 20 percent, 10 quadrats to 40 percent, *etc*. Cut levels for the pseudospecies used by two-way indicator-species analysis (TWINSPAN, described in the section "Multivariate Analyses of Plant Community") were established at 4, 8, 16, 32, and 64 percent.

In September 1997, during the second growing season, species presence was determined within quadrats centered on each of the three *C. lyngbyei* plants being sampled in each plot. For the purposes of multivariate analysis, abundance of each species in each plot was quantified simply as the number of quadrats (1, 2 or 3) in which the species was found. Cut levels for the pseudospecies used by TWINSPAN were set at these three levels. Some analyses were conducted with these abundance levels converted to percent of total quadrats.

In the multivariate analyses, the clearest patterns emerged when data from both years were considered together. Because different methods were used for measuring species-abundance in each of the years, all abundance data were ultimately converted to a simple presence/absence designation for each species in each experimental plot. This approach was intended to diminish any difference in species diversity that might be strictly an artifact of different sampling methods. The assumption was that the larger quadrat might have picked up a greater variety of species than the smaller one, even though there were fewer of the larger quadrats. Analyses were run without the two planted species, *i.e., C. lyngbyei,* which was planted in 1996, and *S. acutus*, which was planted in 1995 and most of which was transplanted out of the plots once it was identified. One outlier (*Solanum dulcamara*) was removed from DCA analysis because it occurred in one quadrat in a single plot in 1 year only. When it was included in the analysis, its position so skewed the ordination that many points were indistinguishable and the interpretation of the remaining plots and species was severely limited.

Whenever possible, species were designated as native or non-native and as weedy based on information available in several regional flora—*e.g.*, description as weedy or inclusion in a book of weeds (Hitchcock *et al.* 1955, 1959, 1961, 1964, and 1969; Hitchcock and Cronquist 1973; Taylor 1990; Hickman 1993; Pojar and MacKinnon 1994; Cooke 1997). The latter flora were consulted because many of the non-native species were not included in the otherwise comprehensive works of Hitchcock and associates. The definition of weed varies, but Hickman (1993) and Cooke (1997: 393) share a generally accepted one: "a plant that is usually exotic, usually undesired, often aggressive, and often adapted to disturbed sites." (See also Parker and Reichard (1997) on invasive species.) In his book on Northwest weeds, Taylor (1990: 1) emphasized the pioneering aspects of the plants' biologies: "they are opportunitists with a broad ecological tolerance, able to grow under a wide range of climatic and soil conditions." (See also the ruderal strategy described by Grime (1979).) In general, the species identified as weedy in this study are early seral (primary successional), and therefore not characteristic of the target community, or aggressive and capable of diverting succession away from the target community. They also characterize areas affected by human activity (Baker 1974).

Observations of Goose Behavior

Geese were observed grazing on the exposed *C. lyngbyei* upon the removal of the exclosures (5 and 6 April 1997). During a preliminary period immediately following the removal of the exclosures, goose behavior was observed twice in the morning (0805-1040) and in the evening (1750-2030), which were the times of the day when grazing behavior was expected (Stabins 1996). Goose behavior was categorized every 5 min according to the behavior of longest duration during that 5-min period for each goose on site. Behavior categories were as described below for the sustained behavior study. The preliminary data indicated that grazing on *C. lyngbyei* may have been more intensive in the 2 weeks immediately following exclosure removal than it was on average over the following two months. The sustained behavior study (which follows) may therefore represent a conservative estimate of grazing pressure. On the other hand, these preliminary data may have been subjected to observer bias (*i.e.,* active behavior recorded as the predominant behavior more often than resting or maintenance behavior) and the objective nature of the sustained study may therefore be more reliable.

In order to provide an index of the grazing pressure on site and to provide a basis for comparisons to other grazed sites in the future, observations of goose behavior were conducted regularly between 26 April and 19 June 1997 and more intermittently between 20 June and 11 September 1997. During the latter time period, observations were focused on those daylight hours (early morning, late afternoon, and early evening) during which geese had most commonly been observed grazing on *C. lyngbyei* during the earlier months of observation. Since the behavior of primary interest was grazing on *C. lyngbyei* and since none of this behavior was observed after 19 June 1997 (although geese were often observed on or near the site), only the two months of regular observations were used to estimate goose-use for the site.

Observations were made for 3-h periods during daylight, between 0600 and 2030 or 2100 (depending on sunset). Each 3-h period was sampled at least six (and as many as nine) times on randomly selected days between 26 April and 19 June 1997.

Behavioral observations were recorded for geese that were on site within previously determined boundaries that included unvegetated mid-intertidal, vegetated and unvegetated high-intertidal, and vegetated upland areas (Figure 3). The band of planted *C. lyngbyei* was in the high-intertidal area. The upland area constituted approximately one third of the total space included for observation. The total area of observation was approximately 1,280 m^2. During the second growing season, *C. lyngbyei* was growing on an area of approximately 300 m^2 (2.5 m x 4 m x 30 plots) and half of that area was accessible to the geese.

Goose behavior was sampled using a mixture of scan- and sequence-sampling techniques. Scan-sampling is used for groups and involves the observer's recording all animals' activities at pre-selected points in time; this technique is primarily used to determine the amount or percent of time that individuals devote to particular activities (Altmann, 1973). In this study, scan-sampling of goose behavior on site was conducted every 5 min for a period of 3 h. Sequence-sampling was employed when a goose was observed to be grazing in an experimental plot. With this technique, a sample-period begins when a particular action begins; and the sample continues until the action sequence ends or is interrupted (Altmann, 1973). The following sequence-sampling method was developed to observe geese grazing on *C. lyngbyei* (Jensen, pers. comm.; Grue, pers. comm.). In this study, sequence-sampling began when a goose was grazing on *C. lyngbyei* in an exposed plot. Bites per 5-min interval were counted. The sequence continued until the start of the next 5-min period or until that goose was no longer grazing. If, at the 5-min mark, another goose was also grazing, bites per minute would be determined for that second goose in an effort to obtain as many independent samples of grazing intensity as possible. When possible, the second goose chosen for bite-counts was on the opposite side of the site. If there were no other grazers and the original goose were still grazing at the start of the next time interval, that goose would continue to be sampled. In this study, one to four geese were observed for bite-counts during a given 3-h observation period that included grazing. Because of the birds' site-fidelity, the same geese may have been sampled several times during the 2 months of observations.

Goose behavior was categorized according to Stabins (1996) as follows:

1) *feeding*—active feeding with locomoting, standing, or sitting;
2) *alert*—stationary, sitting, or standing, with neck extended or upright;
3) *locomotor*—walking, flying or swimming;
4) *maintenance*—preening, active feather cleaning/adjustments while sleeping or sitting;

5) *social*—obvious vocalizations; giving or receiving threats to or from another goose, including biting, chases, and flight initiations directed at another goose; and
6) *resting*—sleep, head on back with or without bill under feathers, standing or sitting; also, stationary with shortened neck coiled downward.

To calculate daytime goose-use of the site, all observations of geese on site during a given 5-min interval were averaged; and then those averages were tallied and standardized to the total number of observation periods (181). To calculate percentage of time spent grazing on *C. lyngbyei* on site, the number of geese grazing on the plant species on site was totaled for all observation intervals and then that number was divided by the total number of geese observed on site for all observation intervals. Goslings were included in the total number of geese on site but were not factored into the grazing calculation until 28 May 1997, at which date they were observed successfully feeding on *C. lyngbyei* plants. Younger geese would occasionally bite at *C. lyngbyei* but were not able to rip any biomass off and would immediately begin to feed on another plant species.

Data Analysis

Nonparametric Analysis

The plant-survival data were converted to percentages and analyzed using the Combined Wilcoxon Test, a nonparametric test for blocked data (Guo, pers. comm.; Marascuilo and McSweeney 1977).

Parametric Analyses

All parametric tests except t-tests were performed using the SAS System for Windows, Release 6.12 (SAS Institute, Inc., 1989-1996).

To determine effects of grazing on plants on the restoration site, analysis of variance (ANOVA) for a randomized block design (RBD) was performed using the means of attributes of three plants sampled within a plot as the plot value (n=5). For determining the effects of grazing on the established native stands of *C. lyngbyei,* an ANOVA for a RBD without replication was used. In this test, the two reference sites were considered to be equivalent to blocks (n=2).

In order to determine the nature of the effect (*i.e.,* gain or loss) of grazing and protection on one-year-old plants at the restoration site, only data from the 15 plots that had been sampled at the end of both growing seasons were analyzed (n=7). The differences (Δ) between attribute-values for the first and second years were calculated. Two-tailed one-sample t-tests were then performed on the Δ values for plants in protected plots and (separately) those for plants in grazed plots. Positive Δ values for the means indicated a year's gain in the specified attribute, and negative Δ values indicated a year's loss in the specified attribute. Confidence intervals (CI) were then calculated (Zar 1984: 103) for all attributes because sample sizes were small and the chance of detecting differences in the grazed plants was limited (Billheimer, pers. comm.). CIs indicate the degree of variability while revealing trends that might be important to resource managers.

For comparing the 2-year-old protected plants at the restored site to grazed plants in the established stands of the reference sites, a three-way ANOVA for an unbalanced split-plot design was performed (SAS Institute, Inc. 1988). Because of an error in the SAS calculations, F-tests for the effect of site (*i.e.,* restored or established) were calculated separately using the appropriate variances (*i.e.,* variance of the site ÷ variance of the block, with the variance of block equaling the Type III Sum of Squares of blocks within sites ÷ degrees of freedom (Billheimer, pers. comm.)). If the results of this slightly conservative test were significant, then the outcome of the comparison of interest (protected planted *vs.* established grazed) was reported. This particular comparison was chosen because it provided a means of estimating how far the protected plants at the restoration site were in their growth trajectory compared to those in the established stands. The grazed established stands were considered the appropriate reference point because being grazed is the normal condition of stands of C. *lyngbyei* in this area of the Duwamish River Estuary.

For all tests, alpha levels were set at 0.05; and statistical significance is reported only for those outcomes that fell below this threshold. The alpha-level represents the risk that an investigator is willing to take of finding a difference that is in fact *not* attributable to a treatment but rather to chance (Zar 1984). P-values less than 0.10 were considered biologically or ecologically meaningful and worthy of the attention of resource managers. That is, making decisions on the basis of results with a one-in-ten (rather than a one-in-twenty) chance of being wrong is an acceptable risk in the context of management (Tear, pers. comm.).

Multivariate Analyses of Plant Community

Two forms of exploratory data analysis were conducted on the plant community that comprised the naturally recruiting plants at the restoration site. Classification (two-way indicator-species analysis, or TWINSPAN) and indirect-ordination analyses (detrended correspondence analysis, or DCA) are used to discover patterns in the data and suggest hypotheses that may be tested by further research (Kent and Coker 1992). For a complete discussion of the following techniques, Kent and Coker (1992) may be consulted.

Classification

Numerical methods of classification group individuals (*e.g.,* quadrats or plots) into sets or classes based on floristic composition. These groups are then interpreted and become the basis for the definition of plant communities or species assemblages in the area being studied. The most useful part of the TWINSPAN output is the two-way table that shows the single-axis ordination (or arrangement) of the plots and their species compositions. Two plots that are closer together along the axis are more similar in species composition than two plots that are farther apart.

Ordination

Ordination techniques are multivariate techniques that arrange sampling units (in this case, plots) along axes on the basis of the similarity of species-composition data. Indirect ordination methods or gradient analyses, such as detrended correspondence analysis (DCA), are based on analysis of floristic data only, *i.e.,* no environmental data or preconceptions about successional sequences (Kent and Coker 1992). It is expected that variation within the floristics data will reflect variation in the environment. Once the mathematical analysis is complete, the floristic variation is "compared and correlated with available environmental data in order to detect possible environmental gradients" (Kent and Coker, 1992: 164).

The analysis of the similarity or dissimilarity of floristic composition of vegetation samples is displayed in graph form. In a sample ordination, each point represents a vegetation sample that is plotted in one, two, or three dimensions. The distances between the points on the graph are measures of their degree of similarity to or difference from each other—*i.e.,* points that are closer together represent plots that are more floristically similar and those farther apart are more different. The axes of the graphs are oriented along dimensions of variation within the samples, with the first axis summarizing the greatest amount of variation and subsequent axes summarizing progressively smaller amounts of variation. Generally, the first axis is the most important and may be correlated with the environmental gradient(s) with the greatest effect on the plant community (Kent and Coker 1992). Each ordination axis has an eigenvalue, which is a measure of its importance. Eigenvalues range from 0 to 1; values greater than 0.5 frequently indicate a good separation of the species along the axis (ter Braak 1995). Biologically relevant information would be expected to be inferred from axes with proportionately larger eigenvalues.

Ordination can also be carried out for species. In the graphs that result from this kind of ordination, "each point represents a species and the distances between the points are an expression of how similar the species are in their distribution across the samples" or plots in this case (Kent and Coker 1992: 174).

CHAPTER 3: RESULTS

Goose-Use of Restoration Site

Goose-use of the site averaged (mean ± standard deviation) 2.91 ± 2.14 geese on site during the daylight hours between 26 April and 19 June 1997, the period during which regular observations were conducted. The peak times were late morning (1010-1125) and early evening (1820-1905) (Figure 5).

During the 2-month spring observation-period, the geese spent 14% of their time grazing (in general) while on site during daylight hours and 3% of those daylight hours grazing specifically on *C. lyngbyei*. Peak *C. lyngbyei* grazing times were less consistent than the presence of geese on site but were concentrated in the late morning and late afternoon and, especially, in the evening from 1830-1940 (Figure 6). These peaks roughly coincided with the peaks in goose presence on site. No patterns with regard to tidal cycles were discerned. Grazing pressure on *C. lyngbyei* at the site during daylight hours was 0.0864 ± 0.384 geese $\cdot$ day^{-1} or 0.000576 ± 0.00256 geese $\cdot$ day$^{-1} \cdot$ m^{-2} of available *C. lyngbyei* (mean ± standard deviation). When feeding on *C. lyngbyei,* geese took an average of 38 ± 39 bites (mean ± standard deviation) per 5-minute interval, or 7.6 bites $\cdot$ minute^{-1}. No grazing on *C. lyngbyei* was observed after 19 June 1997.

Survival of Planted **C. lyngbyei** *Shoots*

Survival percentages for plants at the end of the first growing season were significantly higher in plots protected from geese than in those exposed to goose herbivory (68.0% and 1.1%, respectively; p=0.003). All shoots in exposed plots were immediately adjacent to neighboring protected plots and appeared, based on small size and proximity to the protected plants, to be produced by the protected plants.

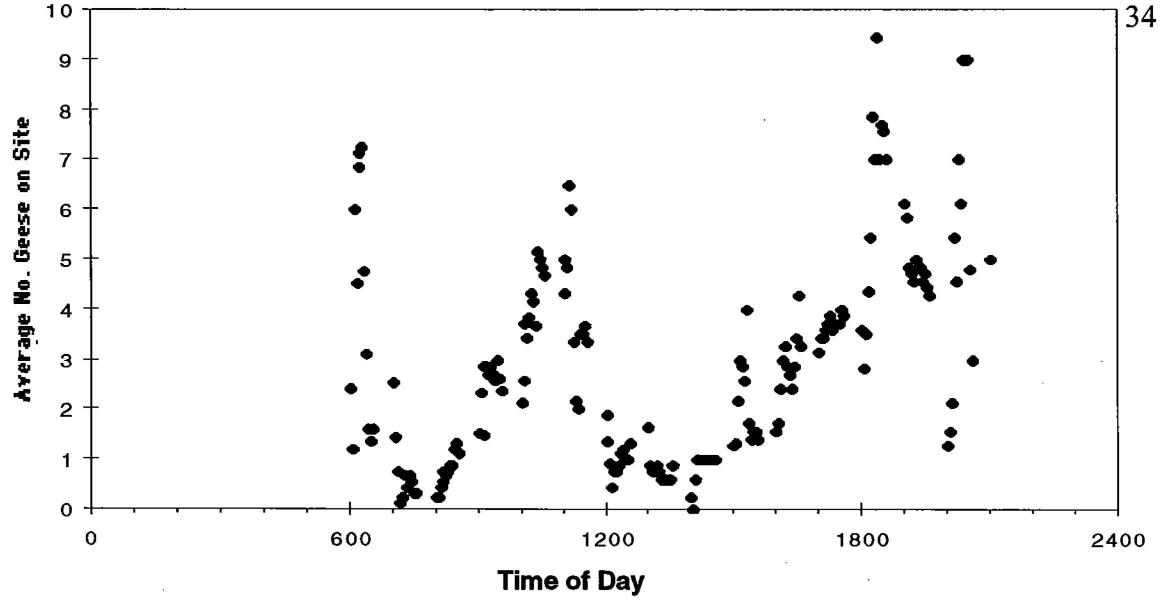


Figure 5. Average number of Canada geese (*Branta canadensis*) at a restoration site on the Duwamish River, Seattle, Washington, during daylight hours (26 April-19 June 1997). Each data point is the average number of geese at the site at a pre-determined 5-minute mark. Mean ± standard deviation is 2.91 ± 2.14 geese day^{-1}.

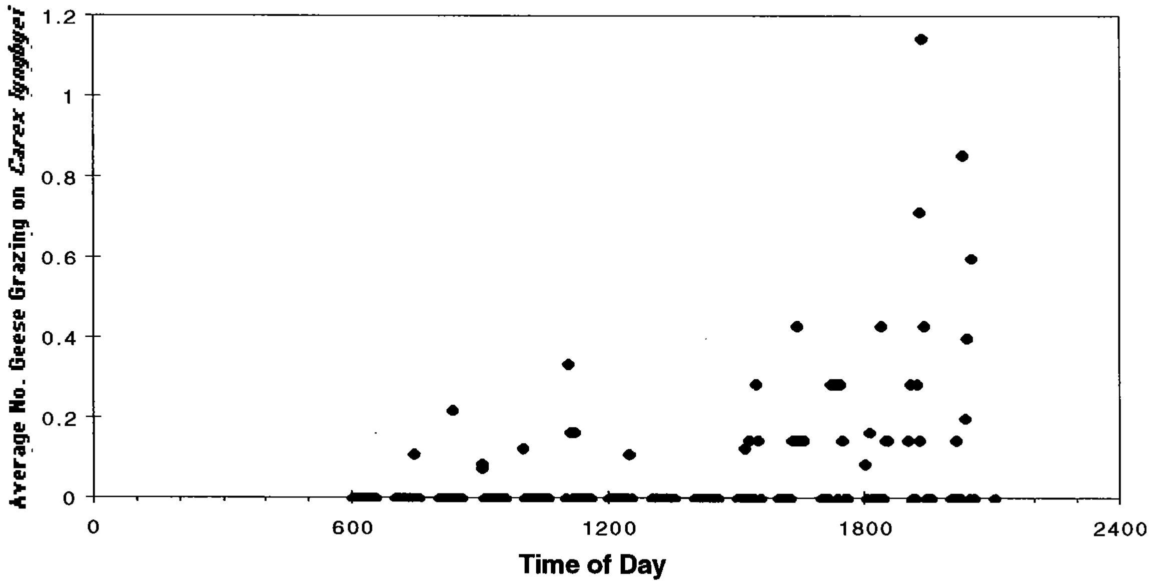


Figure 6. Average number of Canada geese (*Branta canadensis*) grazing on *Carex lyngbyei* at a restoration site on the Duwamish River, Seattle, Washington, during daylight hours (26 April-19 June 1997). Each data point is the average number of geese grazing at a pre-determined 5-minute mark. Mean ± standard deviation is 0.0864 ± 0.384 geese ·day^{-1} or 0.000576 ± 0.00256 geese · day^{-1} · m^{-2}*C. lyngbyei.*

Controlled Experiment at Restoration Site

Protected plants were significantly different from grazed plants with respect to AG biomass (16.1 ± 4.9 and 4.1 ± 2.9 g, respectively; p=0.0001), maximum shoot height (96 ± 18 and 46 ± 14 cm, respectively; p=0.0001), and number shoots (27.8 ± 8.2 and 12.8 ± 7.6, respectively; p=0.0001) (Figures 7a and 8 and Table I). Protected plants were also significantly different from grazed plants with respect to live BG biomass (20.3 ± 7.1 and 5.9 ± 3.6 g, respectively; p=0.028) and number rhizomes (31.8 ± 9.4 and 17.3 ± 9.7, respectively; p=0.0001) (Figures 7b and 8 and Table I). Protected plants were, therefore, generally larger with higher levels of vegetative reproduction than the grazed plants (Figure 9). No significant difference was found between protected and grazed plants with respect to BG dead biomass or percent TNC (9.1 ± 3.3 and 10.1 ± 3.1 %, respectively; p=0.399). On 18 April 1997 after 11 days of exposure to grazing, seed heads were noted on plants in all of the protected plots; none was noted on plants in any of the grazed plots.

Controlled Experiment in Established **C. lyngbyei** *Stands*

No significant differences were found between the protected and grazed plots in established native stands (Table I). BG live biomass, however, was nearly significantly different in protected and grazed plots (48.0 ± 19.2 and 34.8 ± 19.6 g, respectively; p=0.061). This difference is biologically meaningful, especially given the variability of BG samples.

Nature of Effect of Grazing on 1-Year-Old Protected Plants

Once it was established that grazing during a second growing season had a significant effect on the plants at the restored site, the nature of the effect of grazing on one-year-old plants was refined through the use of one-sample t-tests. The tests determined the probability that any mean changes in protected or grazed plants from Year 1 to Year 2 were different from 0 (*i.e.,* no change). Positive Δ values indicated a year's gain in the specified attribute, and negative Δ values indicated a year's loss in the specified attribute.

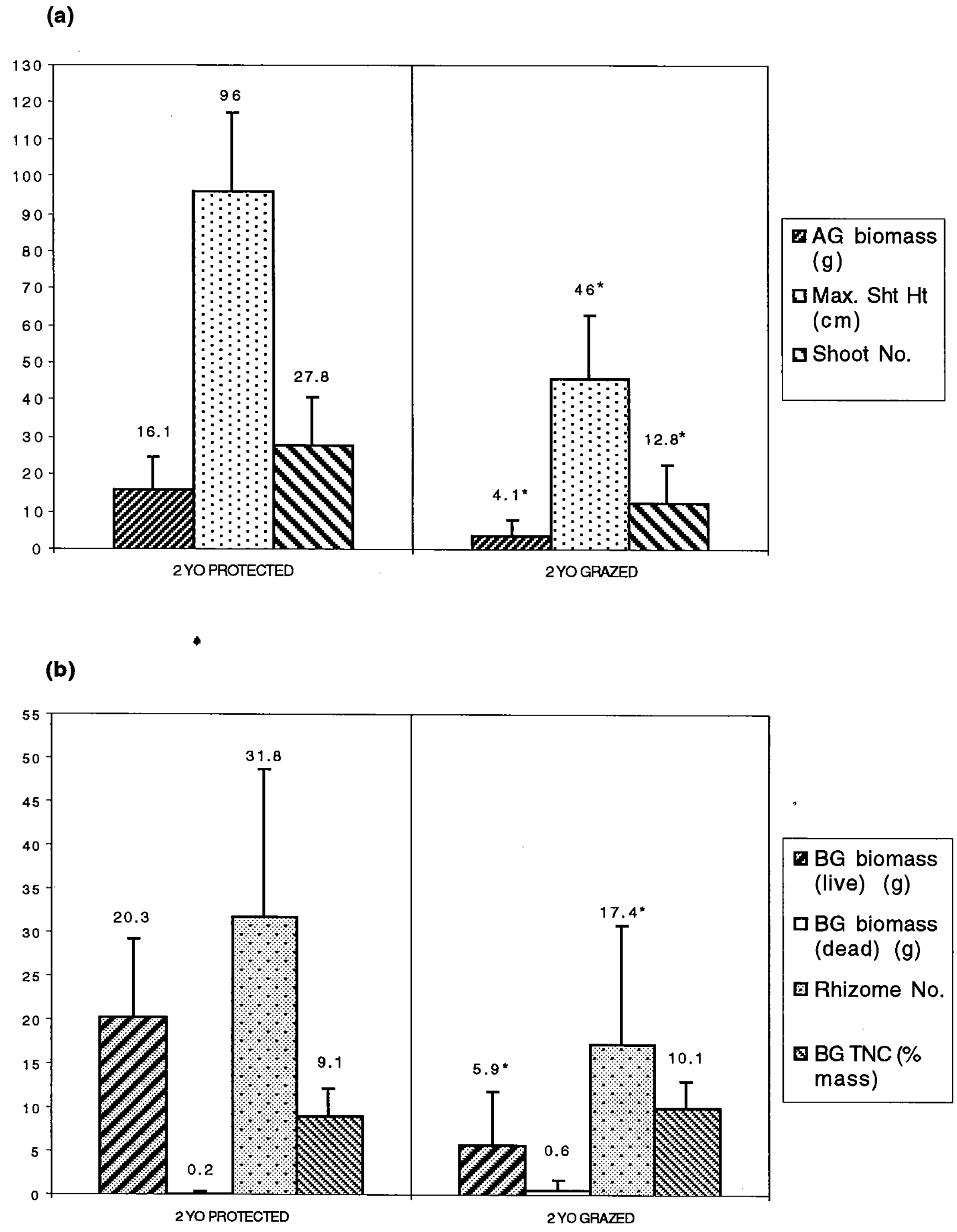


Figure 7. Aboveground (a) and belowground (b) attributes of protected and grazed *Carex lyngbyei* plants sampled at the end of the second growing season (*i.e.,* 2-year-old plants). Values are means for 0.038 m^2 sampling core (22-cm diameter and 15 cm deep). Error bars are plus one standard deviation. * denotes significant difference ($p<0.05$) between treatments for the designated attribute. AG=aboveground; BG=belowground; TNC=total nonstructural carbohydrates; YO=year old.

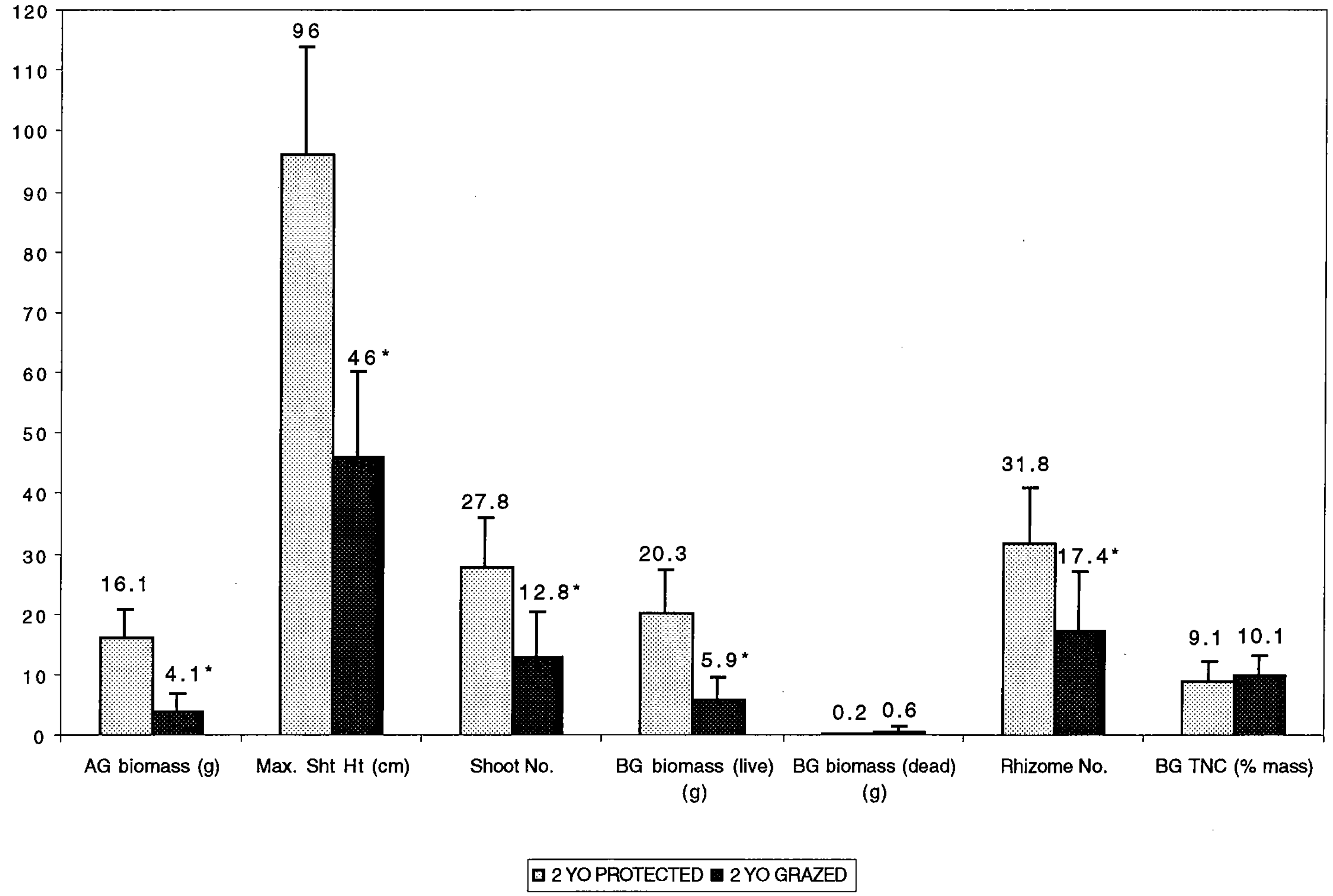


Figure 8. Comparison of aboveground and belowground attributes of protected and grazed *Carex lyngbyei* plants sampled at the end of the second growing season (*i.e.*, 2-year-old plants). Values are means for 0.038 m^2 sampling core (22 cm diameter and 15 cm depth). Error bars are plus one standard deviation. * denotes significant difference ($p<0.05$) between treatments. AG=aboveground; BG=belowground; TNC=total nonstructural carbohydrates; YO=year-old.

Table I. Above- and belowground attributes for all groups of *Carex lyngbyei* plants sampled in the Duwamish River estuary. Results of analyses of variance (ANOVA) for 2-year-old plants (protected vs. grazed), established stands (protected vs. grazed), and 2-year-old protected vs. established grazed plants are presented as p-values. Data are per 0.038 m^2 sampling core (22-cm diameter) centered on plant at the restoration site and randomly placed in the established native stands. Data for 1-year-old plants are provided for reference purposes only (see Table II for comparison of plants in Year 1 and Year 2). Values are mean ± one standard deviation. YO = year old. * denotes statistical significance ($p<0.05$). Bold p-values are <0.10. No carbohydrate analysis was conducted on established plants. 2 YO (n=5); established (n=2).

PLANT ATTRIBUTE	1-YO Plants	2-YO Plants			Established Stands			2-YO Prot'd vs. Establ'd Grazed
Aboveground	***Protected***	***Protected***	***Grazed***	***p-value***	***Protected***	***Grazed***	***p-value***	
Aboveground biomass (g)	12.1 ± 8.1	16.1 ± 4.9	4.1 ± 2.9	**0.0001***	11.7 ± 8.5	7.2 ± 3.7	0.258	**0.0002***
Maximum shoot height (cm)	81 ± 16	96 ± 18	46 ± 14	**0.0001***	48 ± 20	48 ± 18	0.841	**0.0001***
No. shoots	12.7 ± 5.4	27.8 ± 8.2	12.8 ± 7.6	**0.0001***	39.0 ± 25.7	34.3 ± 12.9	0.483	0.2297
Belowground								
Belowground biomass (live) (g)	9.9 ± 6.1	20.3 ± 7.1	5.9 ± 3.6	**0.0001***	48.0 ± 19.2	34.8 ± 19.6	**0.061**	**0.0059***
Belowground biomass (dead) (g)	0	0.2 ± 0.2	0.6 ± 1.1	0.166	1.0 ± 0.9	1.2 ± 1.2	1.00	**0.0188***
No. rhizomes	17.0 ± 5.8	31.8 ± 9.4	17.4 ± 9.7	**0.0001***	69.2 ± 41.4	46.0 ± 31.6	0.568	**0.0015***
Total nonstructural carbohydrates (%)	21.2 ± 3.9	9.1 ± 3.3	10.1 ± 3.1	0.399	NA	NA	NA	NA

From the first growing season to the second, BG biomass of protected plants increased by 113% (12.0 ± 2.9 g (Δ ± one standard error); p=0.002) (Figures 9 and 10 and Table II). Indicators of vegetative reproduction in protected plants also more than doubled: the number of rhizomes increased 141% (20.1 ± 2.7; p=0.0001), and the number of shoots increased 171% (17.8 ± 2.4; p=0.0001). AG biomass of protected plants increased less dramatically by 43% (5.8 ± 2.8 g; p=0.066), as did maximum shoot height by 24% (19 ± 6; p=0.009). Percent total nonstructural carbohydrates dropped sharply by 44% (-11.0 ± 2.8 % TNC; p=0.011) in 2-year-old protected plants. In summary, all changes in attributes of protected plants were statistically significant, except for the gain in AG biomass, which was nevertheless biologically significant.

Two statistically significant differences were noted in the one-yr-old protected plants that were exposed to grazing during the second growing season: AG biomass decreased by 69% (-6.7 ± 3.0 g; p=0.05), and maximum shoot height decreased by 36% (-25 ± 6; p=0.002). Other differences were not statistically significant. The 95% CI were calculated for these attributes because the sample sizes for this test were so small given the variability of the data. The CI of BG biomass of grazed plants (-10.9, 2.7 g) indicates that most 1-yr-old plants would be expected to lose BG biomass in response to grazing. On the other hand, grazed plants could experience a loss or gain in vegetative reproduction: the 95% CI for change in number of shoots was –4.4 to 7.1; the CI for number of rhizomes was –4.4 to 8.5. Although the loss in TNC was not statistically significant in grazed plants, the CI (-16.8, 2.1 %) indicates a probable loss in TNC during the second growing season.

Comparison of 2-Year-Old Plants to Reference (Grazed Established) Stands

When 2-year-old protected plants were compared with nearby established stands of *C. lyngbyei* that had been grazed, a number of significant differences were found: AG

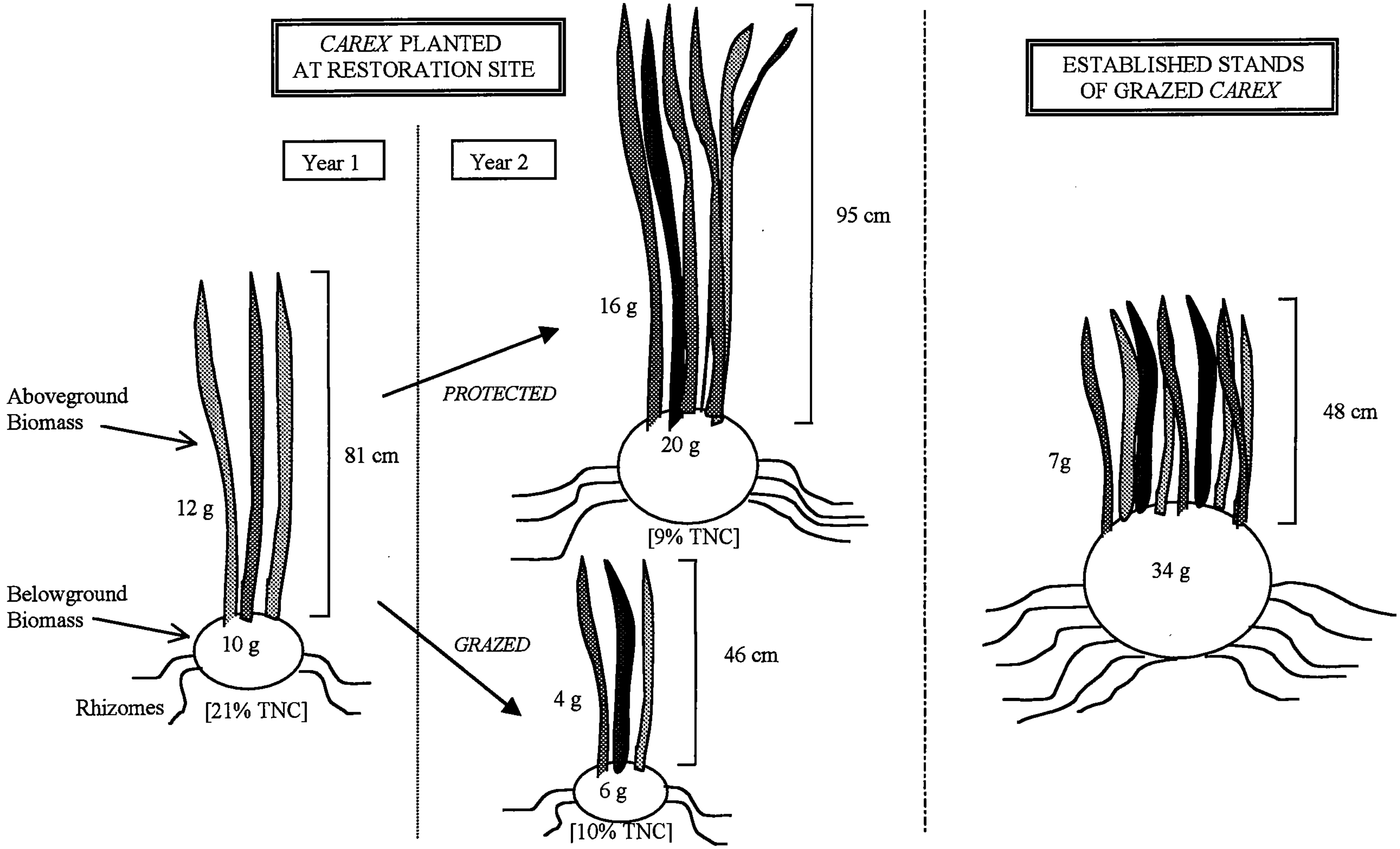


Figure 9. Response of *Carex lyngbyei* to grazing by Canada geese (*Branta canadensis*) at a restoration site in the Duwamish River estuary, Seattle, Washington. Reference stands (*i.e.*, established grazed stands) are provided for purposes of comparison. Values are means rounded to nearest whole number (see Table I). Numbers of shoots and rhizomes are proportional to each other. TNC=toatal nonstructural carbohydrate.

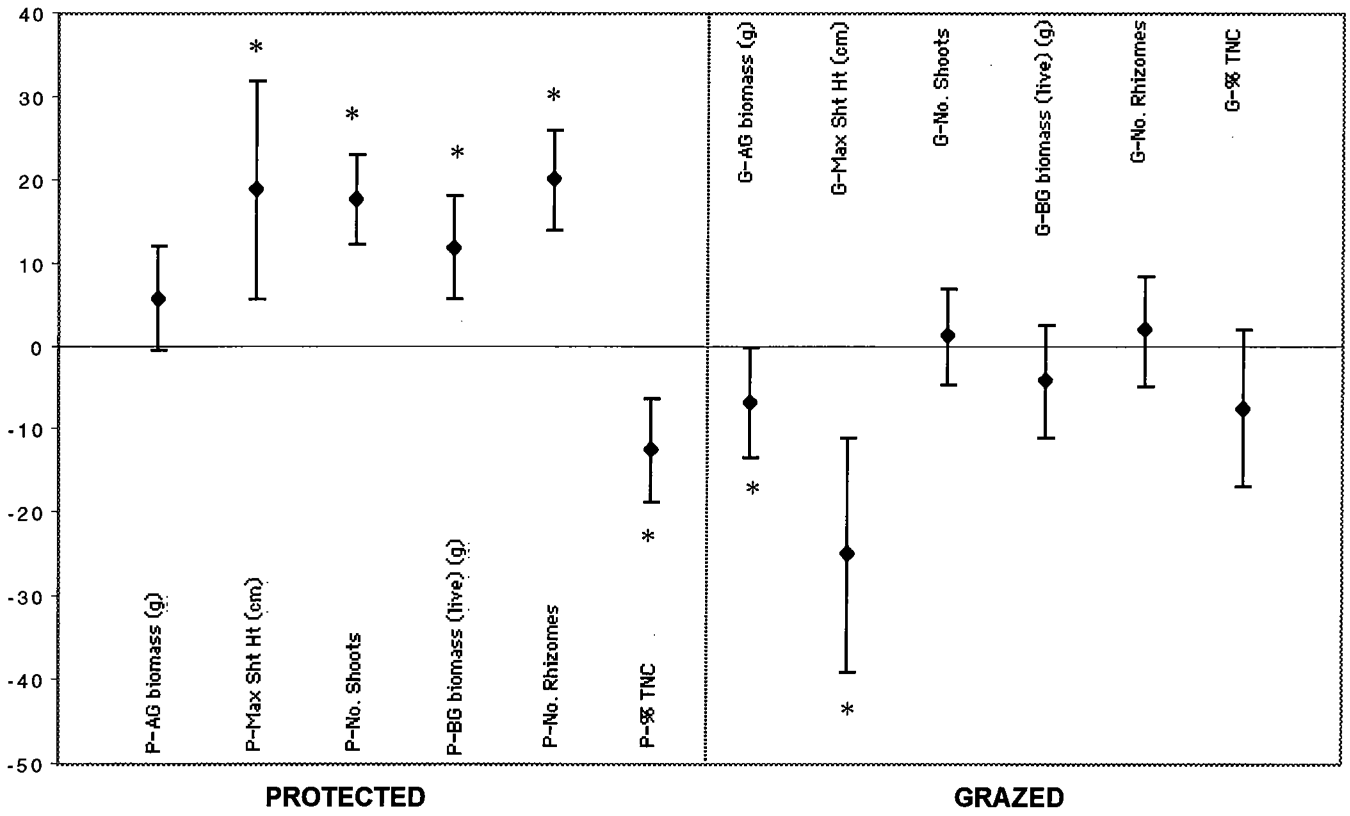


Figure 10. Changes from Year 1 to Year 2 in*Carex lyngbyei* plants in protected and grazed plots at a restored wetland in the Duwamish River estuary, Seattle, Washington. Values are means of changes (Δ) for the specified attribute in protected or grazed plots. Positive values indicate a year's gain in the specified attribute; negative values indicate a year's loss in the specified attribute. Error bars indicate 95% confidence intervals. * denotes significant difference from no change ($p<0.05$). P=protected (n=8); G=grazed (n=7). AG=aboveground; BG=belowground; TNC=total nonstructural carbohydrates.

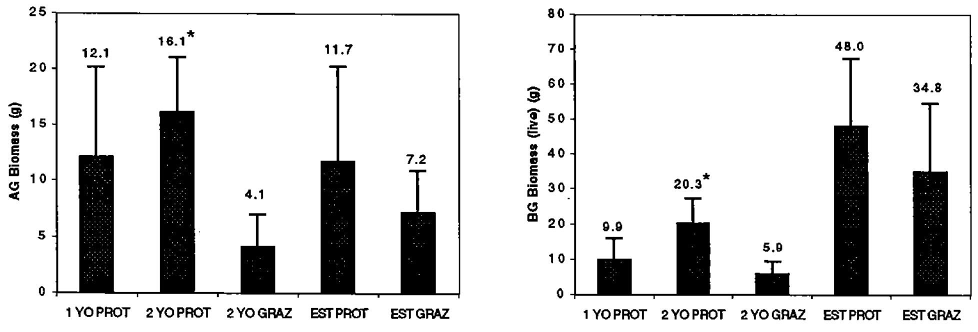
Table II. Comparison of 2-year-old protected and grazed *Carex lyngbyei* plants to 1-year-old protected plants in experimental plots at a restoration site in the Duwamish River estuary, Seattle, Washington. Data reported for each above- and belowground attribute is the mean difference (Δ) between the years for plants in plots of the specified treatment (i.e., Δ=Year 2 minus Year 1 for a given plot); positive (+) values represent a gain and negative (-) values represent a loss in a particular attribute in Year 2 compared to Year 1. Δ values are least-squares means ± one standard error for 0.038 m^2 sampling cores (22 cm in diameter). Percent (%) change is relative to the mean values for Year 1 for plots used for the t-test. Results of one-sample t-tests of the null hypothesis (H_o) are presented as p-values. Statistical significance ($p<0.05$) is denoted with an asterisk (*). Bold p-values are <0.10. Confidence intervals (C.I.) are provided at the 95% level. P=protected plants (n=8); G=grazed plants (n=7).

PLANT ATTRIBUTE	**DIFFERENCE (Δ) between Year 2 and Year 1**							
Aboveground	***Δ Protected Plants***	***% Change***	***p-value for $H_o: \mu(\Delta P)=0$***	***C.I.***	***Δ Grazed Plants***	***% Change***	***p-value for $H_o: \mu(\Delta G)=0$***	***C.I.***
Aboveground biomass (g)	5.8 ± 2.8	43	**0.066**	-0.5, 12.0	-6.7 ± 3.0	-69	**0.050***	-13.3, 0.0
Maximum shoot height (cm)	19 ± 6	24	**0.009***	6, 32	-25 ± 6	-36	**0.002***	-39, 11
No. shoots	17.8 ± 2.4	171	**0.0001***	12.5, 23.2	1.3 ± 2.6	2	0.626	-4.4, 7.1
Belowground								
Belowground biomass (live) (g)	12.0 ± 2.9	113	**0.002***	5.7, 18.3	-4.1 ± 3.1	-45	0.21	-10.9, 2.7
No. rhizomes	20.1 ± 2.7	141	**0.0001***	14.1, 26.2	2.0 ± 2.9	15	0.504	-4.4, 8.5
Total nonstructural carbohydrates (%)	-12.4 ± 2.5	-50	**0.004***	-18.8, -6.1	-7.3 ± 3.8	-39	0.108	-16.8, 2.1

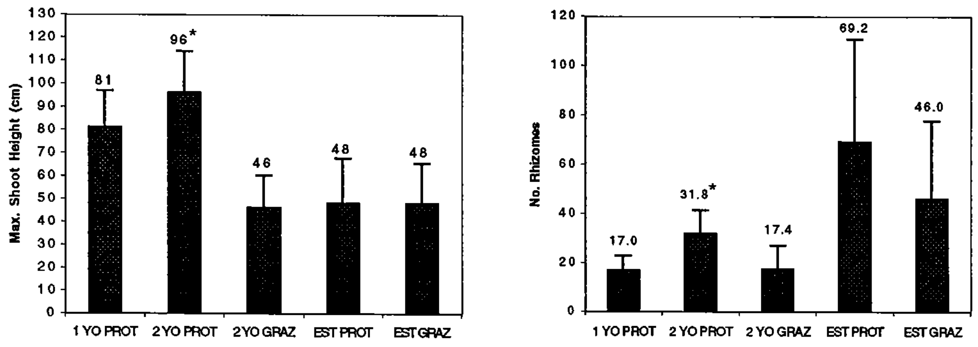
biomass was larger in the 2-year-old protected plants than in the established stands (16.1 ± 4.9 g and 7.2 ± 3.7 g, respectively; p=0.0002), as was maximum shoot height (96 ± 17.9 cm and 48.25 ± 17.68 cm, respectively; p=0.0001) (Figures 9 and 11 and Table I). By contrast, BG biomass of 2-year-old protected plants was lower than that of the established stands (20.3 ± 7.1 g and 34.8 ± 19.6 g, respectively; p=0.0059), as was the number of rhizomes of 2-year-old protected plants compared to that of the established stands (31.8 ± 9.4 and 46.0 ± 31.6, respectively; p=0.0015). Although the number of rhizomes was lower in the 2-year-old plants, the other measure of vegetative reproduction—*i.e.,* number of shoots—was not significantly different when the two groups were compared. The 2-year-old plants had developed 81% of the shoots, 58% of the BG biomass, and 69% of the rhizomes of their established counterparts.

Comparison of **Carex lyngbyei** *on the Duwamish to Other Stands in the Pacific Northwest*

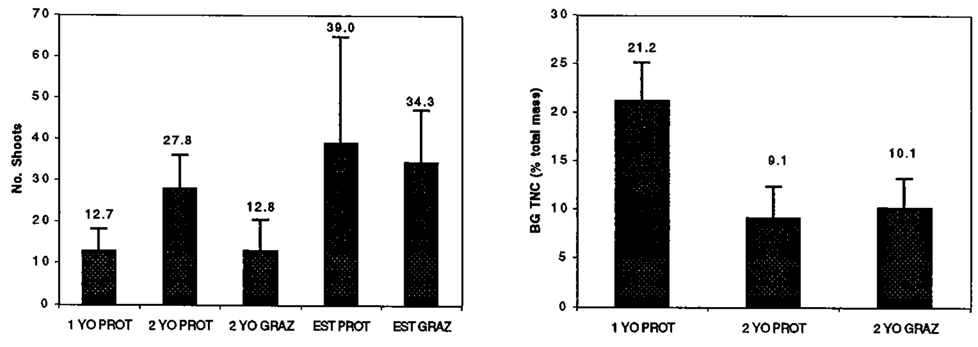
Standardization of *C. lyngbyei* biomass and shoot number means to m^{-2} revealed that the restoration site was similar to other created marshes in the Pacific Northwest and that the reference stands on the Duwamish were less productive than other *C. lyngbyei* stands in the region (Table III). The protected plants (253 g m^{-2} AG biomass, 323 g m^{-2} BG biomass, and 438 shoots m^{-2}) were within the range of *C. lyngbyei* development in other restoration projects, although the BG biomass was a great deal lower than the created slough on the Chehalis River. The grazed 2-year-old plants (64 g m^{-2} AG biomass, 102 g m^{-2} BG biomass, and 202 shoots m^{-2}), however, exhibited the least development of all cited *C. lyngbyei* studies in the Pacific Northwest. The protected reference stands had standing crops (257-385 g AG biomass m^{-2}) and stem densities (842-1,302 shoots m^{-2}) that were at the high end of the range for all cited studies. BG biomass (1,113-1,555 g BG biomass m^{-2}) was on the low end of the range of established stands in the Pacific Northwest. The standing crops of the grazed reference stands (181-197 g m^{-2} AG biomass and 786-1,106 g m^{-2} BG biomass) were at the low end of the range of all established sites. Shoot density (833-973 shoots m^{-2}), however, was at the high end of


(a) Aboveground biomass

(d) BG biomass (live)


(b) Maximum Shoot Height

(e) Rhizomes


(c)Shoots

(f) BG total nonstructural carbohydrates

Figure 11. All ages (1- and 2-year-old planted and established native stands) and treatments (protected and grazed) of *Carex lyngbyei* at a restoration and reference sites in the Duwamish River estuary, Seattle, Washington. Values and abbreviations areas in Figure 8 with the following additions: PROT=protected; GRAZ=grazed; EST=established native stand. * denotes 2 YO protected plants that are significantly different($p<0.05$) from established grazed stands with respect to the specified attribute. Data are per 0.038 m^2 core (22 cm diameter). For BG data, core is 15 cm deep.

Table III. Mean peak standing crop (aboveground biomass (AG)) and belowground biomass (BG), stem densities, and maximum stem heights at time of peak AG for *Carex lyngbyei* populations throughout the Pacific Northwest. Locations are arranged from north to south. Current study locations are in bold itallics.

Estuary Location (and Characteristics of *Carex lyngbyei* Population)	**Mean Peak AG (g dry wt/m^2)**	**Mean BG at time of peak AG (g dry wt/m^2)**	**Stem Density at Time of Peak AG (shoots/m^2)**	**Average Maximum Stem Height at Time of Peak AG (cm)**	**Source**
British Columbia					
Salmon River	1,030				Kennedy & Brink 1986
Campbell River	1,100				Kennedy & Brink 1986
Little Qualicum River					
--	1,450				Kennedy & Brink 1986
Short form (mixed stands)				50	Dawe & White 1982
Channel edge (tall)	1,693			150+	Dawe & White 1982
Nanaimo River Delta					
Channel edge (monospecific)	321-578		745-1,294	62-80	Smythe 1987
Elevated flats (")	604		1,349	70	Smythe 1987
Channel edge (mixed stands)	151		283	62	Smythe 1987
Foreshore flats (")	73-226		378-602	38-46	Smythe 1987
Elevated flats (")	4-322		9-410	39-90	Smythe 1987
Squamish River Delta					
Channel edge (monospecific)	153-608		320-704	58-122	Smythe 1987
Foreshore flats (")	330-382		484-564	70-84	Smythe 1987
Intermediate flats (")	446-560		532-688	66-104	Smythe 1987
Foreshore flats (mixed stands)	152-172		224-252	56-63	Smythe 1987
Intermediate flats (")	428-454		508-560	85-93	Smythe 1987
Elevated flats (")	20-133		60-2,012	43-71	Smythe 1987
Levee (")	432-560		312-480	83-108	Smythe 1987
Fraser River Delta					
--	735	2,865	452	130	Kistritz & Yesaki 1979
--	724	~2,896 *a*	460 *b*		Kistritz *et al.* 1983
Reifel marsh	1,070	2,463 *c*	739	98	Yamanaka 1975
Whole foreshore	927				Yamanaka 1975
Nearly pure stands	~325-1,150 *d*			~83-122 *e*	Pidwirny 1989
Mixed stands	~50-480 *d*			65-78	Pidwirny 1989
Cowichan River	1,200				Kennedy & Brink 1986

Table III. *Continued*

Estuary Location (and Characteristics of *Carex lyngbyei* Population)	**Mean Peak AG (g dry wt/m^2)**	**Mean BG at time of peak AG (g dry wt/m^2)**	**Stem Density at Time of Peak AG (shoots/m^2)**	**Average Maximum Stem Height at Time of Peak AG (cm)**	**Source**
Puget Sound					
Nooksack Delta	920 *f*	881 *f*			Disraeli & Fonda 1979
Skagit Delta					
More saline (8-12 ppt)(33-71% cover)	233-531		717-1,989 *g*	≥42	Ewing 1983
Less saline (0-4 ppt)(>90% cover)	988-1,738	10,000-14,000 *h*	1,025-2,761 *g*	≤182	Ewing 1983
Channel edge (monospecific)	252-608		340-870	68-111	Smythe 1987
Elevated flats (“)	150-560		90-592	107-118	Smythe 1987
Channel edge (mixed stands)	107-433		66-341	88-113	Smythe 1987
Intermediate flats (“)	231-861		258-588	84-137	Smythe 1987
Elevated flats (“)	97-533		53-383	94-128	Smythe 1987
Levee (“)	71-1,081		311-623	49-141	Smythe 1987
Duwamish River					
--	816-1,026*i*	1,397-2,053 *j*	706-848 *k*		Cordell *et al.* 1994 *l*
Ungrazed	1,062-1,613 *m*	1,543-2,235 *j*	462-651	159-185	Wenger 1995
Grazed	716 *m*	2,179 *j*	811	82	Wenger 1995
--			411-748 *n*	47-140 *n, o*	Cordell *et al.* 1999
Created marsh—Protected (2 yrs)	253 *p, q*	323 *p, q*	438 *p, q*	95 *p*	Present study
Created marsh—Grazed in 2nd year	64 *p, q*	102 *p, q*	202 *p, q*	46 *p*	Present study
Reference stands					
Protected (78% growing season)	257-385 *p*	1,113-1,555 *p*	842-1,302 *p*	35-65 *p*	Present study
Grazed	181-197 *p*	786-1,106 *p*	833-973 *p*	42-54 *p*	Present study
Puyallup River					
Created marsh (Gog-le-hi-te)	204-415 *r*	118-756 *r*	37-227 *s*		Simenstad, pers. comm. *t*
Nisqually Delta					
Short				50	Burg *et al.* 1980
Tall (dead and live)	1,390			150	Burg *et al.* 1980
--	1,036-2,064	1,278-3,071	616-939	152-194	Wenger 1995
--	439	452	216		Simenstad, pers. comm. *t*
Hood Canal					
Big Beef Creek	744	12,678	238		Simenstad & Thom 1996

Table III. *Continued*

Estuary Location (and Characteristics of *Carex lyngbyei* Population)	Mean Peak AG (g dry wt/m^2)	Mean BG at time of peak AG (g dry wt/m^2)	Stem Density at Time of Peak AG (shoots/m^2)	Average Maximum Stem Height at Time of Peak AG (cm)	Source
Grays Harbor					
Chehalis River					
Ann's Slough (reference)	455-1,041 *u*	2,112-15,551 *u*	114-344 *u*		Simenstad *et al.* 1997, 2001
Created slough	92-871 *v*	2,396-7,724 *v*	62-299 *v*		Simenstad *et al.* 1997, 2001
Bowerman Basin	700				Thom 1981
Newskah Creek (freshwater)	491				Thom 1981
Columbia River					
Baker Bay (low marsh)	865-873 *w*	2,863 *x*			Macdonald 1984
Trestle Bay (low marsh)	859-1,730 *w*	1,817 *x*			Macdonald 1984
Oregon					
Siletz Bay					
Streamside	1,200				Gallagher & Kibby 1981
Backmarsh	900		1,078-1,626		Gallagher & Kibby 1981
Nehalem Bay					
Short	724		1,140	30-92	Eilers 1975
Tall	1,714		1,240	180+	Eilers 1975
Coos Bay					
Mixed stands	~210 *y*	~4,346 *z*			Hoffnagle 1980
Beaver Marsh	466 *aa*			90	Taylor 1980
Joe Ney Slough mitigation marsh	123 *bb*				Taylor 1980

a Calculated as 4 times the amount of AG, per author's statement that peak AG was 25% of BG.
b Mean stem density for May-August.; no significant differences were found among stem densities of this period
c Crowns, underground shoot root, roots to 10 cm deep, and ≤5 cm of shoots (not included in AG); extrapolated from 12.5-diameter core (0.01227 m^2)
d AG estimated from graphs of *Carex lyngbyei* along transects established along an elevation gradient
e AG estimated from graph of *Carex lyngbyei* height regressed on elevation
f maximum standing biomass figure for *Carex lyngbyei/Agrostis alba* community adjusted for portion (56.49%) of total plant cover of all species (137%)
g range means at sampling points measured April-August
h macro-organic matter (>1 mm) sampled to a depth of 40 cm in pure stands in April
i stem densities extrapolated from 0.015625 m^2 (12.5 x 12.5 cm quadrat)
j live and dead (combined) BG that includes some non-*Carex* organic material; extrapolated from 5-cm core (0.001963 m^2) with a depth of 20 cm

Table III. *Continued*

k extrapolated from 0.0625 m^2 (25 x 25 cm) quadrat
l includes AG as corrected in Wenger 1995
m AG extrapolated from 0.0156 m^2 (12.5 cm x 12.5 cm) quadrat
n 3 years of data collected 1995-1997
o height data is tallest stem per 0.0625 m^2 (25 cm x 25 cm) quadrat
p AG and BG and stem densities extrapolated from 0.038 m^2 core sampled to a depth of 15 cm; October sampling underestimates AG and maximum height, most noticeably in reference stands, in which some export of material appeared to have occurred earlier in the season; BG includes alive and dead
q average figures for plants at created wetland are converted to m^2 (extrapolated from 0.038 m^2 cores sampled to depth of 15 cm) and then multiplied by 0.6 in order to account for gaps among *Carex lyngbyei* shoots planted on 0.3-m (1-foot) centers
r 3 years of data collected 1986-1995; AG extrapolated from 0.1 m^2 quadrat (33.3 cm x 33.3 cm) for 2 years, 0.0625 m^2 quadrat (33.3 cm x 33.3 cm) for 1 year; 2 years of BG extrapolated from 0.0625 m^2 m (25 cm x 25 cm) square core driven 30 cm deep, 1 year extrapolated from 0.00196 m^2 (5-cm core) pounded 20 cm deep
s 7 years of data collected 1986-1995; for 5 years collected from permanent 1- m^2 quadrats, 1 year from 0.1 m^2 quadrats, and 1 year from 0.0625 m^2 quadrats; low end of range represents drop (possibly the result of grazing) after sustained upward trend
t corrected data from Simenstad & Thom 1996
u 5 years of data collected1990-2000; AG extrapolated from 0.1 m^2 quadrat (33.3 cm x 33.3 cm); BG (live and dead) extrapolated from 156 cm^2 x 25 cm deep (14 cm diameter core), 79 cm^2 x 20 cm deep (10 cm diameter core), and 100 cm^2 x 20 cm deep (11.28 cm diameter core).
v 4 years of data collected 1990-2000; AG and BG as for *u*
w AG (live and dead) extrapolated from 0.1 m^2 quadrat
x BG extrapolated from 50.26 m^2 (8-cm core)
y AG estimated from graph of biomass of *Carex lyngbyei* during growing season
z BG is calculated as 13.65% of live and dead root standing crop for month of June at 3 marshes dominated by *Carex lyngbyei*; percentage (13.65) was based on amount of peak AG attributable to *C. lyngbyei* ; BG was sampled to a depth of 40 cm, rather than the 10-20 cm used by other studies.
aa extrapolated from one 20 cm x 50 cm sample, live and dead AG
bb extrapolated from two 20 cm x 50 cm samples, live and dead AG

the range for all sites. Stem heights for all reference stand treatments (35-65 cm for protected and 42-54 for grazed) were at the low end of the range for all sites in the region.

Volunteer Plant Community

Twenty-nine (29) species volunteered in the experimental plots (Table IV). Assessments of the character and dynamics of the community took into account the species' duration, origin, and whether or not they are considered weedy.

Four groups of plots, each group characterized by certain species, were developed from the two-way table produced by TWINSPAN (Figures 12 and 13). Group I (n=18) consisted largely of 13 plots from Year 1 (during which all plots were protected) and 5 plots that were protected during Year 2. These plots were exclusively from plots in two blocks on the site in which *C. lyngbyei* plants were significantly larger than in the third block. (Plants averaged over both treatments in Blocks 2 and 3 had more BG biomass during the second growing season than those in Block 1 (16.32 ± 9.82 and 13.38 ± 8.77 contrasted to 9.65 ± 8.50 g, respectively; p=0.022); and the same was true of aboveground biomass (12.19 ± 6.27 and 10.91 ± 8.06 compared to 7.18 ± 7.12 g, respectively; p=0.010).) Species characteristic of Group I (*i.e.,* occurring in at least half of the plots in the group) were *Cotula coronopifolia, Eleocharis palustris, Juncus bufonius,* and *Spergularia marina.* Group III was similar in species composition, except that *J. bufonius* was absent and *Aster subspicatus* and *Plantago major* were present. The plots in this group (n=10) consisted of 2 plots from Year 1, 4 plots that were protected during Year 2, and 4 plots that were exposed to grazing during Year 2. All the plots were from the same two blocks as those described for Group I. Only two species (with minor percent covers) in the two groups were considered weedy. The species assemblages in Groups I and III contained larger *Carex* and were less weedy in character than the other groups (Figures 12 and 13).

Table IV. Plant species that volunteered within exclosures at a restoration site in the Duwamish River estuary, Seattle, Washington. Codes are those abbreviations used in multivariate analyses. Duration, origin, and weedy habits were obtained from the following references: Cooke, *et al.* (1997) (C); Hickman (1993) (Hm); Hitchcock, *et al.* (1955-1969) (H); Pojar and MacKinnon (1994) (P); and Taylor (1990) (T). A=annual; B=biennial; P=perennial. Non=non-native; uncert.=uncertain origin.

Code	Scientific Name	Common Name	Duration	Origin	Weed(y)	Family
AGST	*Agrostis stolonifera*	Creeping bentgrass	P	Non (H); Uncert (T)	Yes (T)	Poaceae
ASSU	*Aster subspicatus*	Douglas' aster	P			Asteraceae
ATPA	*Atriplex patula*	Spearscale	A		Yes (T)	Chenopodiaceae
BAOR	*Barbarea orthoceras*	American winter cress	B		Yes (P)	Brassicaceae
CHAL	*Chenopodium album*	Lamb's quarters	A	Non (T)	Yes (T)	Chenopodiaceae
COCO	*Cotula coronopifolia*	Brass buttons	P	Non (H,P)		Asteraceae
ELPA	*Eleocharis palustris*	Creeping spikerush	P			Cyperaceae
GNCH	*Gnaphalium chilense*	Cotton-batting cudweed	A or B	Native (T)	Yes (T)	Asteraceae
JUBU	*Juncus bufonius*	Toad rush	A	Native and introduced races (P)	Yes (P)	Juncaceae
JUSP	*Juncus* sp.					Juncaceae
LELA	*Lepidium latifolium*	Pepperwort	P	Non (H,Hm)	Yes (H)	Brassicaceae
LIOC	*Lilaeopsis occidentalis*	Western lilaeopsis	P			Apiaceae
LYHY	*Lythrum hyssopifolia*	Hyssop loosestrife	A or B	Native (P)		Lythraceae
MEAL	*Melilotus alba*	White sweet-clover	A or B	Non (H,P)	Yes (H,T)	Fabaceae
PHAR	*Phalaris arundinacae*	Reed canarygrass	P	Non (C,T); Uncert.(P)	Yes (H,T)	Poaceae
PLMA	*Plantago major*	Common plantain	P	Non(C,T)	Yes (T)	Plantaginaceae
POPA	*Potentilla pacifica*	Silverweed	P	Native (P)		Rosaceae
POPE	*Polygonum persicaria*	Ladysthumb	A	Non (T)	Yes (H,T)	Polygonaceae
RASP	*Ranunculus occidentalis*	Western buttercup	P			Ranunculaceae
RUCR	*Rumex crispus*	Curly dock	P	Non (T)	Yes (P,T)	Polygonaceae
RUSP	*Rumex* sp.					Polygonaceae
RUOB	*Rumex obtusifolius*	Broadleaf or bitter dock	P	Native (C); Non (T)	Yes (H,T)	Polygonaceae
SOAS	*Sonchus asper*	Prickly sow-thistle	A or B	Non (P,T)	Yes (T,P)	Asteraceae
SODU	*Solanum dulcamara*	Bittersweet nightshade	P	Non (C,P,T)	Yes (T)	Solanaceae
SOOL	*Sonchus oleraceus*	Annual sow-thistle	A	Non (T)	Yes (T)	Asteraceae
SPMA	*Spergularia marina*	Salt marsh sand-spurry	A	Non (C,H,P)		Caryophyllaceae
TAOF	*Taraxacum officinale*	Dandelion	P	Non (H,P,T)	Yes (H,P,T)	Asteraceae
TAVU	*Tanacetum vulgare*	Tansy	P	Non (H,P,T)	Yes (P,T)	Asteraceae
TRRE	*Trifolium repens*	White clover	P	Non (C,H,P,T)	Yes (H,T)	Fabaceae

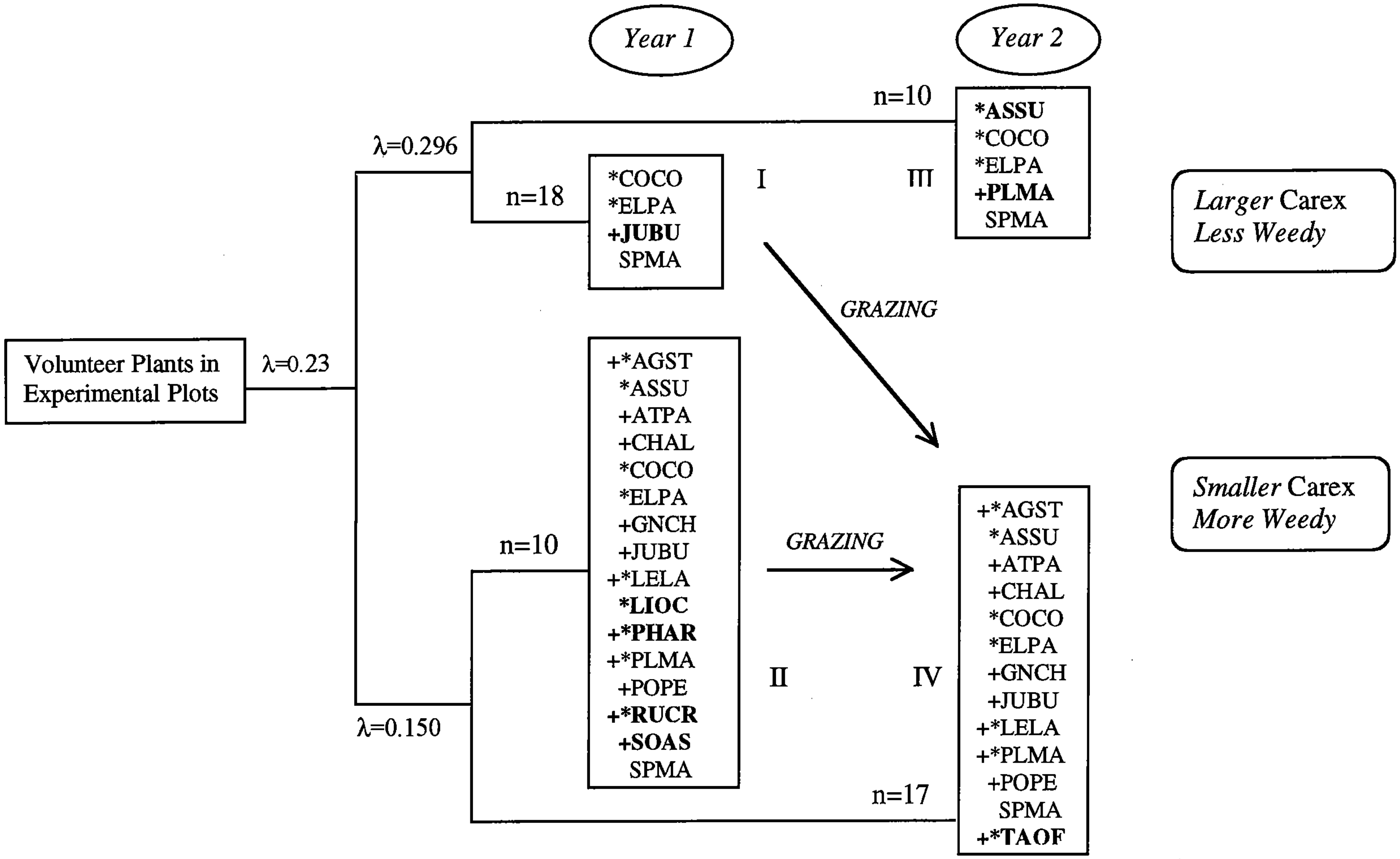


Figure 12. Dendrogram of volunteering plant species that are characteristic of groups of experimental plots set up at a restoration site in the Duwamish River estuary, Seattle, WA. Roman numerals designate groups distinguished by Two Way Indicator Species Analysis (TWINSPAN). Species codes as in Table III. Differences in species composition between pairs of subgroups are indicated in bold type. * = perennial species; + = weedy species; n = number of experimental plots. Eigenvalues (λ) indicate the degree to which a given division accounts for the variation in the data. Arrows and labels in margins indicate putative trends.

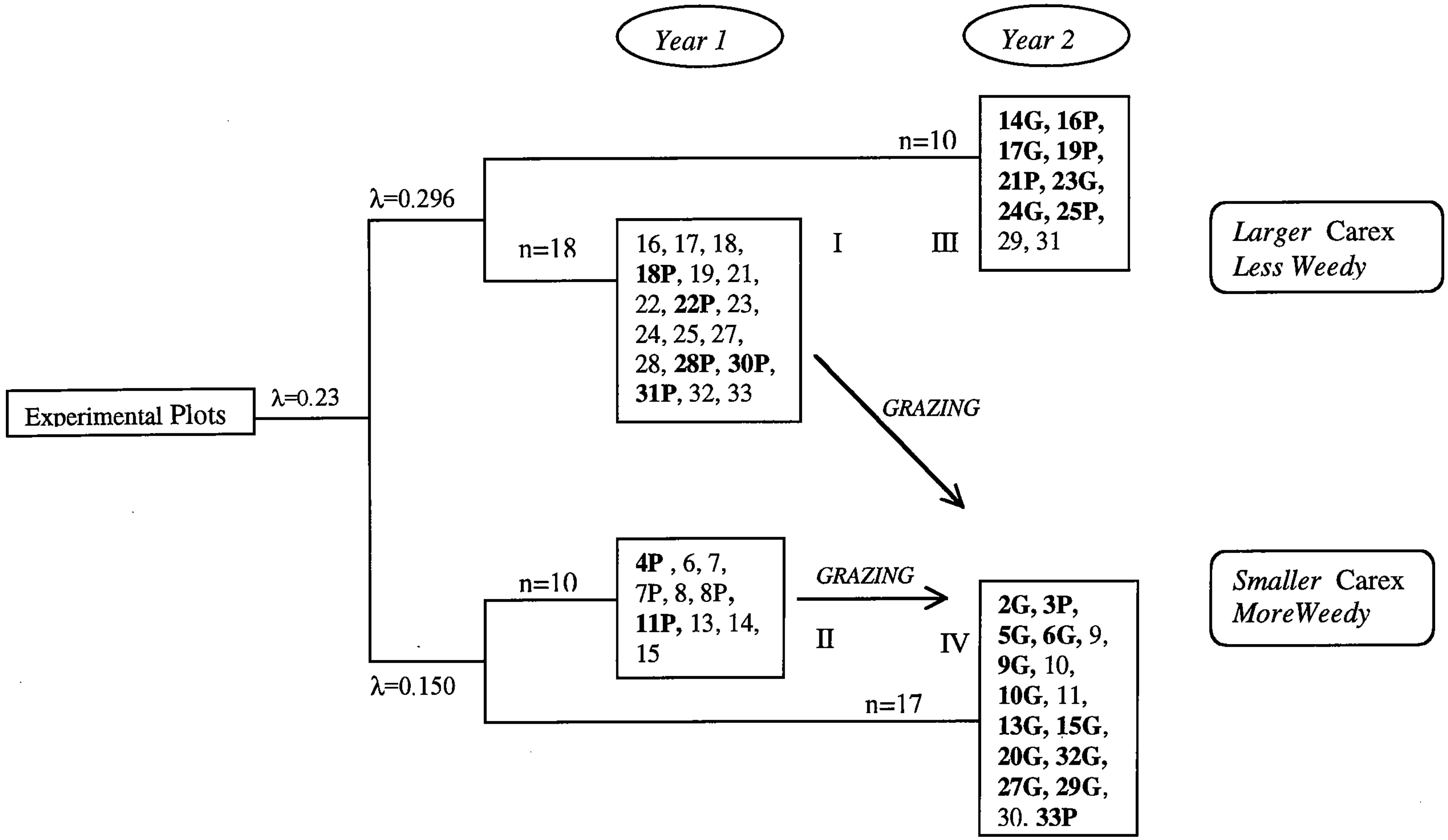


Figure 13. Dendrogram of groups of plots distinguished by Two Way Indicator Species Analysis (TWINSPAN). TWINSPAN groups are labeled with Roman numerals. See Figure 12 for species characteristic of each group. Plots that were treated during the second growing season (Year 2) are indicated in bold type. P = protected; G = grazed; n=number of experimental plots. Eigenvalues (λ) indicate the degree to which a given division accounts for the variation in the data. Arrows and labels in margins indicate putative trends. See Figure 3 for location of numbered plots at restoration site.

Of the plots in Group II (n=10), 6 were from Year 1; and 4 were plots protected during the second year. Seven of the 10 plots in this group—including all 4 from the protected Year-2 plots—were in the experimental block in which *C. lyngbyei* plants grew consistently smaller. Species characteristic of Group II were *Agrostis stolonifera, Aster subspicata, Atriplex patula, Chenopodium album, C. coronopifolia, E. palustris, Gnapthalium chilense, J. bufonius, Lepidium latifolium, Lilaeopsis occidentalis, Phalaris arundinacae, P. major, Polygonium persicaria, Rumex crispus, Sonchus asper,* and *S. marina.* Group IV (n=17) was similar in composition, except for the presence of *Taraxacum officinale* and the absence of *L. occidentalis, P. arundinacae, R. crispus,* and *S. asper.* Of the 17 plots in this group, 11 were grazed during the second year; 2 others were protected during Year 2; and 4 were from Year 1. Plots in this group were from all three blocks on site, although nearly half (8) were from the block in which *C. lyngbyei* grew smaller than it did in other blocks. Most of the plots in Groups II and IV were weedy in character and contained smaller *Carex* than the other groups (Figures 12 and 13).

When the plots were followed from Year 1 to Year 2 in the TWINSPAN dendrogram, some transition-patterns emerge and are indicated with arrows and labels (Figures 12 and 13). Protection during Year 2 sometimes resulted in a plot's staying in the group in which it started, *i.e.,* 5 of 15 plots retained the species assemblage of the first year. Upon exposure to grazing during Year 2, many plots made the transition to the species assemblage characteristic of Group IV; 11 of 15 grazed plots are in this group, including 2 plots that started out in this group. The remaining 4 grazed plots are found in Group III, along with a number of other plots predominantly from Year 2. Groups III and IV are characterized by plots from Year 2, while Groups I and II are characterized by plots from Year 1 (Figures 12 and 13).

The ordination plots from DCA suggest some trends that reinforce those suggested by the TWINSPAN classification. The plots from Year 1 and from the grazed treatment in Year 2 occupy relatively well defined portions of the graph (Figure 14). These two groups are separated along Axis 2. The plots that were protected for 2 years occupy the broadest area, spanning the entire graph and defining the extremes on both ends of Axis 1. This protected group overlaps the other two in the middle of the graph. In general, the grazed plots converge in species composition while the protected plots diverge during the second growing season.

When the TWINSPAN groups are located on the ordination plot, strong separation is apparent among them (Figure 15). Groups I and III (the "Larger *Carex*, Less Weedy" Groups) are on the left side of Axis 1, and Groups II and IV (the "Smaller *Carex*, More Weedy" Groups) are on the right side of the axis, which has an eigenvalue (λ) of 0.237. This axis appears to span the site conditions, from sediments that were mixed, well draining, and unconsolidated to those that were in the downstream portion of the site (Block 1), where a layer of consolidated clay over sand with low organic matter was found in many of the plots (Figure 16).

Groups I and II (consisting of plots predominantly from Year 1 and Year 2-Protected) are separated from Groups III and IV (consisting of plots from Year 2) along Axis 2, which has a λ of 0.138. This axis appears to be correlated with a factor or factors that have a time component. Because all volunteering plants were removed during the first year, Axis 2 cannot represent the passage of time that accompanies true successional changes. It could, however, represent the difference between the species-assemblages that may establish when newly planted *C. lyngbyei* is on the site and the assemblages that may establish during the second growing season of the larger *C. lyngbyei*.

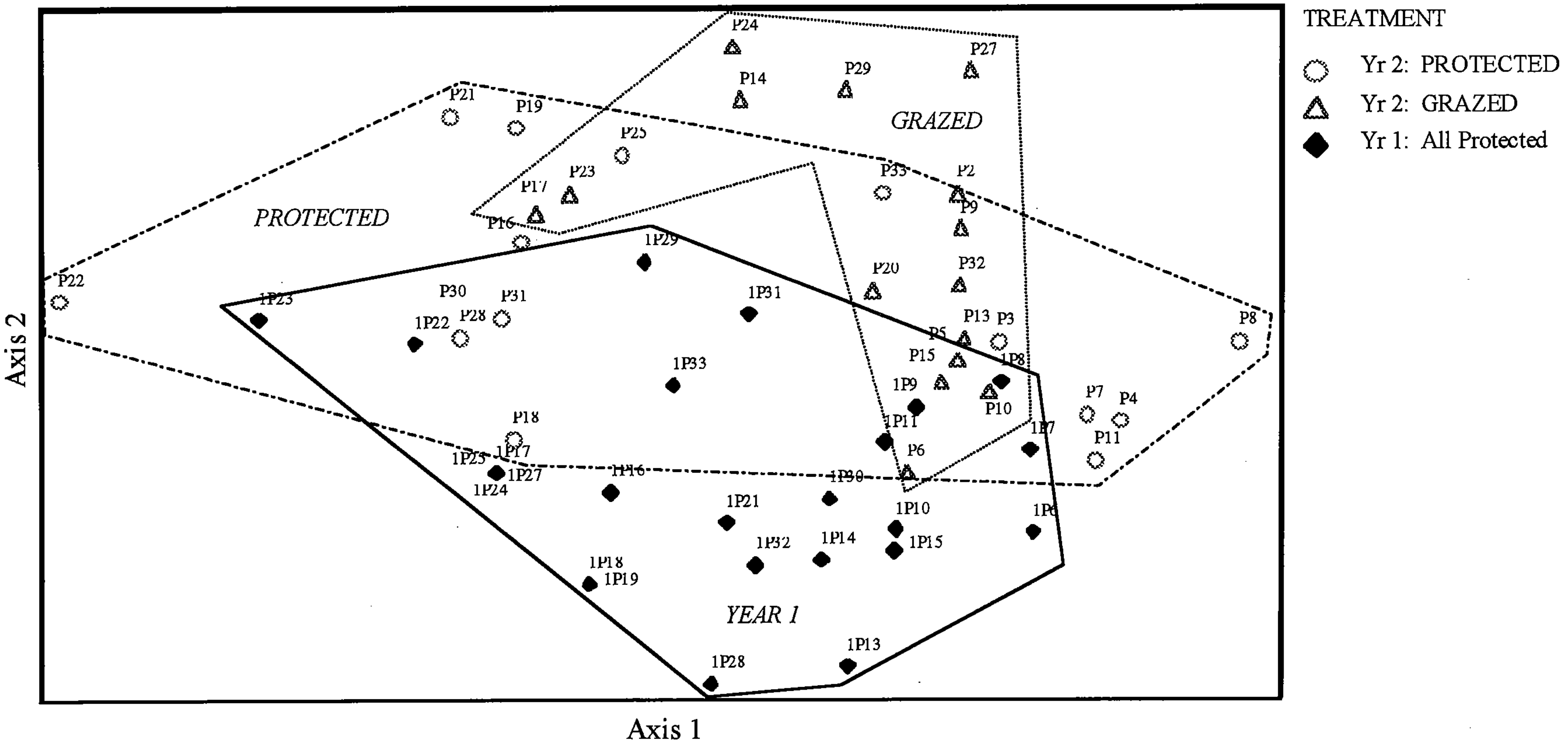


Figure 14. Detrended correspondence analysis (DCA) ordination plot of all experimental plots, including Year 1 plots (all protected) and Year 2 plots (grazed and protected), at a restoration site in the Duwamish River estuary, Seattle, WA. Analysis was conducted without *Solanum dulcamara*, a strong outlier. Groups of plots subjected to the same treatments are outlined and labeled. Eigenvalue (λ)=0.237 for Axis 1; λ=0.138 for Axis 2. Plot numbers are coded for different years: 1P# = a plot in Year 1; P# = a plot in Year 2. A given plot retains its number from year to year. See Figure 3 for location of numbered plots at restoration site.

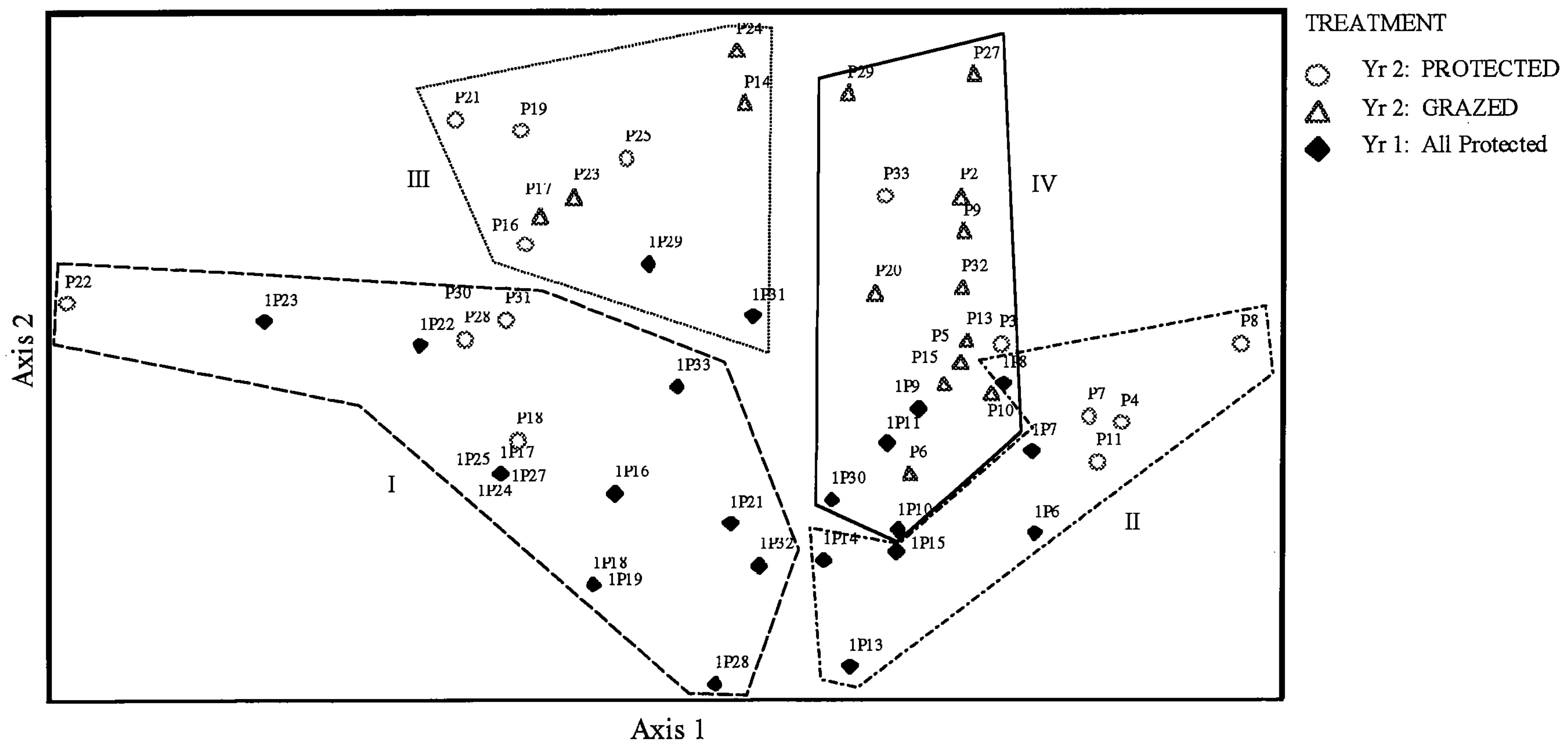
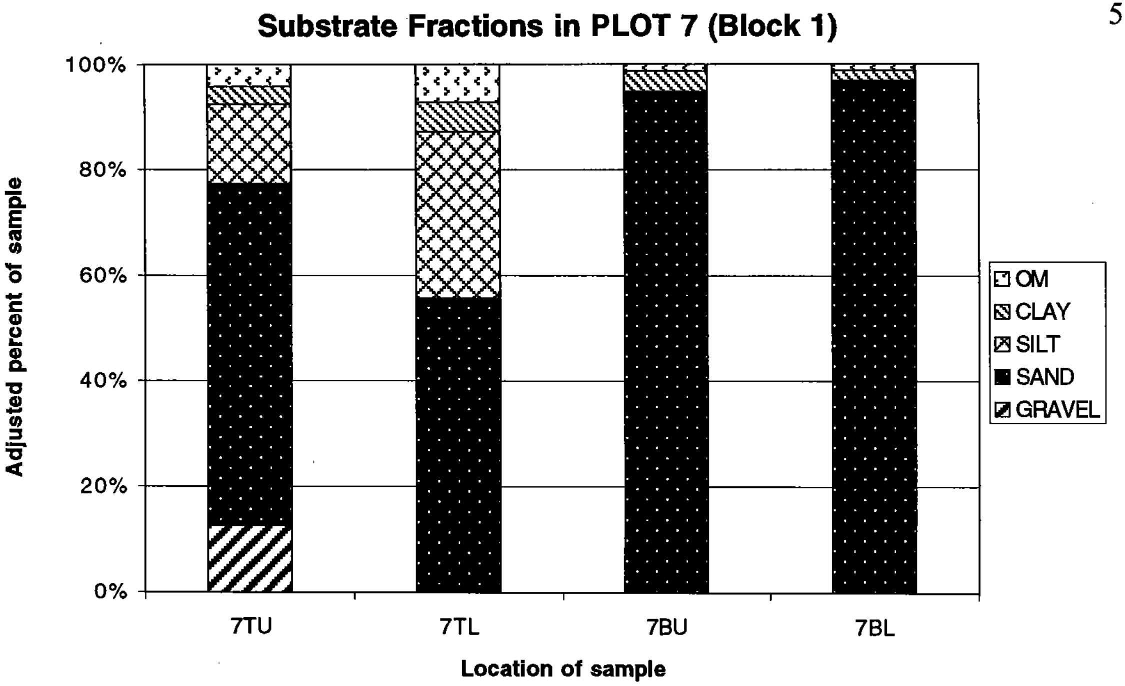


Figure 15. Detrended Correspondence Analysis (DCA) ordination plot of all experimental plots, including Year 1 plots (all protected) and Year 2 plots (grazed and protected), at a restoration site in the Duwamish River estuary, Seattle, WA. Groups of plots corresponding to the Two-Way-Species-Indicator Analysis (TWINSPAN) groups are outlined and labeled with Roman numerals (see Figure 13). Analysis was conducted without *Solanum dulcamara*, a strong outlier. Eigenvalues (λ), which indicate the degree to which an axis accounts for variation in the data, were 0.237 for Axis 1 and 0.138 for Axis 2.. Plots coded for different years: 1P# = Year 1 plot; P# = Year 2 plot. A given plot retains its number from year to year.



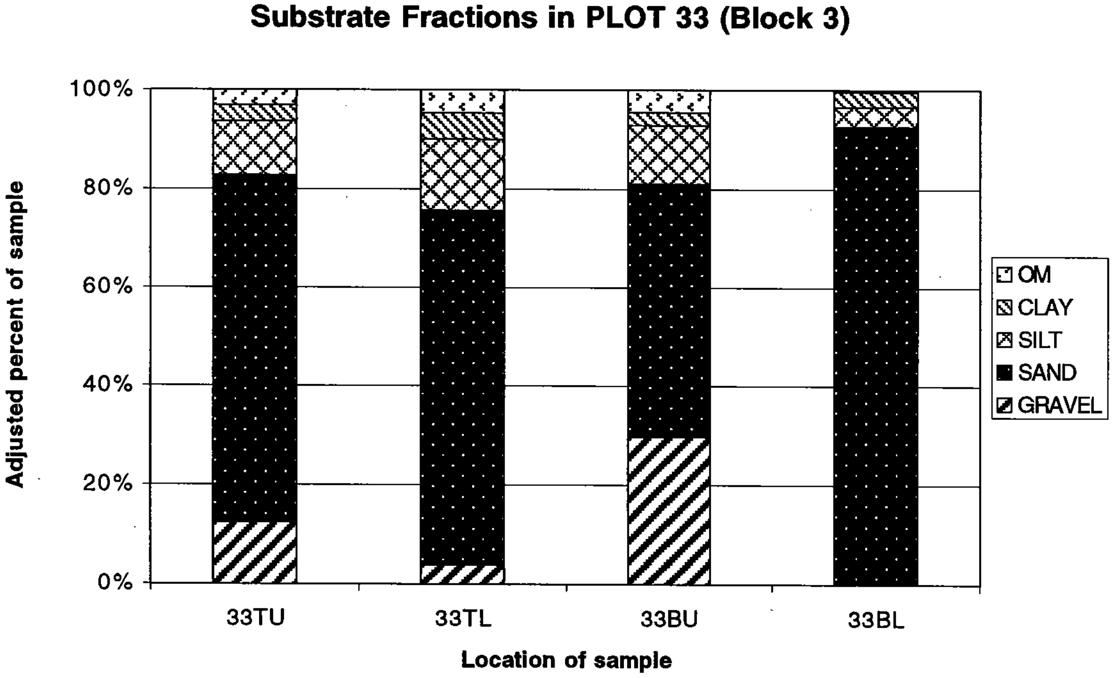


Figure 16. Organic matter, soil texture, and percent gravel in substrate samples at two experimental plots at a restored wetland in the Duwamish River estuary, Seattle, Washington. Based on data in Brown *et al.* (1997). Gravel and soil fractions are recalculated as portions of the inorganic material left over from ignition of organic matter and may be slightly underestimated. T=top (surface); B=bottom (~35 cm deep); U=upper (landward) end of plot; L=lower (waterward) end of plot. See Figure 3 for plot locations.

When the ordination of both the experimental plots and the species is examined, *E. palustris* and *C. coronipifolia*, common wetland species, are found at one end and *M. alba* and *T. vulgare*, upland species, are found at the other end (Figure 17). The species ordination indicates a transition from productive wetland conditions to less productive, disturbed wetland-upland ecotone conditions. This range of conditions is consistent with the differential response of *C. lyngbyei* growth across the site—*i.e.,* the plants grow larger in the two upstream blocks within the excavated cove than they do in the downstream block that is exposed to more river energy.

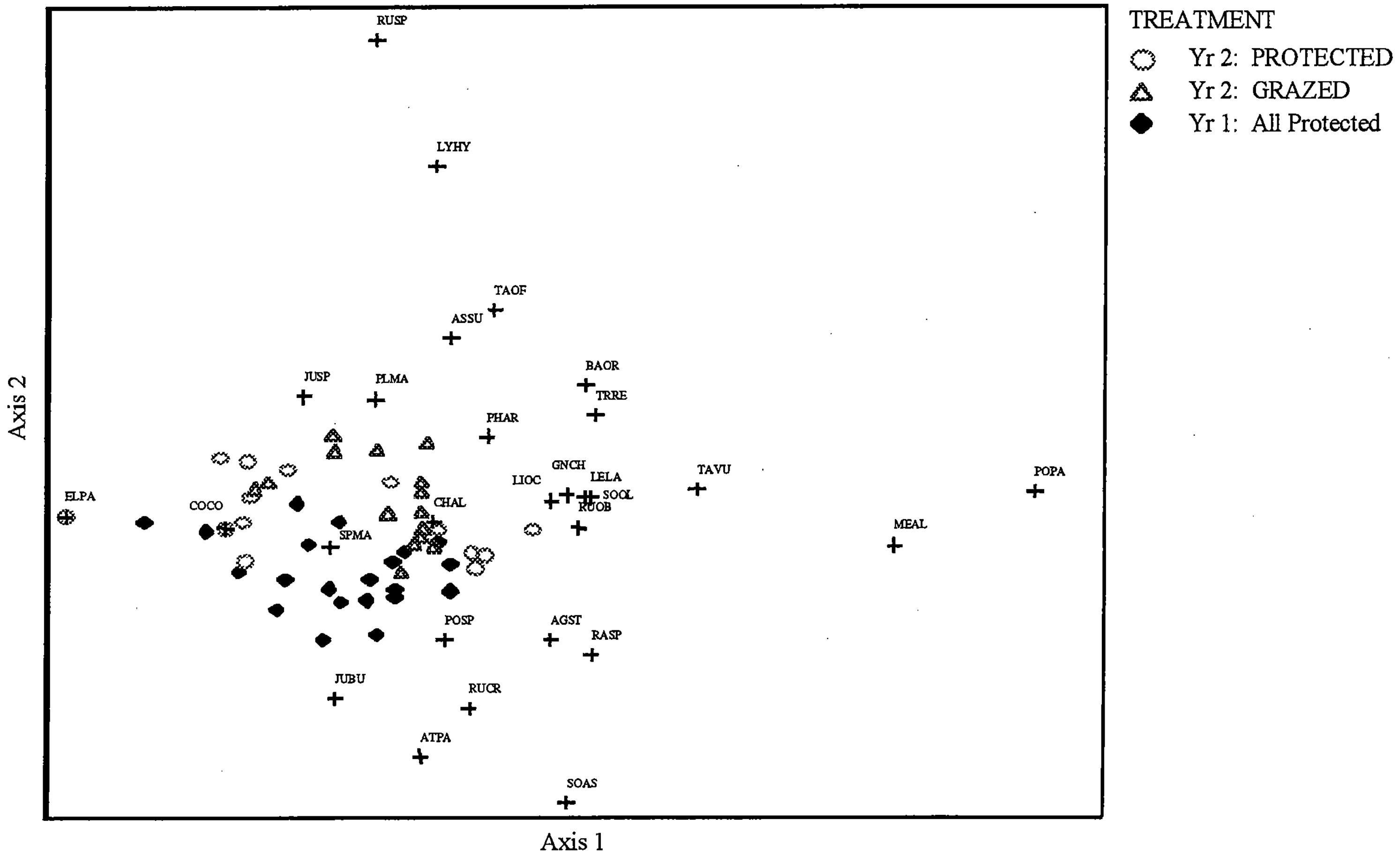


Figure 17. Detrended Correspondence Analysis (DCA) of volunteer species present in all experimental plots, including Year 1 plots (all protected) and Year 2 plots (grazed and protected). Species codes are defined in Table IV. Eigenvalues (λ), which indicate the degree to which an axis accounts for variation in the data, were 0.237 for Axis 1 and 0.138 for Axis 2. DCA was performed without SODU, an outlier.

CHAPTER 4: DISCUSSION

Goose Behavior

Although the visible impact of springtime grazing on the site was considerable, goose use did not seem to be of heavy intensity when quantified: 2.91 geese on site during daylight hours, 3% daylight hours grazing on *C. lyngbyei,* 0.0864 geese day^{-1} grazing on *C. lyngbyei*, and 0.000576 geese day^{-1} m^{-2} of available *C. lyngbyei.* The estimate of daylight hours (14%) that Canada geese spent feeding in general while on site is considerably lower than daytime percentages determined by other investigators for other subspecies of Canada geese. Stabins (1996) found that Aleutian Canada geese spent 53% of daylight hours feeding during the nonbreeding season in California, and Ballard and Tacha (1995) found that wintering Canada geese spent 60% of their diurnal time foraging in sorghum fields in Texas between October and February. The goose observations of general grazing and specific *C. lyngbyei* grazing may therefore be underestimates. The scanning technique tends to underestimate behaviors of short duration (Altmann, 1973), but grazing behavior frequently lasted for several minutes at a time and Stabins (1996) used the same technique. Also, there was some observer effect in this study that could have caused a decrease in grazing time: the site was relatively intimate and at least three times the observer arriving at 6 a.m. was detected by one or two geese, which stopped grazing and/or left the area shortly thereafter. Further, the timing of this study—*i.e.*, during the breeding season—may have resulted in a lower observed frequency of grazing. Seddon and Nudds (1994) found that breeding adults (subspecies maxima) with broods devoted more time to vigilance (*i.e.,* spent more time "alert") and less to feeding than adults without broods. In addition, the geese in this study do not migrate; and their seasonal feeding habits or patterns may be different from those populations that do migrate (C. Grue, pers. comm.).

It is also possible that early grazing on *C. lyngbyei* (*i.e.*, after exposure of the plants and before systematic observations began) at the site had such a great impact that the quantity of the vegetation decreased enough to make other sites more attractive or more efficient grazing habitats. Finally, the boundaries of the area designated as "on site" could affect the percentage of time that a particular behavior was observed. In this study, more than half of the "on site" area was an unvegetated area where geese regularly rested, preened and slept in small and large groups. If the area of observation had been delineated without this unvegetated resting area, the percentage of feeding time might have been higher than that reported in this study. Goose-use, however, was a function of geese in *C. lyngbyei* and the total number of observation intervals during the daylight hours and would therefore have remained the same regardless of site size.

The method developed for determining natural goose-use and grazing intensity in this study is apparently unique in the literature. The advantages to the approach of this study were that 1) typical levels of grazing would occur rather than a contrived level (e.g., exposure to grazing by goslings for 1 hour) and 2) the method might be a tool to predict the effect of grazing on *C. lyngbyei* at other restoration sites likely to be frequented by geese. In other grazing studies involving wild geese, grazing intensity has been measured by monitoring number of geese on a field (*i.e.,* geese acre^{-1} during the winter season) (Clark and Jarvis, 1978), the density of goose droppings (Bedard *et al.* 1986, Percival and Houston 1992), and the percentage of plant biomass removed (Smith and Odum 1981). In grazing studies involving captive geese, grazing intensity has been measured using a combination of pre-determined duration of grazing time within pens and the percent or amount of AG biomass removed (Hik and Jefferies 1990, Zellmer *et al.* 1993, Beaulieu *et al.* 1996, Mulder and Ruess 1998). In a study of the interactions among geese, arrowgrass, and its neighboring plants, Mulder and Ruess (1998) stated that correlations such as the following probably already exist: a heavily grazed plot may have a high percentage of bare ground and may contain a few small plants with high nutrient content. The authors (Mulder and Ruess 1998) caution that exposing plots to a natural range of grazing intensities complicates the process of separating causal factors such as size of forage species, species composition, and forage quality.

The apparent shift in goose diet from lots of *C. lyngbyei* during the spring to little, if any, during the summer may be explained by changes in foraging options available to geese as the growing season progresses. Seasonal changes in diet are well documented for geese and result from the animals' preference for plant material that is high in nitrogen and low in lignin, both of which are qualities of young plant material (Prins and Ydenberg 1985, Buchsbaum *et al.* 1986). In any stand of *C. lyngbyei* in the Pacific Northwest, geese would be expected to have the most impact in the spring because *C. lyngbyei* is one of the first plants to send up shoots at the beginning of the growing season (Gallagher and Kibby 1981, pers. obs.).

Initial Plant Survival

Although the difference between survival rates in the protected and exposed plots during the first growing season is extreme, the percentage of *C. lyngbyei* shoots surviving after exposure to goose herbivory during the first growing season is a conservative estimate: the 1% of the shoots recorded as surviving in the exposed plots were, in every case, at the edges of the plots and were probably vegetative shoots produced late in the growing season by protected plants in adjacent plots. For practical purposes, this value is better interpreted as 0 % and underscores the necessity of protecting plants following initial planting. In subsequent sampling of individual plants, an effort was made to sample plants at least 0.5 m from the edge of a plot in order to minimize the effect of this potentially complicating factor on the experiment.

Effect of Grazing on 1-Year-Old Plants

Protected plants were more productive and had greater vegetative reproduction than plants that were grazed for one growing season at a level of 0.000576 geese day^{-1} m^{-2}. There were significant decreases in all AG attributes measured in grazed plants, but these differences are not the most meaningful because the AG biomass is consumed during the treatment (grazing). Even if productivity over a season were equal in protected and grazed plants, AG biomass and maximum shoot height would be expected to be lower in grazed plants than in plants that had not been grazed.

Consequently, the differences between BG attributes in protected and grazed plants are better quantitative indicators of treatment effects. They are also more qualitatively important in terms of determining the fitness of *C. lyngbyei* plants: the BG biomass of the plant is the overwintering part of this perennial species and is the site of energy storage and vegetative reproduction (Gallagher and Kibby 1981; Kistritz *et al.* 1983). The significant differences between protected and grazed plants with regard to biomass and rhizome number suggest that the fitness of protected plants was greater than that of grazed plants and that the second year of protection from grazing provided a significant benefit to newly established *C. lyngbyei* plants. In one of the few grazing studies that looked at BG biomass, Cargill and Jefferies (1984) found that there was no difference in this attribute between grazed and protected plots of *Carex subspathacea* and *Puccinellia phyganodes* in an arctic salt marsh. In contrast, when the effect of multiple defoliations (*i.e.,* simulated grazing) was examined in two grasses in rangelands, Painter *et al.* (1989) found that BG biomass decreased in both historically grazed plots and a 50-yr-old grazing exclosure. Smith and Odum (1981) also found that grazing by snow geese caused a decrease in BG biomass of two grass and one sedge species in a coastal marsh. However, the definition of grazing in this study included grubbing, or direct removal of BG tissue, and is therefore less analogous to the goose activity explored in the current study.) In response to simulated grazing, Archer and Tieszen (1983) found that the Alaskan sedge *Eriophorum vaginatum* initially increased leaf production at the expense of BG structures: root initiation, depth of root penetration, and total root biomass were reduced. Although the number of new tillers was not affected by simulated grazing, the amount of biomass developed in the new tillers was lower in the clipped plants than in the unclipped plants.

TNC variances in the current study were large and the resulting power of the statistical test to detect a difference was small (0.15), but the lack of difference in percent TNC in protected and grazed plants suggests that energy reserves are stored at a consistent concentration in plants of a given age. BG biomass that is more developed should possess more reserves; and perhaps, the appropriate measure of fitness is the amount of BG biomass, or total amount of TNC, rather than the concentration of TNC (see similar assertion in Canham *et al.* 1999). The results of this study differ from those of Beaulieu *et al.* (1996), who found a significantly higher percent TNC in ungrazed plants than grazed plants of a sedge (*Eriophorum scheuchzeri*) and a trend toward higher percent TNC in an ungrazed grass (*Dupontia fisheri*). Steinmann and Brandle (1984) also found that cutting off shoots of bulrushes during the summer interrupted the storage of carbohydrates in rhizomes and jeopardized the health of the plant.

No work has yet been published on percent TNC for *C. lyngbyei*, but some work has been done on other members of the genus. Roseff and Bernard (1979) analyzed a New York population of *Carex lacustris* using a technique similar in principle to that of the current study. These authors (Roseff and Bernard 1979) found seasonal variations in BG TNC levels, which ranged from a low of 16.4% in young rhizomes in mid-summer to a high of 44.9% in late October. All BG tissue (old and new) increased in TNC to approximately the same magnitude by the end of the growing season, so the range of values for *C. lacustris* appears to be higher than the TNC levels determined for *C. lyngbyei* in the current study. The TNC levels in *C. lacustris* also dropped during the course of the winter to as low as 3.1 % in early December. Cizkova-Koncalova and Bauer (1993) found that roots of *C. gracilis* contained 9.2 ± 0.9 % TNC and rhizomes contained 9.2 ± 1.7 % per g of fresh weight in August, when TNC levels might be expected to be lower in the temperate Czech Republic. TNC levels dropped to as low as 5.3 ± 0.7 % in response to nitrogen-additions that increased the oxygen demand in the saturated growing conditions. These figures were for fresh material rather than dried material, however, and would be expected to be higher if dried biomass had been analyzed. Fonda and Bliss

(1966) found that rhizomes of the diminutive alpine *C. bigelowii* had total carbohydrate levels of 24 % (17 % starch) at the end of August (near the end of the growing season). This value is similar to that of the *C. lyngbyei* TNC levels of the first year and much higher than those of the second. *C. lyngbyei* at the restoration site may have a species-specific level of TNC, may have been sampled before the peak of TNC storage, or may have lost some TNC during prolonged storage. An examination of the TNC levels of plants sampled on a given day and refrigerated for different lengths of time before processing did not reveal a consistent relationship between storage time and TNC levels, however.

Grazing inhibited the production or retention of seed heads because they were observed on protected plants but not on grazed plants. Recruitment of new *C. lyngbyei* plants via seeds may occur within exclosures on the restoration site or in areas up- and downstream that prove favorable for a water-borne seed of this species. However, Ewing (1982 and pers. comm.) found very low viability of *C. lyngbyei* seed (mostly 0 % but up to 8 %) and did not see a seedling in three years at sites in the Skagit River delta, an area with salinities similar to those of the Duwamish site. Seedlings are not expected to do well around established adults that will shade them early in the season. Vegetative reproduction has been the focus of this study because it is the more relevant means of reproduction for this species.

Effect of Grazing on Established* C. lyngbyei *Stands

Although no statistically significant differences among plant attributes were found between protected and grazed plots of established stands of *C. lyngbyei*, the difference in BG biomass (p=0.061) is considered biologically meaningful, especially for purposes of natural resource management. An increase in BG biomass one year should benefit the stand in ensuing years. The established stands appear to be maintaining their productivity levels despite the grazing pressure (Cordell *et al.* 1999), but occasional years or periods of protection might provide a boost to plants in an herbivore-stressed environment such as the Duwamish.

Comparisons among Plants of Different Ages and Treatments

With respect to BG productivity and vegetative reproduction as expressed by number of shoots and number of rhizomes, 2-year-old plants (*i.e.,* plants sampled at the end of two growing seasons) that were protected for two growing seasons were more than twice as large as 1-year-old plants protected for one subsequent year. The less dramatic increase of AG over the same time-period may have been a result of the plants' condition when they were sampled. The 1-year-old plants were still green when collected in late October, and little if any AG biomass had decomposed or been exported. In the second growing season, many of the 2-year-old plants appeared to have peaked in August; and, by the time they were sampled in October, many had senesced and some export of the AG biomass had already occurred. The sharp drop in percent TNC in 2-year-old plants may be explained by the development of secondary growth tissue, which contains a lot of structural carbohydrates (Scott, pers. comm.). The BG samples from the second year seemed to have more woody material that required special grinding effort than did those from the first year. Incorporation of this material in the ground sample would result in a decrease in the concentration of TNC even if total energy reserves increased as biomass increased. Fonda and Bliss (1966) found that rhizomes of vegetative shoots of *C. bigelowii* had total carbohydrate levels that were two-fold higher than the levels in rhizomes of reproductive shoots. They speculated that the difference might result from higher respiratory demands during seed development in the reproductive shoots. Since many more *C. lyngbyei* seed heads were noted during the second growing season than the first season at the Duwamish restoration site, the drop in TNC levels plants may be caused by the production of reproductive stems early in the second year (before the grazed plants were exposed).

Plants grazed during the second growing season produced less than half of the AG biomass produced by the end of the first growing season. Although not statistically significant, BG biomass of these grazed plants also dropped in response to grazing (Δ=-4.1 ± 3.1 g, p=0.21), especially as indicated by the 95% confidence interval (-10.9, 2.7), which spans a decidedly negative range. This drop supports the assertion that plants should be protected for at least 2 years. Without a second year of protection, the plants did not appear to maintain an existing level of fitness and regressed, or fell below the fitness level established at the end of the first protected year. Continued exposure to grazing and further regressing could lead to irreversible degradation and, eventually, the loss of the plant. In a Dutch restoration effort in a former tideland, Clevering and Van Gulik (1997) found that *Scirpus lacustris*, a taller and more robust species than *C. lyngbyei*, completely disappeared after three seasons of grazing by mute swans (*Cygnus olor* L.).

Effect of Site Conditions on 1-Year-Old Plants

Plants in Blocks 2 and 3 were significantly larger than plants in Block 1 with respect to both AG biomass (12.19 ± 6.27, 10.91 ± 8.06, and 7.18±7.12 g, respectively; p=0.022) and BG biomass (16.32 ± 9.82, 13.38 ± 8.77, and 9.65 ± 8.50 g, respectively; p=0.010). Substrate, salinity and elevation data from Plot 33 (Block 3) and Plot 7 (Block 1) suggest that the plants are responding to different conditions in these portions of the site.

The two plots differ in their substrates, which were sampled at both ends of the plot and at the surface and at a depth of 35-40 cm (14-16 inches) (Brown *et al.* 1997). Plot 33 is located within the basin of the site (Figures 2 and 3) and is characterized by mixed soil texture (Figure 16; Brown *et al.* 1997). A silt fraction is found throughout the samples in Plot 33. Silty soils are generally associated with a favorable supply of nutrients and medium capacity to hold them (Brady and Weil 1996). In contrast, Plot 7 is located outside the basin in an area more exposed to river energy (Figures 2 and 3) and is characterized by a compacted silt-clay layer of approximately 5 cm (2 inches) over sand.

Although this plot contained more silt than the other in the surface layer, much of the root growth was below this silt/clay layer and in the sands. Sands are generally considered nutrient poor (Brady and Weil 1996, Zedler 1996). Ewing (1986) found that, at low salinities (<4 ppt), *C. lyngbyei* was more productive in clayey sites than sandy sites. The growth of larger plants in the well-mixed substrate of Plot 33 is consistent with the findings of these other studies.

Pore-water salinities differed slightly in the two plots. Salinity in Plot 33 averaged 6.6 ppt (measured approximately weekly from 2 August to 21 September 1997). Salinity was slightly higher in Plot 7, averaging 7.9 ppt over the same time period. The salinity range for *C. lyngbyei* in the Pacific Northwest is 0-20 ppt (Hutchinson, undated), and the average salinities at these plots are both at the lower end of that range. Ewing (1986) found that growth and standing crop of *C. lyngbyei* decreased as salinities increased, so even slight differences in average salinity could contribute to differences in growth. The growth of larger plants in the experimental plot with lower salinity is consistent with both Ewing's (1986) and Smythe's (1987) findings. Plot 33 was closer to the mouth of the adjacent stream than Plot 7, and this proximity to freshwater input may have resulted in lower pore-water salinities.

Finally, elevation differences (determined by relative elevation measured on an incoming tide) probably also contribute to differences in growth. Plot 33 is an average of 28.5 cm (11.2 inches) lower than Plot 7. Plants growing at lower elevations experience more inundation, and in this case probably lower salinities as a result. Plants at higher elevations may be subjected to less inundation and more evaporation (and evapotranspiration), and therefore higher salinities, during low tides on hot summer days. Elevation also affects competition from other species: *C. lyngbyei* plants growing at lower elevations had few naturally-recruiting competitors, whereas those plants growing at higher elevations had numerous other species competing for light, nutrients, etc.

(personal observation). *C. lyngbyei* emerges early in the growing season (February or March) and, in productive areas, can quickly grow tall enough to shade out other species.

In summary, the differences in *C. lyngbyei* growth at this restoration site may be attributed to differences in soil texture, pore-water salinity, and elevation. These differences underscore the value of planting *C. lyngbyei* in areas in which it is likely to be more productive. Management issues, such as the removal of recruiting species, are likely to be reduced in areas in which the planted species is doing well.

Appropriate Scale for Evaluating Impacts of Grazing

Belsky (1987) stated that some of the confusion regarding the impacts of grazing derives from the consideration of different scales—*i.e.,* the individual plant, the community, or the ecosystem. According to Belsky (1987), the individual plant is the appropriate scale; and she asks such questions as "Does the individual plant benefit from having some of its tissue removed?" Others evaluate grazing impacts based on the productivity (McNaughton 1979) or nutrient cycling (Ruess *et al.* 1989) of the ecosystem. With regard to restoration projects, evaluation of grazing-impacts on the scale of the individual plant is initially most appropriate. Species are re-introduced to the area in units of individual plants (or smaller units of bare-root shoots), the initial survival of which is essential to the success of the project. Therefore, the impact of grazing on the scale of the individual is most relevant. Since a particular plant community and ecosystem functions are often the ultimate goal of a restoration project, evaluation of impacts of grazing on a community level may eventually become appropriate, especially once a target species such as *C. lyngbyei* has had a chance to establish.

Grazing and the Landscape

The landscape context of the *C. lyngbyei* stands used for reference sites is different from the landscape context of the restoration site (Figure 3). This context may have an effect on the grazing pressure experienced by the reference sites. At low tides, the geese most often rested on exposed sand-flats “peninsulas” at the restoration site and just upriver and on the other side of a stream that bordered the restoration site on the southeastern (upstream) side. Geese have greater visibility in these areas than they do in areas closer to shore. These resting areas were adjacent to the restoration site, and the nearby *C. lyngbyei* plots were easily accessible.

Although the reference sites were located within 300 m of the restoration site, their place in the landscape was different from that of the restoration site and different from each other. The Boeing site is located upriver of the restoration site, in the last portion of the river that is relatively narrow before it widens to the Upper Turning Basin and the dredged reaches. Above this stand, the bank is covered with blackberry (*Rubus discolor)*. Waterward of this *C. lyngbyei* bench, the river bottom drops sharply. Exposed sand flats are limited to patches within the bench and a small area upriver and downriver of the stand. The river bank as been armored with riprap on both ends of the *C. lyngbyei* stand. In contrast, at low tide the Port of Seattle site (downstream of the restoration site) is adjacent to exposed sand and mudflats primarily on the upstream side. Geese were occasionally seen resting in this area but not with the frequency or in the numbers observed at the restoration site. So this reference site shares some of the landscape characteristics of the restoration site.

How might the landscape context affect grazing pressure exerted by Canada geese at these sites? The more resting area that is adjacent to the *C. lyngbyei* stands, the more grazing is likely to occur there; so the restoration site might have experienced more grazing than either of the reference sites. On the other hand, the more open a grazing area is, the more attractive it appears to be to geese. The reference site downriver might then have experienced higher levels of grazing than the restoration plots, which hugged the shoreline and were arranged in a convoluted pattern because of the contours of the excavated basin. Of the two reference sites, the downriver site might have experienced the greater grazing pressure per growing season. This stand was in fact the smaller and the less productive stand—but environmental factors (*e.g.*, salinity) may affect the *C. lyngbyei* cover and productivity more than differences in grazing pressure.

Initial plantings at the restoration site and the exposure of 1-year-old plants to grazing during the second growing season may have drawn geese away from the nearby established sites. This shift could have resulted in the reference stands' experiencing lower grazing pressures during the study seasons than in years prior to the experiment. Geese were regularly observed "making the rounds" on the river, *i.e.*, swimming from one location to another, except when goslings were too young to swim. If the geese have long been making the rounds on the river, the addition of vegetation at the restoration site may not have significantly re-directed goose grazing efforts.

Volunteer Plant Species and Primary Succession

The plants volunteering within the goose exclosures were unexpected contributors to the plant community and productivity of this restoration site. Their appearance highlights the important role of Canada geese in this system and the necessity of protecting plants—whether planted or volunteering—from grazing where revegetation efforts are attempted.

Volunteer species-assemblages differed depending on the site conditions, the year (first or second growing seasons), and the treatment (protected or grazed) of the experimental plot. Common to these factors is the size of the *C. lyngbyei* plants—*i.e.*, the plants were larger in more favorable portions of the site, during the second growing season, and in protected plots than they were otherwise. Larger *C. lyngbyei* would be expected to compete more effectively than smaller *C. lyngbyei* for nutrients and especially for light, a resource for which it successfully outcompetes other species in brackish marshes (Pidwirny 1989). The overall species-diversity and proportion of weedy species were lower in plots with large *C. lyngbyei* than they were in plots with small *C. lyngbyei*. Given the low proportion of weedy species (especially those that are annuals), the assemblage with lower diversity may prove to be longer lasting than the area with greater diversity but more weedy species. The plots with large *C. lyngbyei* were primarily in the portions of the site with well-mixed substrate (within the excavated cove) and/or were identified during the second growing season. A higher diversity of species, predominantly weedy species, became established in the plots with smaller *C. lyngbyei* plants. These plots included those on portions of the site with poorer conditions (*i.e.,* consolidated clay underlain by sand with low organic matter) and those that were grazed during the second growing season.

Grazing was an important factor in determining volunteer-plant assemblages: grazed plots throughout the site contained species assemblages that were more alike as a group than those found among protected plots. It appears that grazing superceded favorable site conditions (*i.e.,* substrate, elevation, and perhaps pore-water salinity) and resulted in species composition similar to that of poor quality portions of the site. In contrast, site conditions were the primary factor within protected plots. When conditions were favorable for *C. lyngbyei* growth, the portion of weedy pioneers was low.

Although the removal of volunteer species during the first growing season did not permit succession to be tracked over 2 years at this site, it is likely that planted *C. lyngbyei* would become and remain dominant at intertidal sites that are brackish and well oxygenated during the tidal flux and that have well-mixed substrate. In these areas, no volunteer species appears yet to pose an early threat to *C. lyngbyei* plants that are protected. Because of its height and biomass, *C. lyngbyei* has been shown to be a strong competitor for light in brackish marshes of the Pacific Northwest (Pidwirny 1989). By contrast, in less favorable areas, some degree of management of the recruits might be required in order for *C. lyngbyei* to remain the dominant species. For example, repeated removal of such rapid growers as *M. alba* and *L. latifolium* might be necessary. Also, a stand of *Typha augustifolia* has been encroaching on grazed experimental plots on the end of the site at which *C. lyngbyei* is smaller; and the *Typha* stand may become a threat to the protected *C. lyngbyei.* No planting of *C. lyngbyei* should be attempted in portions of a site that are not favorable because of the species's diminished ability to retain dominance. Repeated removal of weedy species to facilitate the dominance of particular species over large areas may be impractical or futile (Zedler 1996).

Despite the debate about the effects of grazing on plants, it is generally agreed that grazing causes changes in species composition within plant communities (Painter and Belsky 1993). Much of the work on community dynamics and geese has been conducted by Jefferies and co-workers (Jefferies *et al.* 1979, Bazely and Jefferies 1986, Hik *et al.* 1992) in arctic salt marshes grazed by lesser snow geese (*Anser caerulescens caerulescens*). These investigators found two floristic effects associated with geese: 1) delay of successional changes otherwise caused by geological instability and 2) maintenance of a community that diminished when the grazer was removed from the existing system. The lesser snow geese slowed—but did not stop or change the ultimate direction of—these larger scale successional changes by denuding depressional areas that were recolonized by a new species assemblage unlike the original (Jefferies *et al.* 1979, Hik *et al.* 1992). Additionally, by grubbing for storage organs at the edges of pools, the geese created terraces that—similarly—are recolonized by species other than the originals (Jefferies *et al.* 1979). In another study in portions of the same marsh, Bazely and Jefferies (1986) found that the composition of vegetation changed rapidly following exclusion of the geese. Over the course of 5 years, species diversity in exclosures more than doubled; dicotyledons increased in frequency; and the sedge *Carex subspathacea* replaced the grass *P. phyganodes* as the dominant graminoid. Hik *et al.* (1992) later characterized the system using a multiple-state model of community structure: a return to a previous level of grazing that initiates change does not cause the system to return to its original species composition.

Grazing and Restoration

The restoration context for grazing effects on plant communities is generally addressed in systems that have a long grazing history and from which the grazers are removed or excluded from experimental plots (Huffaker and Cooper 1995, Stohlgren *et al.* 1999). Conditions at the Turning Basin differ from these approaches in that the location of the restoration effort is a degraded urban area with very little intertidal vegetation remaining anywhere in the system. The restoration site itself had been filled for decades and was then excavated to reintroduce tidal influence, so there was no long-standing plant community that the Canada geese were affecting. Rather, in the second growing season, the geese were grazing 1-year-old *C. lyngbyei* and other young recruits—all recently established. With the exception of the planted *C. lyngbyei*, the geese were shaping the community in the grazed areas. Grazing resulted in a convergence of plant communities across site conditions that were otherwise (in protected areas) supporting a greater variety of assemblages. The species assemblages in the grazed experimental plots may therefore be a distinct state in a multi-state system of community structure (see Hik *et al.* 1992). The fate of these grazed assemblages following exclusion of geese would be of interest to restorationists.

A few studies have looked at the effects of grazing on primary succession in an area undergoing restoration. Joenje (1985) studied primary succession on desalinating sandflats in the Netherlands and found that grazing by migrating waterfowl (*Branta leucopsis, Anas penelope,* and *Crecca crecca*) favored annual species in the colonizing community and delayed by several years—but did not prevent—the development of a community dominated by perennial grasses. Early results on the degraded Duwamish do not indicate that succession under grazed conditions will result in similar development of a community dominated by perennials, but studies that follow the site over time may reveal a pattern similar to that found in The Netherlands. Such work (especially without any planted species) could begin to address questions concerning the necessity of planting desirable species at restoration sites in urban ecosystems with high goose populations. (See also discussion on "Successional Pathways.")

In a dune restoration and stabilization project in Louisiana, the substrate was relatively bare before being planted and then grazed (Hester *et al.* 1994). Nutria (*Myocastor coypus*) not only caused the loss of all planted dune grass (*Panicum amarum*) in grazed plots but also preferentially grazed this palatable species over two volunteering species (*Heterotheca subaxillaris* and *Spartina patens*). The selectivity of the herbivore has implications for community structure and ecosystem function in these systems since the desirable species may be the most difficult to establish. Canada geese have been shown to select food sources based primarily on palatability (*i.e.,* low content of phenolic compounds) and secondarily on nutrient content (Buchsbaum *et al.* 1984). How this preference might affect volunteering communities in Puget Sound both with and without the addition of planted *C. lyngbyei* would also be of interest to restorationists. *C. lyngbyei* appears to be quite palatable to Canada geese and is preferentially grazed by them, at least during the first half of the growing season (pers. obs.). Development of a strain of *C. lyngbyei* that is high in phenolics for use in restoration work might be a worthwhile pursuit for restoration horticulturists. Unfortunately, an elevated phenolic content might have a negative impact on other ecosystem functions performed by *C. lyngbyei.*

Successional Pathways

Restoration or creation of marshes is predicated on some assumptions: 1) the ecosystem has been altered in some way; 2) remnants of native communities may be used as reference points and target communities; and 3) native species have ecological importance. If a site has not been modified at all, allowing a plant community to develop through natural succession would be preferable to jump-starting or accelerating succession because of the other processes (*e.g.,* nutrient cycling by microbes) that would be expected to evolve along with the succession of plants. Systems such as the Duwamish River estuary, however, have been highly modified and degraded. In this study, weedy species (*sensu* Grime (1979) and *sensu* Parker and Reichard (1998)) have successfully volunteered at the site. In addition, no recruitment of *C. lyngbyei* seedlings was seen in 2 years of field work. As stated earlier, *C. lyngbyei* viability was found to be low in the Skagit River Delta; and no seedlings were found there in 3 years of field work (Ewing 1982). Given that native species are ecologically important (Zedler 1996) and no recruits of a target species were noted, planting of *C. lyngbyei* at restoration efforts under similar conditions in this system is recommended. This recommendation is consistent with Grime's (1979: 152) summary of approaches to areas with "dissected and depauperate floras" resulting from urbanization (among other factors such as intensive agriculture and forestry): "It seems inevitable that landscape reclamation and nature conservation must involve procedures whereby succession is accelerated and diversity created through deliberate introductions of under-dispersed plants."

This position is reinforced by Zedler (1996) in a summary of lessons learned from tidal wetland restoration on the Pacific Coast . Among the problems identified in these restoration projects was invasion by exotics due to dispersal (*e.g.,* deliberate or accidental introductions), disturbance (*e.g.,* of the substrate), temporary relief from environmental stress (*e.g.,* a lowering of salinity due to freshwater influence), and prolonged changes in the environment (*e.g.,* major hydrologic changes) (Zedler 1996). In addition, the more slowly the establishment of native wetland perennials proceeds, the more susceptible the areas may be to invasion by exotics (Zedler 1996). Planting may also be necessary to ensure establishment of target species because many marsh species may not germinate in salinities that they can tolerate as adults (Zedler 1996). Although the Duwamish restoration site was within 300 m of reference sites upstream and downstream, both of these sites were grazed and would be unlikely to produce many if any seeds that could form a seedbank in the system (pers. obs.). Protected *C. lyngbyei* produced seeds early in the growing season (in the spring), which is the same time that the unprotected plants were heavily grazed. As noted earlier, no seed heads were observed on plants that had been grazed at either the experimental or reference sites. Essentially, a trade-off is recommended—*i.e.,* sacrificing some things that might accompany the colonization of the site for jump-starting succession in order to increase the chances of successful establishment of a target plant community, which over the long term would support native insect communities and wildlife.

Carex lyngbyei ***and Canada Goose Populations on the Duwamish River***

Data on *C. lyngbyei* stands on the Duwamish River have been collected since 1993, when a monitoring program was initiated to establish baseline and reference conditions in the area before several restoration efforts were begun along the river (Cordell *et al.* 1994, Cordell *et al.* 1996, Cordell *et al.* 1999). The Boeing *C. lyngbyei* bench has been both a reference stand for the river-wide monitoring and for the current grazing study. All available data for the Boeing site from both of these studies were graphed against time to facilitate a search for trends (Figure 18). The stand was grazed in 1993 (personal observation) and protected during the 1994 season (Wenger 1995). In the current study (1997 season), the Boeing stand was divided into protected and grazed plots. The number of plots per treatment was low (n=3), but the difference in live BG biomass in protected and grazed plots (48.04 ± 19.17 g and 34.82 ± 19.62 g, respectively; p=0.061) was biologically meaningful if not statistically significant. Live BG biomass means from protected and grazed plots, which were available only in the 1993, 1994, and 1997 field seasons, were therefore plotted separately. Since no significant differences were found in other plant attributes in protected and grazed plots, data for these attributes were plotted without taking treatment in any year into account.

Canada goose populations in Seattle, as indicated by Christmas Bird Counts (CBC) (National Audubon Society 1989-1998), were plotted with the *C. lyngbyei* data against time (Figure 18). Conducted from mid-December to the first few days of January, the CBCs were plotted as the winter population of Canada geese for the new year because non-migratory Canada geese start grazing on *C. lyngbyei* as early as February in the Seattle area (pers. obs.). The annual variation in December/January counts would therefore be well correlated with the populations grazing on the plant in February, a month or so later. Several types of population control have been conducted in Seattle by

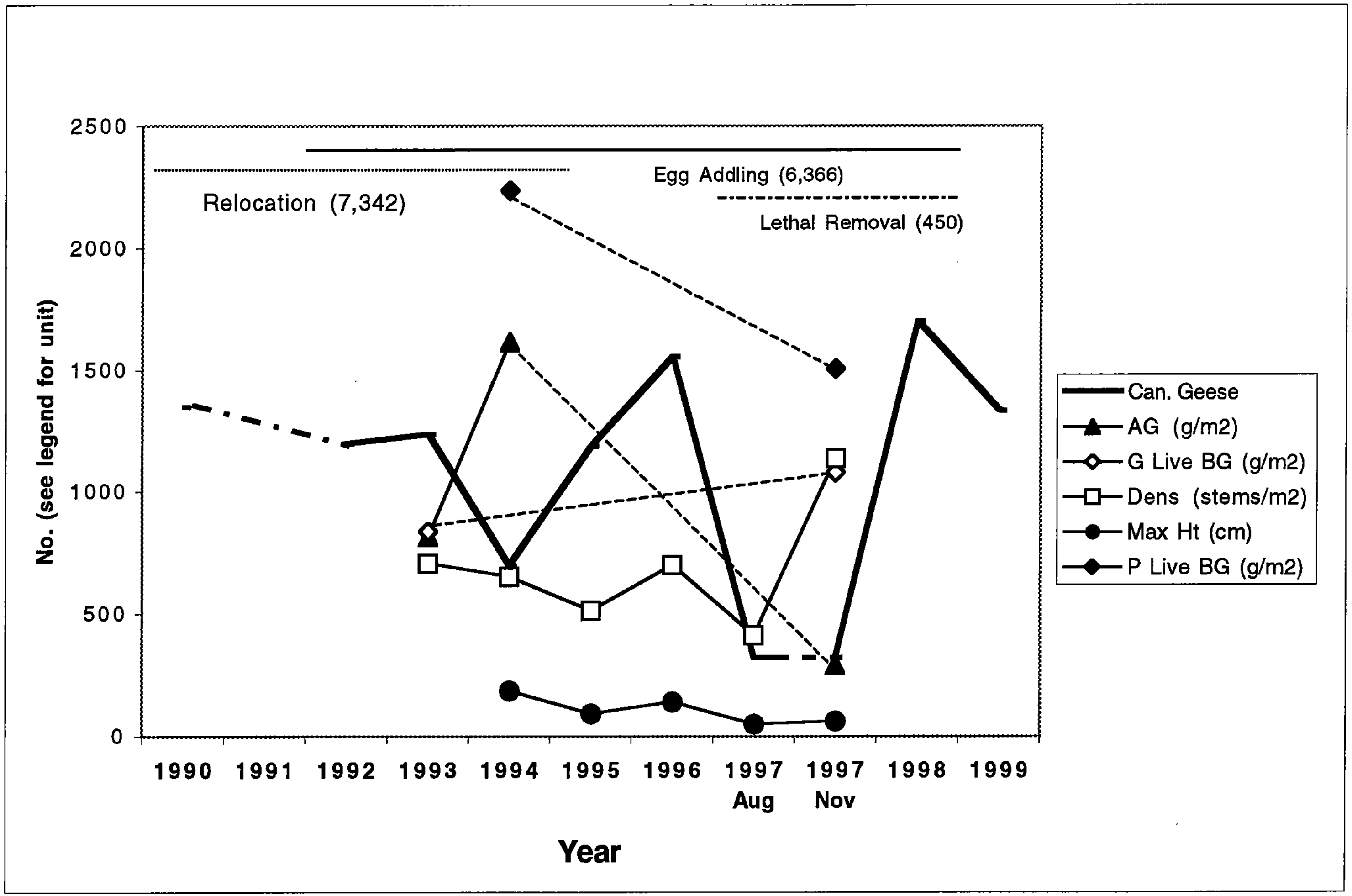


Figure 18. Canada goose (*Branta canadensis*) populations in Seattle and attributes of *Carex lyngbyei* at the Boeing reference site,on the Duwamish River, Seattle, Washington. Goose data is from the Christmas Bird Counts in Seattle sponsored by the National Audubon Society (http://birdsource.tc.cornell.edu/cbcdata/). *C. lyngbyei* data were compiled from the current study and Cordell *et al.* (1994, 1996, and 1999).

the Wildlife Services of the U.S. Dept. of Agriculture, which manages wildlife that cause crop damage (U.S. Dept. of Agriculture 1999). These control measures (shown at the top of Figure 18) coincide with temporary drops in the goose population.

The small amount of consistent *C. lyngbyei* data dictates caution in any interpretation, but the following trends deserve some discussion:

1) An inverse relationship exists between standing crop of AG biomass and goose populations—*i.e.*, it increased in years in which there was a decrease in the goose population and vice versa. The exception to this pattern is November 1997, when AG biomass would be expected to be low since much of it had senesced and been exported by that time of year. AG biomass measurements taken in August of the same year may have been higher than those recorded in early November.

2) Stem height at the site dropped by over 65% (from 185 cm to 59 cm) from 1994 to 1997. The stand was protected in 1994 during a study (Wenger 1995), so heights would be expected to be similar to that of stands in less degraded, low saline areas (*e.g.*, 182 cm on the Skagit River (Ewing 1986)). Plant fitness is difficult to assess using stem height because the act of grazing removes the attribute that is being measured, and the resulting stem height does not indicate the total production of the plant over the course of a growing season. On the other hand, the decrease in stem heights after 1994 may indicate an increase in grazing pressure coupled with a decrease in plant fitness over the years. Reference sites are intended to represent a target state for restoration sites. If this *C. lyngbyei* target state is not static but is in fact declining, the planted *C. lyngbyei* may have to be protected for more than 3 years to reach a state of resilience to grazing.

3) Stem densities observed in August trended down from 706 shoots m^{-2} (in 1993) to 411 shoots m^{-2} in 1997. The November 1997 increase is probably a result of the emergence

of a new cohort of overwintering shoots. A decrease in stem densities over the years can indicate a decrease in production and fitness of the stand, or it can indicate that a plant is producing fewer but more robust stems per m^2. Taken in combination with decreases in other attributes, it is more likely to indicate the former. More protection of planted *C. lyngbyei* would again be suggested.

4) Interpretation of trends in BG biomass is limited by the small number of years sampled. BG biomass of the grazed stand rose slightly from August 1993 to November 1997, although the difference is probably within the range of annual variability. In contrast, protected BG biomass dropped between 1994 and 1997, but it was always higher than BG biomass under grazed conditions. The grazed BG biomass might have increased less and the protected BG biomass might have dropped more precipitously if the 1997 samples had been taken in August, before translocation of nutrients and the concommitant increase in BG biomass at the end of the growing season (Kistritz *et al.* 1983). These data nevertheless reinforce the value of protecting existing grazed stands as a means of giving them a boost.

The limitations of this analysis are severe and several: more replicates and additions to a time-series would be necessary to determine if trends were sustained; and the different sampling times (*e.g.*, November in 1997 and August in other years) probably introduced seasonal variation to the data. Stem densities increase as fall approaches and a new cohort of overwintering shoots develops. Also, seasonal differences exist for the biomass measurements: a) a good portion of the standing crop of AG had already been exported by the time the November sampling was completed; and b) BG increases at the end of the growing season as AG material senesces and nutrients are translocated to the roots and rhizomes.

Goose data from the monitoring studies on the Duwamish (Cordell *et al.* 1999) were examined for other patterns. From Summer 1995 to Summer 1998, nine seasons of data were collected on birds observed at several sites along the Duwamish. The frequency with which Canada geese were observed at the sites was generally highest in spring (50-100% of the observation periods). Geese were also found to graze most intensively on *C. lyngbyei* during the spring in the current study at the Turning Basin restoration site. There were otherwise no consistent patterns—such as increasing frequency or seasonal variation—in the Duwamish bird data.

Despite the limitations, the data suggest that the native established stands of *C. lyngbyei* on the Duwamish River may not be withstanding the effects of grazing pressure. They also support the assertion that native stands may benefit from one or more growing seasons of protection from grazing by Canada geese.

Comparison to* Carex lyngbyei *Stands in the Pacific Northwest

AG development of protected *C. lyngbyei* at the Duwamish Turning Basin was comparable to those at other restoration sites in the Pacific Northwest. The high stem density combined with the high AG biomass in the protected Duwamish plots indicates that this *C. lyngbyei* is producing more shoots of larger size than are the other created wetlands. BG development, however, was far below the older sites. The created wetland at the Chehalis River is 6 years older than the Duwamish site (Simenstad *et al.* 1997, 2001), and BG biomass would be expected to accumulate over time. In addition, BG biomass was sampled to a depth of 20-25 cm in Chehalis, as opposed to 15 cm at the Duwamish site. The Gog-Le-Hi-Te plantings were 10 years older than the Duwamish plantings and would also be expected to have developed more BG; but the Puyallup River system is degraded in ways similar to the Duwamish (including goose populations), so the development of *C. lyngbyei* would be expected to be more limited than that of the Chehalis River.

Grazed *C. lyngbyei* at the restoration site was less developed than all restoration sites and established marshes in the Pacific Northwest, although its stem density was higher than that found in Gog-Le-Hi-Te's eighth growing season. The decline of *C. lyngbyei* at this point in Gog-Le-Hi-Te's history may have been due to encroachment of *T. latifolia* at higher elevations, grazing by Canada geese, extremely low river flows, and increased salinity intrusion (Simenstad and Thom, 1996). Similar stresses may await *C. lyngbyei* at the Upper Turning Basin on the Duwamish River, especially once protection from grazing is removed.

AG biomass and maximum heights of protected reference stands on the Duwamish were on the low end of the range among Pacific Northwest sites. This shortness may have been caused by some grazing that occurred before exclosures were installed at the end of March 1997. Early grazing may affect the plants' ability to produce leaves of normal (completely ungrazed) length. BG biomass and stem densities were comparable to other established sites. This similarity suggests that the amount of protection provided that year allowed BG reserves and capacity for vegetative reproduction of the Duwamish stands to remain at levels that have developed over many years.

AG biomass of grazed reference stands was very low, comparable with AG development in created marshes and mixed stands of established *C. lyngbyei* . By contrast, BG biomass in the grazed stands was lower than in the adjacent protected stands and most other established stands. This difference suggests that the current growing season's growth below ground is an important contribution to the total biomass (at least in the top 15 cm sampled). Maximum stem height was low, as would be expected for structures that are consumed during grazing. Medium high stem densities may be a remnant of past health or may be a reaction to grazing of the last few years.

Applications to Management

Trajectory of Newly Established C. lyngbyei *Plants*

The grazed established plants were used as the reference or "target condition" in assessing the success and future of the newly established *C. lyngbyei* plants. Duwamish River Monitoring efforts that immediately preceded this study indicated that the *C. lyngbyei* stands maintained their level of fitness through 1997 (as indicated by stem density and height, Cordell *et al.* 1999), so these stands seem to be self-sustaining under a "natural" level of grazing similar to that occurring at the restoration site. (But see discussion in "*C. lyngbyei* and Canada Goose Populations on the Duwamish River.")

C. lyngbyei plants protected for 2 years have developed between 58% and 80% of the fitness of the reference stands, as measured by BG biomass and indicators of vegetative reproduction. At this rate, a third year of protection might enable the new plants to approach the BG state of these stands and remain able to withstand some level of grazing thereafter. The recommendation of 3 years of protection is supported by the work of Clevering and Van Gulik (1997), who found that a 3-year-old stand of *S. lacustris* was able to recover from several grazing episodes during a single growing season. Simenstad and Thom (1996) found that planted stands of *C. lyngbyei* lagged 5 years behind established stands in terms of BG development, so more than 3 years of protection may be necessary for full trajectories to be achieved. Also, the biomass figures for the planted *C. lyngbyei* overestimate the biomass for the whole plot because of the gaps between the plants that amount to approximately 40% of area of the whole plot. The distribution of *C. lyngbyei* biomass (AG and BG) can be patchy in natural stands and gaps are not unusual (pers. obs.). But overestimation of the biomass in protected plots indicates that more than three years of protection is probably necessary for the restored area to match the reference stands in BG development. Further, if *C. lyngbyei* is determined to be on the decline in this system, then the premise that the reference stands represent a target state is in doubt and protection of more than 3 years would be indicated.

Is there an optimum size of C. lyngbyei *stand that is resilient when grazed?*

Restoration ecologists are concerned not only about how long planted species should be protected but also about what an optimum size of *C. lyngbyei* stands or other grazed species that can withstand some levels of grazing (Simenstad, pers. comm.). The exposed edges of established *C. lyngbyei* stands and some of the experimental plots tend to be grazed more frequently than interior portions or areas that are physically blocked (*e.g.*, by large woody debris) (pers. obs.). As the growing season progresses, a gradation of stem heights develops, from smaller at the edge of the stand to larger in the interior. Because *C. lyngbyei* is the first available intertidal vegetation of the year (as early as February) and because the overwintering shoots are not very tall (<10 cm), all unprotected *C. lyngbyei* shoots that have been examined in this area of the Duwamish are at least initially grazed by the resident populations of geese (pers. obs.). There may exist an optimum stand-size with enough "sacrifice" area around the edges that portions of the interior can "escape" grazing later in the season as geese become satiated or reach their limits of agility around taller stems.

The determination of an optimum area would draw on knowledge of existing established *C. lyngbyei* stands and of current goose populations in the area. As is typical for the *C. lyngbyei* stands along the highly modified, steep shorelines of the Duwamish River, the reference stands for this study were long and narrow, with a lot of waterward edge. One stand was 50 m by 4-5 m (~225 m^2), and the other was 20 m by 1-2 m (~30 m^2). In less disturbed areas of Washington, bands of *C. lyngbyei* along river banks such as the Chehalis are common (Simenstad, pers. comm.) and large expanses (meadows) are found in less disturbed deltas of Puget Sound, such as the Nisqually and Skagit River deltas (pers. obs.). According to the Wildlife Services of the U. S. Agriculture Department, there are 20,000-25,000 resident geese in urban Puget Sound (Hunt, 1999b). At least 4,000 of these center their activities on Lake Washington (Hunt, 1999a). For the purposes of this study, it is assumed that the population on the Duwamish River is less than that of Lake Washington. On any given day during the 18 months (two growing seasons) of this study, the number of geese at the restoration site—but not necessarily grazing—ranged from 1 to 36 (pers. obs.). Except when sitting on the nest and when the young goslings were unable to swim, the geese would travel to a number of sites along the river during the course of a day (pers. obs.).

Clevering and van Gulik (1997) stated that the feasibility of restoring *Scirpus maritimus* and *S. lacustris* at a particular site depends mostly on the grazing pressure exerted by waterfowl at that site. The authors (Clevering and van Gulik 1997) concluded that stands of >100 ha of *Scirpus* spp. would have to be planted in order to reach a balance with the numbers of greylag geese (*Anser anser*) and mute swans (*Cygnus olor*) in a large freshwater lake created from the diking of a river. It is unclear how Clevering and van Gulik (1997) calculated this area because neither waterfowl populations nor the conversion factors were stated. It is likely that Clevering and van Gulik (1997) based their figure on a ratio calculated by Loosjes (1974, as cited by Clevering and Gulik 1997) who stated that 200 geese ha^{-1} may graze on *S. maritimus* without causing harm, but only if each remaining tuber produced 40 new tubers. In a study that examined the effect of winter (30 October-24 April) grazing by dusky Canada geese (*Branta canadensis occidentalis*) on winter ryegrass in agricultural fields, Clark and Jarvis (1978) found that populations of similar, although slightly higher, magnitude could be supported without damaging the agricultural crops. (These numbers might be higher because the intensity units were goose-days ha^{-1}.) Clark and Jarvis (1978) reported no difference in a) percent cover on fields experiencing a grazing intensity that ranged from 237 to 550 goose-days ha^{-1} and b) seed yield on fields with a grazing intensity that ranged from 32 to 653 goose-days ha^{-1} during the winter season.

These grazing pressures are similar in magnitude to the grazing pressure experienced by *C. lyngbyei* at the Upper Turning Basin restoration site: when 0.0006 geese day $^{-1}$ m^{-2} of available *C. lyngbyei* is multiplied by 55 days (of observed grazing from 26 April to 19

June) and then converted to hectares (ha), the grazing intensity is expressed as 330 goose-days ha^{-1} of available *C. lyngbyei*. If the intensity of grazing is assumed to be the same beginning 6 April when the plots were first exposed to grazing (and before the systematic observation began), that number becomes 450 goose-days ha^{-1}.

This study has demonstrated that 1-year-old *C. lyngbyei* plants in plots that are 2.5 by 3.5-6 m at this restored site cannot withstand this level of grazing intensity. Judging from the fact that the smaller reference (established) stand seemed to be surviving if not thriving (even with a lot of waterward edge), it is possible that established stands at least 3 times the size of one experimental plot (*i.e.*, 30 m^2 rather than ~10 m^2) could withstand this level of grazing, or be considered resilient. One restoration approach might be to plant *C. lyngbyei* shoots in patches or bands of at least 30 m^2 and protect them from grazing for at least 3 years or until the plants develop a level of BG biomass comparable to that of established stands. Protection could then be remove with some confidence that the stand would survive. An optimum stand-size would be inseparable from a protection-plan. Minimization of the edge-to-area ratio could also increase the chances of growing a resilient stand.

Is C. lyngbyei *a wise choice for urban restoration sites?*

C. lyngbyei is clearly palatable to geese and is a preferred forage species for the first half of the growing season in the Duwamish River estuary. One might be prompted to ask if the species should be planted in areas frequented by Canada geese. If, through protection, it is allowed to develop levels of BG biomass comparable to those of established stands, the species may be reasonably well suited for re-introduction in areas in which grazing is likely to occur. Kotanen and Jefferies (1987) have shown that geese do not damage the basal meristem of a *Carex* species on which they graze. Further, the rhizomatous perennial habit of *C. lyngbyei* makes the sites of vegetative reproduction generally inaccessible to grazing (but not grubbing) geese. The roots and rhizomes of the plant appear to constitute the "ungrazable reserve biomass" that may be necessary for a stable grazing system to exist (Smith and Odum 1981).

Management Recommendations

This study provides evidence for a number of recommendations for management of restored or created wetlands in urban estuarine environments frequented by Canada geese.

1) Physically protect *C. lyngbyei* shoots in areas frequented by Canada geese in order to prevent total loss of plant material.

2) Protect plants for at least two growing seasons. Protection for only one growing season followed by exposure to grazing may result in serious, and possibly irreversible, degradation of *C. lyngbyei* plants. Protection for two growing seasons following planting may result in the *C. lyngbyei* plants' achieving almost 60 % of the BG biomass that is characteristic of established native stands that are grazed. A third year of protection may result in development of BG biomass nearly equal to that found in native stands of *C. lyngbyei*, at which point the plants may be able to withstand some level of grazing pressure.

3) Set up exclosures in native established stands of *C. lyngbyei* that are currently grazed by geese in order to provide a boost to the BG development of the stands.

4) Plant *C. lyngbyei* in conditions for which it is well suited so that it can compete successfully with volunteering plant species that may also be able to grow once grazing pressure is removed.

5) Monitor other plant species that may volunteer in a protected area at a restoration site, and remove aggressive species in areas in which it is clear that *C. lyngbyei* can do well.

Future Research

Several questions are suggested by this research and could form the basis for future research.

1) How much plant biomass are Canada geese removing from this estuarine ecosystem?

2) What is the growth trajectory of *C. lyngbyei*, and can a growth model be used to predict how much protection from grazing is required for new plants to reach the level of BG biomass development that is comparable to that of established stands?

3) Is there an optimum size of planted *C. lyngbyei* plot that, once developed, would contain some areas that could be "sacrificed" to grazing and other areas that would then effectively "escape" grazing?

4) What is a stable plant community(ies) at the restoration site?

5) Can a strain *C. lyngbyei* with higher phenolic compounds be developed, and would the phenolics disrupt any of the roles the plant plays in the ecosystem?

CHAPTER 5: CONCLUSIONS

Canada geese are extremely important herbivores in this area of the Duwamish River and affect not only restoration efforts conducted with planted material but also natural recruitment of other species. Survival of newly planted *C. lyngbyei* shoots at an intertidal restoration site frequented by Canada geese was dependent on protection from the geese in the form of a physical barrier. Grazing by Canada geese at the level (0.0006 geese day^{-1} m^{-2} available *C. lyngbyei*) experienced at the restoration site had a negative effect on the fitness of 1-year-old *C. lyngbyei* plants, as measured by BG biomass and vegetative reproduction. The percent of energy reserves (TNC) in BG tissue was not affected by grazing, although TNC in the second year dropped to half of the level of the first year. Plants grazed during the second growing season probably regressed to a fitness (as measured by BG biomass) that was lower than that established at the end of one growing season, thus highlighting the importance of a second year of protection. Protection for two growing seasons resulted in *C. lyngbyei* plants that were approximately 60% as developed as the grazed established stands that served as reference sites and self-sustaining target conditions. A third year of protection may enable the new plants to approach the target state. A less weedy, target plant community may also be achieved through several years of protection of *C. lyngbyei* planted in favorable conditions.

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Appendix A. Plot values for all measured attributes of grazed and protected*Carex lyngbyei* plants (three plants per plot) at a restoration site and for *C. lyngbyei* reference stands (one sample per plot) in the Duwamish River estuary, Seattle.

Table A.I. Data for *Carex lyngbyei* 1996 experimental plots at restoration site at the Upper Turning Basin on the Duwamish River, Seattle, Washington. Values are means of three 1-year-old plants per plot. Aboveground and belowground samples are 0.038 m^2 (22-cm diameter cores sampled to a depth of 15 cm). AG=aboveground; BG=belowground; TNC=total nonstructural carbohydrates. Blocks are separated by horizontal lines.

Plot (field #)	*AG biomass (g)*	*Max Sht Ht (cm)*	*No. Shoots*	*BG biomass (live) (g)*	*No. Rhizomes*	*% TNC*
1 (3)	5.4	56	8.7	6.0	6.7	17.1
2 (5)	4.9	52	11.3	4.5	8.7	15.1
3 (6)	2.0	56	7.3	3.5	6.7	NA
4 (9)	6.7	70	8.7	6.8	10.7	NA
5 (11)	17.1	92	9.7	12.0	15.3	NA
6 (14)	20.3	80	14.0	16.6	21.3	NA
7 (16)	9.3	76	7.7	7.9	12.0	NA
8 (18)	15.9	85	11.3	11.8	16.7	23.4
9 (20)	3.5	72	10.7	7.3	10.7	NA
10 (21)	14.0	85	8.3	10.2	12.7	24.2
11 (25)	19.6	90	13.7	17.3	17.3	24.2
12 (27)	21.7	86	18.0	17.3	21.3	17.8
13 (29)	8.9	70	8.3	8.2	13.0	19.2
14 (31)	21.7	99	17.0	15.5	21.3	26.3
15 (33)	4.0	61	6.7	3.9	12.0	23.5

Table A.II. Data for *Carex lyngbyei* 1997 experimental plots at restoration site at the Upper Turning Basin on the Duwamish River, Seattle, Washington. Values are means of three 2-year-old plants per plot. Aboveground and belowground samples are 0.038 m^2 (22-cm diameter cores sampled to a depth of 15 cm). AG=aboveground; BG=belowground; TNC=total nonstructural carbohydrates. Experimental blocks are separated by horizontal lines. *G* denotes sample from grazed plot; all others are from protected plots.

Plot (field #)	*AG biomass (g)*	*Max Sht Ht (cm)*	*No. Shoots*	*BG biomass (live) (g)*	*BG biomass (dead) (g)*	*BG live:dead*	*No. Rhizomes*	*% TNC*
1 (2) *G*	1.3	36	3.0	1.7	0.9	0.6	7.0	13.8
2 (3)	23.0	97	25.3	26.6	0.1	0.0	22.7	12.3
3 (4)	12.9	87	26.0	19.7	0.0	0.0	21.0	10.1
4 (5) *G*	3.7	40	17.3	7.2	0.4	0.2	9.7	8.3
5 (6) *G*	0.7	24	5.7	2.5	0.1	0.1	10.0	8.9
6 (7)	6.6	61	16.0	8.7	0.0	0.0	22.7	9.3
7 (8)	8.0	72	18.0	13.2	0.0	0.0	23.0	6.2
8 (9) *G*	1.8	45	9.3	2.9	0.1	0.0	12.0	5.3
9 (10) *G*	1.6	22	4.3	1.2	4.3	5.5	14.3	11.1
10 (11)	12.2	77	20.0	12.8	0.5	0.0	27.7	7.8
11 (13) *G*	11.3	57	25.7	13.1	0.6	0.1	47.7	9.2
12 (14) *G*	6.4	55	28.0	7.5	0.1	0.0	20.3	6.2
13 (15) *G*	7.5	56	19.7	9.7	0.1	0.0	19.7	11.4
14 (16)	15.0	79	22.0	18.9	0.2	0.0	31.3	13.1
15 (17) *G*	2.9	42	16.3	3.8	0.2	0.1	18.7	6.4
16 (18)	17.6	92	31.3	18.5	0.2	0.0	36.0	4.8
17 (19)	15.8	93	43.7	18.7	0.1	0.0	45.7	5.7
18 (20) *G*	5.9	45	13.7	8.6	0.0	0.0	15.7	13.2
19 (21)	21.7	120	40.7	33.0	0.5	0.0	42.3	13.7
20 (22)	17.8	112	30.7	31.3	0.5	0.0	23.0	7.5
21 (23) *G*	3.4	59	11.0	5.7	0.1	0.0	17.7	10.8
22 (24) *G*	6.7	75	13.0	5.4	0.2	0.1	17.3	10.2
23 (25)	21.6	107	36.3	25.4	0.2	0.0	52.0	9.7
24 (27) *G*	3.1	58	4.7	3.5	0.7	0.4	11.0	14.5
25 (28)	17.3	103	33.3	21.8	0.0	0.0	31.7	12.9
26 (29) *G*	2.5	42	7.3	4.9	0.3	0.1	25.3	7.3
27 (30)	12.4	114	23.0	12.5	0.1	0.0	33.0	5.9
28 (31)	20.2	119	29.7	17.8	0.2	0.0	38.3	4.7
29 (32) *G*	2.8	33	13.0	11.0	0.3	0.1	14.0	15.3
30 (33)	19.1	105	21.7	25.9	0.0	0.0	27.3	12.8

Table A.III. Data for experimental plots (grazed and protected) at established stands of *Carex lyngbyei* near the Upper Turning Basin on the Duwamish River, Seattle, Washington. Each value is a single sample per grazed or protected plot. Zero (0) values for live-to-dead ratios indicate values <0.05. Aboveground and belowground samples are 0.038 m^2 (22-cm diameter cores sampled to a depth of 15 cm). B=Boeing stand; S=Port of Seattle stand. Sites are separated by horizontal line and were treated as blocks in the analysis. AG=aboveground; BG=belowground; TNC=total nonstructural carbohydrates. *G* denotes sample from grazed plot; all others are from protected plots.

Plot	*AG biomass (g)*	*Max Sht Ht (cm)*	*No. Shoots*	*BG biomass (live) (g)*	*BG biomass (dead) (g)*	*BG live:dead*	*No. Rhizomes*
S-1 *G*	6.3	45	26	44.7	0.4	0.0	89
S-2	14.4	66	49	57.4	2.0	0.0	121
S-3 *G*	3.2	37	34	13.6	1.3	0.1	41
S-4	14.9	65	50	57.0	1.8	0.0	181
S-5 *G*	12.9	80	51	64.8	1.3	0.0	75
B-1 *G*	4.1	31	20	20.1	3.3	0.2	107
B-2	22.9	54	69	68.9	0.1	0.0	178
B-3 *G*	10.0	56	49	44.1	0.2	0.0	137
B-4	2.0	25	3	21.4	1.1	0.1	37
B-5 *G*	6.7	40	26	21.6	0.5	0.0	22
B-6	4.5	28	24	35.5	0.1	0.0	70