Devils Lake Aquatic Plant Propagule Bank Characterization

A project submitted in partial fulfillment of the requirements for the degree of
Master of Environmental Management by

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Summary

Aquatic vegetation problems have been reported in Devils Lake since the 1960's. Initially the problem was caused by increased production of native plants but was subsequently worsened by the introduction of nuisance exotic species that included *Myriophyllum. spicatum* and *Egeria densa*. In 1986, Devils Lake became the first lake in Oregon to legally stock triploid grass carp to control excess aquatic plant growth. After a supplemental stocking in 1993, aquatic plants were eliminated in the lake. The total eradication of macrophytes from Devils Lake was an undesirable consequence of grass carp stocking and has negatively impacted the ecosystem. The restoration of a native aquatic plant community would benefit water quality and wildlife. The objectives of this study were to provide information on the viability of the current seed/propagule bank in Devils Lake in the absence of grass carp and to characterize species composition and distribution. A two-part investigation was conducted to collect field and laboratory data. Metal cages were submersed into the lake to exclude grass carp and sampled for vegetation growth. Sediment cores were collected, exposed to a controlled environment and monitored for growth.

Ten macrophyte species and two charophytes were collected in the field from exclosure cages submersed in water depths of 0.3 to 2.44 m. Denser growth and greater diversity were observed in the cages submersed in the northern end of the lake. Two macrophytes and one charophyte species germinated (also collected in the field) in the laboratory in sediment cores collected from water depths of 0.60 to 2.50 m. The number of cores generating growth was greater in sites further north. Overall, four native macrophyte species were collected and it is likely that both charophytes are native. Nonnative species included *Myriophyllum aquaticum*, a highly invasive exotic and *Egeria densa* considered to be noxious.

While the propagule bank remains viable in Devils Lake, native species diversity is low and there continues to be a threat of re-invasion by nonnative species. Vegetative propagules of native and nonnative species may have been diminished by grass carp foraging, so revegetation will most likely come from seeds. The distribution of species around the lake will be dependent on a gradient of growing conditions within the lake.

Emergence of vegetation does not guarantee that successful aquatic macrophyte populations can become established in Devils Lake. Future management efforts should focus on developing an Integrated Aquatic Vegetation Management Plan that will help identify critical gaps in current knowledge and will set up measurable goals and objectives for long-term sustainable management. The plan should address current grass carp and post grass carp populations. Included in this plan should be a program to prevent nuisance plants from returning to the lake, effective nutrient management to avoid problems with future aquatic plant establishment, methods to enhance native fish habitat and facilitation of revegetation through the deliberate introduction of desirable native plants.

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1. Introduction

Aquatic plants are an important component of lake ecosystems. Submersed aquatic plants, often called macrophytes, function ecologically to dissipate wave energy, stabilize sediment, ameliorate water quality, and provide cover, habitat and forage for lake fauna (Westcott et al., 1997). Excessive aquatic plant biomass, however, can detrimentally impact lake ecosystems and can limit recreational use, degrade fisheries, and impede water movement (McKnight and Hepp, 1995; Maceina et al., 1992; Haag, 1983).

Typically, aquatic plant problems are caused by nonindigenous, invasive species referred to as weeds (Gibbons et al., 1999). Often, all that is needed for their proliferation is their introduction into a system with adequate substrate (*i.e.* shallow basin) (Gibbons et al., 1999; Rorslett et al., 1985). Aquatic weed control can be an arduous task and management approaches must integrate a variety of ecological factors to be successful. Effective aquatic plant management should begin with a basic understanding of the important relationship between phototrophic communities and resource availability.

Shallow lakes typically have two alternative phototrophic states: 1) turbid, phytoplankton dominated or 2) clear-water, macrophyte dominated (Scheffer, 1998; Sand-Jensen and Borum, 1983) . Phytoplankton usually dominates in well-mixed shallow systems with steep-sided slopes while macrophyte production can be greater in shallow lakes with gradually sloping basins (Sand-Jensen and Borum, 1991). A complex variety of processes regulates resource dynamics between phytoplankton and rooted aquatic plants and efforts to manage one community are intimately tied with efforts to manage the other.

Macrophyte establishment and growth can be influenced by factors such as light and nutrient availability, lake morphometry, herbivory, water chemistry and substrate type and availability (Barko et al, 1991; Lodge, 1991; Barko and Smart, 1986; Carpenter, 1981; Spence, 1967). Of these factors, competition for light is probably the most important factor balancing phototrophic communities (Sands-Jensen and Borum, 1991). Phytoplankton has an advantage in light utilization because it is suspended in the water column and reduces light availability to submersed phototrophic communities (Sands-Jensen and Borum, 1991).

Nutrient availability is also a primary factor influencing phototrophic production and can indirectly influence light availability (Barko et al, 1991; Sands-Jensen and Borum, 1991). Because phytoplankton get nutrients from the water column and rooted aquatic plants obtain most of their nutrients for growth from the sediment, fluctuations in nutrient concentrations affect them differently. Excess nutrient-loading can cause profuse growth of native macrophyte species (Gibbons et al., 1999; Harper, 1992) and increased nitrogen concentration in the sediment can boost rooted aquatic plant growth (Sutton and Dingler, 2000; Duarte and Kalff, 1988; Moeller et al., 1988; Anderson and Kalff, 1986). Excess nutrient-loading, however, is not a prerequisite for aquatic weed problems (Gibbons et al., 1999) and there is little evidence to suggest that reducing nutrient levels in a lake will control excess macrophyte growth (Barko et al., 1991; Nichols, 1991). Excess nutrient loading can increase phytoplankton production, thereby increasing turbidity which can ultimately eliminate submersed plant communities through shading (Asaeda et al., 2001; Sands-Jensen and Borum, 1991). Alternatively, phytoplankton biomass and turbidity can be decreased through nutrient reduction (Spencer and Ellis, 1998; Barko et al., 1991; Nichols, 1991; Wetzel, 1983) thereby, elevating aquatic plant production by increasing water clarity (Asaeda et al., 2001). Efforts to manage phototrophic communities through nutrient reduction should consider this central precept.

Numerous physical, mechanical, chemical and biological methods are available to control excessive aquatic macrophyte growth, all of which have benefits and liabilities. Physical and mechanical methods can have immediate effects and can be species specific but typically provide only small scale or short-term control (Gibbons et al., 1999). Chemical treatments, applied as part of a well-designed integrated aquatic vegetation management plan, can be selective, act rapidly and provide long-term control but plants may become resistant to herbicides and environmental and health concerns often restrict their application (Louda, 1997; Nichols, 1991). Concerns such as these have stimulated interest in biological control methods (biocontrol). Classical biocontrol is the practice of importing, and releasing for establishment, natural enemies to control an introduced species (Nichols, 1991). Typically, biocontrols can effectively reduce host-specific species over a large area but few agents are currently available to control problem aquatic plant growth (Gibbons et al., 1999; Nichols, 1991). Additionally, initial attempts at biocontrol introduction caused damaging environmental impacts but current rules governing biocontrol introduction have helped to reduce these impacts.

Among the biocontrols available for nuisance aquatic plants, triploid grass carp (*Ctenopharygodon idella*), provide a cost-effective means by which to reduce plant biomass (Maceina et al., 1992), however, they are not classified as a classical biocontrol because they are not host-specific. Triploid grass carp require low maintenance, can impact large areas (Gibbons et al., 1999) and have a low probability of reproducing which facilitates population management. Their effectiveness in controlling nuisance aquatic plant growth depends on a variety of factors including, stocking rates, water temperature, wind, weather, human disturbance, dissolved oxygen and nutrient levels in the water, the size and age of the fish and the type of vegetation available (Wiley et al., 1987). Because grass carp are generalist herbivores, widespread habitat destruction can occur following their stocking (McKnight and Hepp, 1995; Maceina et al., 1992). The most common consequence is aquatic macrophyte eradication, which can lead to increased phytoplankton abundance and decreased water clarity (Maceina et al., 1992; Richard and Small, 1984; Taylor et al., 1984). Other undesirable consequences include decreased abundance of plant dwelling and benthic invertebrates, and a decline in waterfowl populations (Nichols, 1991). Mitchell (1980) recommended that stocked grass carp be removed after a period of time if aquatic plant control, rather than eradication, is the desired outcome. Decisions on the number of fish to remove, however, should be based on stocking models that are highly data intensive, requiring detailed information on fish consumption, plant growth, and environmental variables (Swanson and Bergersen, 1988, Miller and Decell, 1984; Ewel and Fontaine, 1982).

Most grass carp stocking in the United States has occurred in southern areas but use of this biological control is expanding into northern areas. In Oregon, triploid grass carp are currently permitted for use only when complete aquatic plant eradication is the management objective or is an acceptable result of the management activity. Given the important functional role of aquatic plants in lake ecology, complete eradication is not the management objective in most of Oregon s public lakes.

Aquatic vegetation problems have been reported at Devils Lake since the 1960s. Earlier reports attributed this problem to increased nutrient loading from a sewage treatment plant that discharged partially treated waste into the lake, and increased sedimentation (Liao and Grant, 1983; CH2M Hill, 1993). Initially the problem was caused by increased production of native species but it was subsequently worsened by the introduction of nuisance exotic species, primarily *Myriophyllum spicatum* L. (Eurasian watermilfoil) (Liao and Grant, 1983; CH2M Hill, 1993) . By the early 1970s vegetation was so dense that most motor boats could no longer traverse large portions of the lake (CH2M Hill, 1993). In the early 1980s a feasibility study was conducted to define the problems and to assess restoration alternatives (Liao and Grant, 1983). In 1986, Devils Lake became the first site in Oregon to legally stock triploid grass carp to control excess aquatic plant growth (Bonar et al, 1993). The goal of the project was to reduce the aquatic plant cover from 55% to 20% over a period of five years (Thomas et al., 1990). Plant biovolume and diversity declined during the years following the stocking but plant biomass increased (Thomas et al., 1990). Additionally, *Egeria densa* Planchon (Brazilian elodea), another introduced invasive macrophyte, replaced *M. spicatum* as the dominant species in the lake (Thomas et al, 1990). Supplemental grass carp stocking occurred in 1993 to replace grass carp thought to be lost to predation or natural mortality (CH2M Hill, Inc., 1993). The supplemental stocking and/or year-to-year variation in macrophyte growth rates resulted in the elimination of all submersed vegetation by 1994 and the lake has been essentially devoid of submersed aquatic plants since.

There is a concern about the absence of aquatic macrophytes in the lake and the effects this will have on the ecosystem (Campbell 2000). Early monitoring to evaluate the consequences of grass carp stocking reported a decline in largemouth bass populations, unchanged or decreasing water quality, and a decline in waterfowl foraging (Thomas et al., 1990; CH2M Hill, Inc., 1993). While these problems have not been directly linked to the introduction of grass carp, they began to appear shortly after the stocking and have endured (Campbell, 2001; Sytsma, 1996; CH2M Hill, Inc., 1993). Additionally, phytoplankton blooms are appearing more frequently and persist for longer periods (Campbell, 2000). As recently as the fall of 2000, Devils Lake experienced a wide-spread algae bloom that lasted more than two months and reduced Secchi Disk depth to 0.5 m[1]. Revegetation of native aquatic macrophytes to Devils Lake would be beneficial to both water quality and wildlife. However, the ability of the existing seed/propagule bank to naturally revegetate the lake in the absence of grass carp is uncertain.

Submersed aquatic plants typically rely on asexual mechanisms of reproduction and have little recruitment from the seed bank (McFarland and Rogers, 1998; Kimber et al., 1995; Haag 1983). Sexual reproduction, usually accomplished by seed dispersal and germination, provides genetic variation and is considered to be advantageous in heterogeneous environments (Philbrick and Les, 1996). Generally, aquatic systems have greater chemical and thermal stability than terrestrial systems. (Philbrick and Les, 1996; McFarland and Rogers 1998). Genetic uniformity, perpetuated by asexual reproduction, is more effective in plants adapted to these relatively homogeneous systems (Philbrick and Les, 1996). Tubers, turions and fragmentation are common methods of asexual reproduction used by aquatic plants.

While seed production may only make a secondary contribution to aquatic plant communities in stable lake ecosystems, there is some debate over its role in restoring vegetation in highly degraded lakes. Seed production played an important role in the dispersal of *Vallisneria americana* in a lake that had experienced sever drought conditions for three years (McFarland and Roger, 1998). In a small (1.9-ha) lake that had been devegetated by grass carp, the seed bank provided a means for native macrophyte re-establishment, five years after the fish were removed (Tanner et al., 1990). Westcott et al. (1997) found that regeneration of a disturbed shoreline marsh from buried seeds was unlikely because the bulk of the seed bank existed in sediment too deep for germination to occur. de Winton and Clayton (1996) initially suggested that seed banks in degraded lakes have little revegetation capabilities but latter determined that, under the appropriate conditions, seed banks located in deeper sediment strata

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[1] Secchi Disc reading taken at Devils Lake on Sept. 9, 2000 by M. Waggy. Reading was taken off of marina dock in the northwestern arm of the lake near site 1.

can offer a potential mechanism to restore aquatic plant communities (de Winton et al., 2000). Although research continues in this area, this relationship remains undetermined. Ultimately, the ability of a seed and/or propagule bank to restore vegetation to a damaged ecosystem will rely on its persistence in the sediment, viability over time and appropriate germination cues.

The total elimination of macrophytes from Devils Lake has been an undesirable consequence of the grass carp stocking and has negatively impacted the ecosystem. In 1996, Sytsma (1996) determined that macrophytes will quickly become established if grass carp are removed. Following that study, Devils Lake Water Improvement District (DLWID) concluded that supplementary data regarding seed/propagule bank viability was needed before a revegetation program could be initiated. The purpose of this study was to inform management by providing information on the viability of the current seed/propagule bank in Devils Lake in the absence of grass carp herbivory and to characterize species composition and distribution. A two-part investigation was conducted to collect field and laboratory data. Carp exclosure cages were submersed in designated sites around the lake and left in their locations for four months. In late summer, vegetation growth within these exclosures was assessed. Sediment cores were also retrieved from select locations in the lake bed, exposed to a controlled environment and monitored for plant growth.

2. Study site description

Devils Lake is located 0.50 miles east of the Pacific Coast adjacent to Lincoln City, Oregon (Figure 1). It is 275-ha in area, has a mean depth of 3.0-m and a maximum depth of 6.7 m (Figure 2) (Johnson et al., 1985). The lake is considered to

Figure 1. Location of Devils Lake

be eutrophic and has been productive for at least the last 150 years (Eilers et al., 1993; Johnson et al., 1985). Residential vacation homes represent the primary development along the 14.7 km of shoreline but numerous year-round residents live there also. The lake is a popular recreational site for fishing, swimming and boating.

Figure 2. Bathymetric map of Devils Lake and sampling site locations

The Devils Lake watershed covers 31 km^2, is moderately to steeply sloped, and composed of igneous formations, marine terrace deposits, and alluvial deposits (Liao and Grant, 1983). Rock Creek and Thompson Creek drain into Devils Lake. The Rock Creek drainage is predominately undeveloped forest with a few scattered horse pastures, while the Thompson Creek drainage is used primarily for agriculture and residences (Campbell 2001, Liao and Grant, 1983). The southern portion of the lake drains into the Pacific Ocean by the 300 m long D River. A variety of nonnative game fish, primarily bass and rainbow trout, reside in Devils Lake and are currently competing with the native fishery that includes coho salmon (*Oncorhynchus kisutch*) and cutthroat trout (*Salmo clarki*) (Campbell, 2000; Buckman, 2001). In May 2000, the only aquatic macrophyte observed growing outside of the existing exclosures (Thomas et al., 1990; Sytsma, 1996) was *Nuphar luteum* ssp. *polysepalum*.

3. Methods

3.1 Field Sampling

Exclosures were established in the lake to evaluate seed/propagule germination in the absence of grass carp herbivory. Sixty exclosure cages were constructed out of 14 gauge welded steel wire with a mesh size of 7.62 cm x 5.08 cm. The mesh size allowed for the maximum amount of sunlight while still excluding grass carp (Figure 3). Cages were of two sizes to accommodate different water depths. Forty-four cages were 1m in diameter by 1m tall, while the remaining cages were 1m in diameter by 0.5 m tall. Rebar was attached to the bottom of the cages to keep them anchored at their locations.

Figure 3. Metal exclosure cage

Cages were transported by boat to five locations around Devils Lake during the first and third weeks of May 2000 (Figures 2 and 4). Sites were chosen for their accessibility, low possibility of disturbance, and known former macrophyte populations (Campbell, 2000). Twelve cages were submersed at each of the five sites (Figure 5). The first exclosure submersed at each site was placed randomly. To facilitate future cage locating efforts, the remaining cages were placed in a grid pattern that was approximately parallel to the shoreline with three rows of four cages each. GPS coordinates were obtained for individual cage locations (Appendix A). Ten percent of the metal exclosures were surveyed in June to determine if cages had remained secure.

In early September 2000, 13 exclosure cages were located by divers and sampled for vegetation (Appendix A). The remaining cages could not be located because a phytoplankton bloom reduced diver visibility (Secchi disk transparency 0 .5 m). A second survey of metal exclosures occurred in July 2001 and an additional 9 metal exclosures were located and sampled (Appendix A). Additional samples were obtained (in 2000) from nine previously installed plastic mesh exclosure cages that had been established to survey aquatic vegetation during earlier studies[2] (Figure 2).

Figure 4. Transporting cages by boat

Divers surveyed metal exclosure cages for plants. Cages were surveyed by lifting the cage and making three separate hand grabs into the exclosure and collecting any vegetation present. Vegetation was harvested as close to the sediment as possible (Figures 6 and 7). Plastic mesh exclosures were surveyed using a rake. Vegetation samples were placed in zip-lock plastic bags, labeled and refrigerated until species identification was completed. Species identification was based on a variety of vegetation keys (Borman et al., 1997; Spear-Cooke, 1997; Guard, 1995; Hitchcock and Cronquist, 1973; Steward and Gilkey, 1963; Fassett, 1957). Taxonomic nomenclature followed the United States Department of Agriculture s Integrated Taxonomic

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[2] See Thomas et al., 1990 and Sytsma, 1996 for installation dates and exact locations

Information System (ITIS, 2001). Herbarium specimens were prepared for some of the identified species (Appendix C).

Figure 5. Researcher submersing cage

Figure 6. Researcher sampling cage

3.2 Laboratory core analysis

Sediment samples were collected during the first and third weeks of May 2000. Eight cores were collected from various water depths (0.6 to 3.4 m) at each of the five sites where cages were installed (Appendix B). Additionally, two random samples were collected at two other locations (Figure 2). Shallow cores (10 cm diameter x 5 cm depth) were obtained by divers using a modified clam digger made from PVC pipe (Figures 8 and 9). Each core was transferred into a 0.5-L polyethylene container with as little disturbance as possible. Sediment too loose to core, was collected directly into the polyethylene containers. Seedlings of *Elatine triandra* were present in three of the samples collected. Containers were kept in a cooler on ice, transported to Portland State University (P.S.U.) and stored at 6 °C for up to five days. Bulk samples were collected at each site on September 7, 2000 and sent to P.S.U. s Geology lab for physical analysis.

Figure 7. Vegetation collected from metal exclosure at site 2

Figure 8. Coring device and collection container

Sediment samples were placed into four polyethylene pools with a surface area of 0.70 m^2 (Figure 10). Each pool contained cores from all five sites. Samples were submersed in dechlorinated tap water with an alkalinity between 260-430 μequivalents/L to a depth of 0.30 m. Water temperature was maintained at a mean of 20.6°C (±.80°C SD), close to the optimum conditions for aquatic macrophyte germination. (McFarland and Rogers, 1998; Westcott et al., 1997; Hartleb et al., 1993; Forsberg, 1965). Samples were exposed to a 14-hour photoperiod (reflecting length of summer light availability), at a mean light intensity of 35.25 (±6.54 SD) μEinstein m^{-2}s^{-2}. Pools were monitored weekly, evaporative water losses replenished, and algal growth skimmed off manually. Cores remained in the pools from 83 to 99 days and growth observations were recorded monthly. Species identification was completed in August 2000 using previously cited keys and ocular vegetation cover was estimated for each core (Appendix B). Herbarium specimens were prepared for each of the identified species (Appendix C).

Figure 9. Diver retrieving sediment core

4. Results

4.1 Field Sampling

Figure 10. Laboratory pools

Locating the exclosures in the lake proved extremely difficult. Twenty-two metal exclosures were located but only 19 were intact and still functioning as exclosures. Of the 19 metal exclosures, 13 contained vegetation (Table 1). Metal cages not recovered were either obscured by existing water transparency, displaced or destroyed. Seven of the plastic mesh exclosures surveyed contained vegetation. The two remaining mesh exclosures (2 and 6) had no vegetation because they had been damaged and invaded by fish.

4.1.1 Species collected in the field

Six species were collected from the metal exclosure cages. The same species plus an additional six were collected from the plastic mesh exclosures (Table 1, Appendix A). *Elatine triandra,* a nonnative macrophyte, was the most frequently collected species. While it was not collected in all of the exclosures it was observed at all five sites, forming large matts outside exclosures. The macroaglae *Nitella* spp., was the most frequently collected species in the exclosures. It was present in 7 metal and 3 plastic mesh exclosures. The most commonly collected native macrophyte species was *Potamogeton pusillus* ssp. *tenuissimus,* found in 4 metal and 3 plastic mesh exclosures (Table 1). In addition to *E. triandra*, four other nonnative species were collected from the exclosures, *Egeria densa*, *Myriophyllum aquaticum*, *Nymphaea odorata* and *Vallisneria americana*. *Egeria densa* is categorized as noxious in Oregon and *Nymphaea odorata* and *Myriophyllum aquaticum*, while not considered noxious, often interfere with recreation and can degrade water quality in Oregon lakes (ODA, 2002).

Table 1. Species collected from metal and plastic exclosures. (Column 3 = first number is site; bracketed number refers to number of cages).

Species	*Common Name*	*Site No.*	*No. of Plastic Exclosures*
Chara spp.	*muskgrass*	*1(1)*	*4,9*
Egeria densa[c]	*Brazilian waterweed*	*none*	*3*
Elatine triandra[b]	*waterwort*	*1(5), 2(1),3*,4*,5**	*8,9*
Myriophyllum aquaticum[b]	*Eurasian watermilfoil*	*none*	*1*
Najas flexilis[a]	*slendar naiad*	*1(3)*	*1,3,5,7*
Nitella spp.	*brittlewort*	*1(3),2(1),3(1),5(2)*	*4,5,9*
Nuphar luteum ssp. polysepalum[a]	*yellow water-lily*	*1*,4*,5**	*5*
Nymphaea odorata[b]	*white water-lily*	*1(1)*	*4,7,9*
Potamogeton pusillus ssp. tenuissimus[a]	*small pondweed*	*1(4)*	*3,4,9*
Potamogeton richardsonii[a]	*clasping-leaf pondweed*	*none*	*8*
Sagittaria spp.		*none*	*1*
Vallisneria americana[b]	*water celery*	*1(1), 2(2),5**	*1,4,7,8*

a - native; b- non-native; c - non-native, noxious ; * growth restricted to outside exclosures

4.1.2 Species distribution

Species were collected from cages at water depths of 0.3 to 2.44 m (Table 2). Because most of the cages were recovered from shallow depths, it was difficult to determine a relationship between species distribution and depth, however, the data provides some information on growing conditions at particular depths. Cages submersed in depths less than 1m produced little vegetation growth (Table 2). Sediments at this depth appeared to have higher concentrations of sand that could inhibit growth (Barko and Smart, 1986). All of the species collected in the field were observed growing in water depths between 1 and 1.5 m suggesting that optimal growing conditions exist at this water depth (Table 2). Most of these species were identified in the plastic mesh exclosures that had been established since 1996 so their existence may have more to do with longer periods of reduced disturbance rather than water depth requirements. Finally, the discovery of *V. americana* at depths greater than 2 m shows that macrophytes can still establish from the seed/propagule bank in the lake at this depth (Table 2).

Table 2. Depth distribution of species collected in field

Depth (m)	**Species List** (first two letters of genus, first two letters of species - see Table 1)											
	CHspp	EGDE	ELTR	MYAQ	NAFL	NIspp	NULU	NYOD	POPU	PORI	SAspp.	VAAM
0.3 -1			x									
1.0 - 1.5	x	x	x	x	x	x	x	x	x	x	x	x
1.6 - 2.0	x					x						
> 2.0												x

Species collected in the field varied for different sites (Table 1, Table 3). The two most evenly distributed species were the nonnative *E. triandra* and the macroalgae *Nitella* spp. The only portion of the lake they were not collected in was the midwest were there was only a plastic mesh exclosure sampled (Table 3). Had metal exclosure cages been established in this area, these species may have been collected there also. *Nuphar luteum* ssp. *polysepalum* was the most evenly distributed native macrophyte but it occurred primarily outside of the exclosures (Table 3). Three other native species, *Najas flexilis*, *P. pusillus* ssp. *tenuissimus* and *Potamogeton richardsonii* were collected from inside exclosures but had limited distributions throughout the lake (Table 3). Three of the 12 species collected were exclusive to the northwest corner of the lake (Table 3). This was the only location were the highly invasive, *M. aquaticum* and the noxious species *E. densa* were collected. The third species exclusive to the northwest area was an unidentified emergent *Sagittaria* spp.

Table 3. Location distribution of species collected in field

Location in Lake	**Species List** (first two letters of genus, first two letters of species - see Table 1)											
	CHspp	EGDE	ELTR	MYAQ	NAFL	NIspp	NULU	NYOD	POPU	PORI	SAspp.	VAAM
NW	x	x	x	x	x	x	x	x	x		x	x
NE			x			x						x
MIDW					x		x	x				x
MIDE			x			x				x		x
SW			x			x	x					x
SE	x		x			x	x	x	x			

NW = site1, plastic exclosures 1,2,3,4,5; NE= Site 2, plastic exclosure 6; MidW= plastic exclosure 7; MidE = Site 3, plastic exclosure 8; SW = Site 5; SE = Site 4, plastic exclosure 9

4.2 Laboratory core analysis

4.2.1. Species collected from cores

A total of four aquatic plant species, consisting of three rooted submersed macrophytes and one charophyte, emerged from 36 of the 41 sediment cores (Table 4, Appendix B). Most plant growth resulted from seed germination but some was produced vegetatively. Vegetative growth continued to appear throughout the duration of the trial, but seedling germination was completed by the end of week six. Seedlings were fragile and easily uprooted by any minor turbulence. Vegetative growth appeared in clusters and was not as easily disturbed.

Species identified in the cores were not equally represented (Table 4). *Elatine triandra* was the most common and widespread species, present in 78% of core samples. Stems typically emerged from shallow tufts of roots present in the sediment but numerous seedlings also germinated. The charophyte, *Nitella* spp. was the second most common species, emerging in 24% of the cores. *Potamogeton pusillus* ssp. *tenuissimus* and the unknown species were only represented by one seedling each.

Table 4. Species identified in the 41 sediment cores (Column 2 = first number represents site; bracketed number refers to number of cores)

Species	Sites	Overall % of Cores	Depth Core Collected from (m)
Elatine triandra [b]	1(8),2(7),3(8) , 4(5),5(3), R-1	78	0.60-3.35
Nitella spp.	1(1),2(4),3(2),5(3)	24	1.00-2.25
Potamogeton pusillus ssp. *tenuissimus* [a]	5(1) 1 seedling only	2	1.00
Unknowns dicot spp.	2(1) 1 seedling only	2	1.25

a - native; b- non-native; c - non-native, noxious
R = randomly collected core

4.2.2. *Species distribution*

Species occurrence was not notably associated with water depth or location of sediment core collection (Table 4). *Elatine triandra* occurred in cores collected at all depths while *Nitella* spp. occurred in cores collected at 1.0 m to 2.25 m. The other two species, *P. pusillus* ssp. *tenuissimus* and the unknown dicot, emerged from cores collect at 1 and 1.25 m respectively. The two most common species were collected from all five sites with one exception. *Nitella* spp. did not germinate in any of the cores collected from site 4.

Emergence of vegetation and ocular cover within the cores varied between sites. The number of cores generating growth was lower in sites further south (Figure 11). While almost all the cores collected from sites, 1, 2 and 3 contained vegetation, numerous cores from sites 4 and 5 had very low cover (< 5%) or no vegetation at all (Appendix B).

Figure 11. Number of cores with greater than 5% ocular vegetation cover.

4.3 Sediment characterization

Soils analysis revealed variability in sediment characteristics between sites (Figure 12). Silt concentrations was generally higher for sites further south, while clay concentrations were greater for northern sites. Sand concentrations also varied between sites but no clear north-south trend emerge with regards to distribution. While sampling cages, researchers observed higher concentrations of sand in water depths less than 1 m.

5. Discussion

5.1 Species richness

The results of the laboratory study suggest that there is a viable seed/propagule bank in the top

Figure 12. Breakdown of sediment particle size for each site

5 cm of sediment strata, but it lacks species richness. This condition is likely the result of reduced seed source availability in the surface sediment. The surface seed bank may lack species richness because aquatic macrophytes have been absent from the lake for a long time. Additionally, recent vegetation histories in the lake supported invasive species that did not set seed or that relied heavily on vegetative reproduction. Invasion by such species can modify seed banks and reduce the potential for re-establishment of diverse submersed floras (de Winton, 1996). Vegetative propagules in the surface sediment may have been depleted by the foraging efforts of grass carp, waterfowl and other fauna (Canfield, 2001; Stokes and Stokes, 1996; Sutton, 1996).

More species were collected in the field than from the sediment cores. Seed banks in sediment strata deeper than the top 5 cm may be responsible for the higher species richness in the field exclosures. Increased seed density with increasing sediment depth has been reported in de-vegetated lakes (de Winton et al., 2000; Westcott et al., 1997). However, germination of these seeds is only possible provided that deeper strata are exposed to favorable growing conditions (de Winton et al., 2000; Haag, 1983). Some aquatic plant seed banks possess attributes of longevity and prolonged dormancy and can wait for the appropriate germination cues (de Winton et al., 2000; McFarland and Roger, 1998; Leck and Graveline, 1979). These attributes offer a potential means for vegetation restoration in devegetated lakes (de Winton et al., 2000; Leck and Graveline, 1979). Finally, lakes containing invasive species and/or are de-vegetated, such as Devils Lake, can have significantly lower seed bank density and species richness, even in deeper strata, when compared with lakes that sustain native plants (de Winton et al., 2000).

5.2 Species distribution

Twelve species were collected from this study. Four of these species, *E. triandra*, *Nitella* spp., *N. luteum* ssp. *polysepalum,* and *V. americana,* were found in northern, middle, and southern sites (Table 3). In the absence of grass carp, these species are most likely to revegetate the lake first because of their widespread distribution. However, *E. triandra* and *N. luteum* ssp. *polysepalum* do not seem to be favored as a food source by carp, so it is likely that these species have already colonized all available habitat. *Chara* spp., *P. pusillus* ssp. *tenuissimus* and *N. odorata* were found in one northern and one southern location each, suggesting that these species could eventually spread throughout the lake in the absence of grass carp. Other species identified were more confined in their distribution. *Najas flexilis* was found on the northwestern and midwestern portions of the lake while *P. richardsonii* was only found on the mideastern side of the lake. These species are both natives and could eventually spread to other portions of the lake if not inhibited by grazing activities or out competed by nonnatives. Site one, in the northwestern corner of the lake contained the most site specific species. This is the only section of the lake were *E. densa* and *M. aquaticum* were found. Because these two species are invasive, it is likely they would spread rapidly to other section of the lake in the absence of grass carp.

Factors that will influence distribution of species and future dispersal in the absence of grass carp include, sediment characteristics and substrate availability, light and nutrient availability, competition, and natural and anthropogenic disturbances (*i.e.* wind, boating, fishing) (Lehmann *et al*, 1997; Gopal and Goel, 1993; Barko and Smart, 1986; Carpenter, 1981; Spense, 1967) . Results from this study revealed numerous examples of how these factors may influence vegetation establishment and distribution in Devils Lake. Core samples displayed various levels of growth between sites which may be related to variability in sediment characteristics. Site one exhibited more species diversity and increased growth per cage and core than other sites. Six of the seven cages located at site one had plants and all but one contained dense growth. Aquatic plants were also flourishing in the plastic mesh exclosures near site one. Understanding more about variability of habitat conditions around the lake will help to predict current and future distributional patterns of aquatic plants originating from the seed/propagule bank.

5.3 Native and Introduced Species Composition

Four native macrophyte species were collected in this study and it is likely that both charophytes are also indigenous. *Potamogeton pusillus* ssp. *tenuissimus*, was the only native macrophyte collected in the metal exclosure cages and sediment cores. The other native macrophyte species, *N. flexilis*, *N. luteum* ssp. *polysepalu*m, and *P. richardsonii*, were collected from previously established plastic mesh exclosures or were observed growing outside exclosures.

The seed bank also contains viable propagules from nonnative species. Of these nonnatives, only *E. densa* is considered to be noxious, however, *M. aquaticum* is highly invasive. These two species were found at only one site and were exclusive to the exclosures previously installed by Sytsma (1996). The existence of *E. densa* may be a result of its experimental introduction during earlier research efforts (Sytsma, 1996) and not from propagules deposited in the sediment prior to carp introduction. While nonnative species are undesirable, the low occurrence of noxious species in the seed/propagule bank is encouraging. Native species may have a greater chance of re-establishment if they have fewer noxious species to compete with in the propagule bank.

Indigenous species collected in this study will positively influence habitat values by contributing to the foraging habits of waterfowl, crustaceans, fish and invertebrates and will provide appropriate shelter for lake fauna (Knapton and Petrie, 1999; Borman et al., 1997; Stokes and Stokes, 1996; Elser et al., 1994; Coleman and Boag, 1987). While nonnative aquatic plants typically provide positive habitat values to lakes in their native ranges, their introduction to lakes outside of their region usually degrades ecosystems. The removal of all exotic species would be a noble goal to pursue, however, Devils Lake has been severely infested with numerous weedy species in the past and total eradication may not be feasible. Management strategies should address the most noxious and invasive species first as they will quickly damage the function and health of aquatic ecosystems and degrade beneficial uses (*i.e.*, boating, fishing, wildlife habitat etc.) in the absence of grass carp. Other less aggressive nonnative species should be watched closely in the event that they begin to show invasive tendencies and management should remain vigilant in detecting new nonnative invaders into the lake.

Of the native species collected in this study, only *Naja* spp., *N. luteum*, *Nitella* spp. and *P. pusillus* had been previously reported to inhabit Devils Lake (Table 5). Previous reports observed numerous other native species in Devils Lake, that were not present in this study (Table 5). All of the nonnatives identified from this study had been previously reported in Devils Lake (Table 5). While these reports may not be comprehensive or exact, they do represent the only historical record of aquatic plant populations in which to compare past verses present populations in Devils Lake.

5.4 The significance of the historic seed/propagule bank in future lake restoration

Existing vegetation may not reflect the true composition of the submersed seed bank (Kimber et al., 1995; Haag, 1983) . Remnant seed/propagules from earlier populations may require longer periods of dormancy, decreased disturbance or specific germination cues to emerge (de Winton et al., 2000; Kimber et al., 1995). Additionally, lakes lacking vegetation may have slower seedling germination response times than in lakes where seeds are being actively produced (de Winton et al., 2000). The appearance of *P. pusillus* ssp. *tenuissimus* suggests that given enough time and the appropriate conditions, historic species could re-establish themselves in Devils Lake. While this subspecies had not been previously reported to inhabit Devils Lake, *P. pusillus* (no subspecies) had been last reported in 1982 and it is possible they are the same. Additionally, greater diversity found in previously established plastic mesh exclosures also suggests that remnant seeds and propagules can germinate if given enough time and adequate germination requirements. However, it is uncertain if the historic seed/propagule bank will provide the lake with a native or non-native plant community since many of the dominant species recently inhabiting Devils Lake have been exotic (Table 5).

Of special concern would be the re-establishment of two noxious species that have dominated the lake in recent past, *E. densa* and *M. spicatum*. *Egeria densa*, is present in the lake and could be dispersed vegetatively but the risk of reinvasion from the seed bank is not a threat. Although *E. densa* produces seeds in its native range in South America, it only reproduces by fragmentation in other regions. This plant is dioecious and all populations outside its native range are male (Carter and Sytsma, in press). Seed set does occur in *M. spicatum*, however seedlings are rare and seeds buried under more than 2 cm of sediment seldom germinate (Hartleb et al., 1993).

Table 5. Vegetation history in Devils Lake

Scientific Name	Common Name	Year(s) Reported	Reference(s)
Brasenia schreberi [a]	water shield	1986	Thomas et al., 1989

Ceratophyllum demersum[a]	coontail	1946, 1982, 1986	Bonar et al., 1993; Thomas et al., 1989; Bierly & Walmstrom, 1982; Pitney 1949
Callitriche spp.	water starwort	1996	Sytsma 1996
Chara spp.	muskgrass	1982	CH2M Hill 1994
Egeria densa[c]	Brazillian waterweed	1986,1988, 1996*	Sytsma, 1996; CH2M Hill, 1994; Bonar et al., 1993; Thomas et al., 1989
Elatine triandra[b]	waterwort	1996	Sytsma 1996
Elodea canadensis[a]	common waterweed	1946, 1982, 1986	Bonar et al., 1993; Thomas et al., 1989; Bierly & Walmstrom, 1982; Pitney 1949
Myriophyllum aquaticum[b]	parrotfeather	1996	Sytsma 1996
Myriophyllum spicatum[c]	Eurasian watermilfoil	1986, 1996	Sytsma, 1996; CH2M Hill, 1994; Bonar et al., 1993; Thomas et al., 1989
Najas spp.	slender naiad	1996	Sytsma 1996
Nitella spp.	brittlewort	1996, 1982	Sytsma, 1996; Bierly & Walmstrom, 1982
Nuphar luteum[a]	yellow water-lily	1972	CH2M Hill 1994
Nymphaea odorata[b]	white water-lily	1982 (photo)	CH2M Hill 1994
Potamogeton pectinatus[b]	sago pondweed	1982, 1996*	Sytsma, 1996; CH2M Hill, 1994
Potamogeton pusillus ssp. tenuissimus[a]	small pondweed	1946, 1982	Bierly & Walmstrom, 1982; Pitney, 1949
Potamogeton robbinsii[a]	fern pondweed	1982	CH2M Hill, 1994; Bierly & Walmstrom, 1982
Potamogeton zosteriformis[a]	flat-stem pondweed	1986	Bonar et al., 1993; Thomas et al, 1989
Utricularia vulgaris[a]	bladderwort	1983	Bierly & Walmstrom, 1982
Vallisneria americana[b]	wild celery	1982, 1986, 1996*	Sytsma, 1996; CH2M Hill, 1994; Bonar et al., 1993; Thomas et al., 1989

a - native; b- non-native; c - non-native, noxious;

* species observed in this year may have been a result of experimental introduction

6. Conclusions

The seed/propagule bank in Devils Lake remains viable and will assist in the revegetation of aquatic plants in the absence of grass carp but the process will be slow. Initially, species richness may be low but could increase over time. Vegetation establishment and distribution of species around the lake may be dependent on a gradient of growing conditions within the lake. In the absence of a control, most of the species identified in this study could eventually spread throughout the lake. Native plants will revegetate but there remains a risk of reinvasion by problem-causing nonnative species like*, E. densa, M. aquaticum* and *N. odorata*. Vegetative propagules of native and nonnative species in the remainder of the lake may have been diminished by foraging efforts, so revegetation will most likely come from seeds. Furthermore, recruitment of viable seeds will be primarily from sediment depths greater than 5 cm provided that seeds are exposed to adequate germination cues.

Emergence of vegetation does not guarantee that successful aquatic macrophyte populations can become established. Low light levels resulting from increased turbidity from abiotic and biotic sources, high rates of sedimentation and natural and anthropogenic disturbances will influence the revegetation of Devils Lake. Restoration of the aquatic plant community in Devils Lake will be supported by supplemental knowledge on seedling germination requirements, seed/propagule bank density, depth and viability, variability of growing conditions, and emergent plant mortality rates.

7. Recommendations

7.1 *Develop an integrated aquatic vegetation management plan (IAVMP)*

If it is the goal of DLWID to restore a stable, diverse, aquatic plant community containing high percentages of desirable native species, the first step should be to establish a IAVMP. An IAVMP will help identify critical gaps in current knowledge and will set up measurable goals and objectives for long-term sustainable management. Choosing an effective, rational, and environmentally sensitive course of action in the face of competing questions, interests and solutions should be the ultimate goal of the IAVMP. The Plan should include prevention, survey and detection, and management elements that will address current grass carp populations and post-carp management.

Because aquatic plant growth and management is influenced by other activities in and around the lake, the IAVMP should be implemented as part of a broader lake management plan. Furthermore, components of an IAVMP are inherently linked and must be implemented collectively rather than in a piecemeal manner. Failure to fully implement an integrated management plan can result in failure of the management effort (Shesthra and Sytsma, 2001).

7.1.1 Grass carp populations

The seed/propugle bank in Devils Lake will not be able to revegetate the lake with the existing grass carp population. Grass carp populations may begin to rapidly decline as soon as the 1986 stocked fish begin to suffer age-related mortality but that may not be for numerous years. Predictions about the short lifespan of grass carp are proving to be false. In warm climates grass carp do not die off in any appreciable amounts for at least 20-25 years (Canfield, 2001). Although the grass carp population will decrease as the initially stocked fish die, the supplementally stocked fish may be capable of maintaining the current level of control given the low plant productivity in the lake. Canfield (2001) concluded that only total elimination of grass carp from a system will allow aquatic plant communities to return because individual grass carp consume more as their numbers decrease. Thus, grass carp could continue to control vegetation growth in the lake for at least another 10 years. Therefore, the DLWID likely has time to plan for post-carp vegetation management without the pressures that result from an existing weed infestation. Any attempts to remove grass carp should be done as a part of an IAVMP to avoid reinfestation by noxious weeds. Active removal, however, may not be plausible because there are currently no efficient and practical methods existing to eliminate triploid grass carp from large lakes (Canfield, 2001; Mallison et al., 1995; Nichols, 1991).

7.1.2 Begin a formal prevention program

The re-establishment of nuisance aquatic plants will continue to be a threat in Devils Lake so it is important to begin a program immediately to prevent this from happening. As a first step, the exclosures in the northwestern arm of the lake, containing *E. densa*, *M. aquaticum* and *N. odorata* should be removed to permit grass carp to eradicate those populations before they spread throughout the lake. Secondly, a rigorous plan to prevent the introduction of weeds on boat trailers should be designed and implemented. Many other coastal lakes are infested with noxious species, such as *E. densa* and *M. spicatum,* and can pose a long-term reinfestation threat to Devils Lake. Signs, boat inspections and boat washing stations should be included in this plan.

The IAVMP should include a formal monitoring program designed to determine the existence of noxious submersed macrophytes in Devils Lake and in the watershed. Any noxious aquatic plant sightings within the lake should be investigated immediately. As a part of the program, specific procedural guidelines should be developed in the event that noxious plants re- invade and should include appropriate removal techniques and follow-up monitoring to ensure weed eradication. Control of aquatic weed populations in the watershed should be done prior to any active grass carp removal to reduce the likelihood of an infestation in the absence of the grass carp.

7.1.3 Nutrient loading and light availability

Positive changes have occurred at Devils Lake in response to recommendations made by researchers regarding nutrient loading (Liao and Grant, 1983; ODEQ, 1982). Workshops and programs have been initiated to educate the public on water quality issues. Sewer systems have been installed in some of the residential properties along the west shore. A county ordinance has been enacted to prevent erosion during construction. Regular water quality monitoring has been performed for the last five years and minor improvements have been made to the watershed. In spite of these efforts, excess nutrient availability continues to be a serious concern at Devils Lake (Campbell, 2001). Today however, equal concern is given to internal loading of nutrients as well as external sources. Nutrient control strategies in Devils Lake must now consider the reduction of nutrient levels to the lake from the watershed as well as the management of the existing high-nutrient state within the lake. High nutrient levels will effect all phototrophic communities including macrophytes, and should be addressed in the IAVMP.

Although algae blooms have increased in Devils Lake, current phytoplankton populations do not exclude macrophyte germination and growth. It is important that nutrient levels be controlled in the lake to avoid increased phytoplankton production and the reversal of this tendency. Greater turbidity resulting from increased phytoplankton abundance could inhibit establishment and growth of submersed phototrophic communities following grass carp removal or mortality (Asaeda etal., 2001; Sand-Jensen and Borum, 1991; Rorslett etal., 1986). However, nutrient reduction to control phytoplankton production could lead to excessive aquatic plant growth as a result of increased water clarity (Asaeda et al., 2001; Berger and Wells, 1999).

A number of local efforts to control aquatic weeds have demonstrated how water clarity can impact management strategies. Fairview Lake, in East Multnomah County at the headwaters of the Columbia Slough, is only about one-meter deep, but is free of aquatic weed problems because sediment resuspension by wind keeps water clarity too low for macrophyte establishment (Waggy et al., 1999). Conversely, phytoplankton abundance in the Columbia Slough, downstream from Fairview, was recently controlled by a manipulation of the hydraulic regime and nutrient load reduction (Berger and Wells, 1999). The enhanced water clarity in the Slough permitted establishment of aquatic vegetation that currently restricts water flow and causes flooding concerns. Thus, strategies included in the IAVMP to control nutrient loading must focus on its relationship with water clarity and macrophyte growth.

7.1.4 Prepare to assist in the revegetation of the lake bed.

Following grass carp eradication, the seed/propagule bank will assist in the natural revegetation of Devils Lake but restoration efforts should also facilitate this process. The intentional introduction of desirable species will assist in increasing native plant diversity, distributing desirable species throughout the lake and may suppress nuisance species (Smart et al., 1998; Nichols, 1991). Transplanting techniques have been successfully used to restore freshwater marshes, streams and lakes (Less, 1989; Cox, 1986) and methodologies have been identified to initiate such a plan (Moss et al., 1996; Nichols, 1991; Smart and Barko, 1985).

Successful revegetation should begin with the identification of desirable species for the habitat under consideration. Waggy (2000) identified a number of native species found in nearby Oregon coastal lakes that may act as potential candidates for introduction. Nichols (1991) proposed a number of consideration to be contemplated before any aquatic plant species is introduced into a lake and advised against selecting native species that exhibit invasive tendencies. Species that reproduce vegetatively will probably provide the simplest means for introduction if propagules from these species are available. Initial population establishment might be enhanced by the creation of a nursery in a quiet area of the lake. Individuals grown in the nursery could be distributed around the lake as their populations increase (Nichols, 1991). Submersed aquatic plant restoration is a relatively new concept and proper culturing, transplanting and establishment techniques are not well known for many native species so some experimentation may be necessary.

7.1. 5 Address Coho salmon habitat needs

There is reason to believe that native costal coho salmon populations are declining in Oregon. Recently they were added to the Endangered Species List but currently their listing is under review. Devils Lake is considered to be a favorable site for juvenile coho (Buckman, 2001; Campbell, 2001) which may translate into increased adult populations (Buckman 2001). Previous research at Devils Lake has emphasized habitat needs of the nonnative bass fishery while superficially addressing the habitat requirements of the native salmonid species (CH2M Hill, 1994; Thomas et al., 1989). Restoration efforts should now extend to the special habitat needs of the coho. It may be difficult, however, to define these needs because most habitat studies focusing on coho refer to stream and riparian ecosystems rather than lentic systems. Generally, aquatic plants could provide cover for salmon and invertebrate food sources (Adams et al., 1998; Blackwell and Juanes, 1998; Shirvell, 1990; Wilzbach, 1985; Harney and Norden, 1972) so it is likely that increased native plant density and diversity will benefit this fish.

7.2 Suggested Research

7.2.1 Perform additional soils analysis

Sediment characteristics will play a role in the establishment of a healthy aquatic macrophyte population in Devils Lake. The basic soils analysis done for this study determined a gradient of sediment characteristics in the lake and variability of sediment characteristic was observed within each sampling site. Data collected in the laboratory showed that this variability may influence the distribution of aquatic macrophytes in the lake Restoration efforts will be enhanced if more information is known about the sediments and how this gradient condition effects the distribution and growth of aquatic macrophytes in Devils Lake.

7.2.2 *Examine seed/propagule bank viability at deeper strata*

Sediment cores collected in depths greater than 5 cm should be examined to determine if seeds or vegetative propagules remain viable at deeper depths. Greater species diversity observed in the field versus laboratory results suggests that the seed bank remains viable in sediment depths greater than 5 cm for some species. de Winton and Clayton (2000) determined seed banks located in deep strata possess attributes of longevity and may only be waiting for appropriate germination cues to emerge. While those conditions may not exist today, future disturbance to the lake-bed might provide a means for these types of seeds to germinate. Seed/propagule count, relative viability of seeds, germination rates and species composition might also be evaluated. Further laboratory analysis could produce more accurate predictions on species composition and diversity in Devils Lake.

7.2.3 Establish additional grass carp exclosures

Additional grass carp exclosures should be established in the lake. The exclosures provide valuable information on the current status of the seed/propagule bank and allow prediction of vegetation response to grass carp removal. Furthermore, the exclosures provide foci for vegetative expansion of aquatic plants, which will likely be the most effective mechanism of plant community establishment. Improved methods of locating the exclosures using transect lines and the use of heavier gauge metal for cage building would facilitate the process.

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Appendix A

Metal Exclosure Location Data

Species key: ELTR = *Elatine triandra*, NAFL = *Najas flexilis*, Nisp= *Nitella spp.*, *NYOD =Nymphae odorata*, POPU = *Potamogeton pusillus ssp. tenuissimus*
* cage left in lake after surveyed
** Unidentifiable cage found in 2001 at this site (Site 3 had 2, Site 4 had 1)

Site 1

Cage #	GPS North	GPS West	Date Installed	Depth(m)	Buoy Color	Date Found	Species
1A	44 59.779'	123 59.664'	13-May-00	2.0	orange	not found	
1B*	44 59.790'	123 59.658'	13-May-00	1.8	orange/white	2-July-01	Chara spp.
1C*	44 59.802'	123 59.802'	13-May-00	1.9	orange	2-July-01	nothing
1D	44 59.803'	123 59.680'	13-May-00	2.2	unknown	not found	
1E	44 59.802'	123 59.648'	13-May-00	1.7	orange/white	not found	
1F	44 59.816'	123 59.634'	13-May-00	1.1	green	not found	
1G	44 59.783'	123 59.647'	13-May-00	1.2	orange/white	12-Sept-00	POPU,NYOD,ElTR
1H	44 59.765'	123 59.664'	13-May-00	1.3	orange/white	not found	
1I*	unkown	unkown	13-May-00	1.0	orange/white	12-Sept-00	ELTR, NAFL,POPU,VAAM
1J*	unkown	unkown	13-May-00	1.0	orange/white	12-Sept-00	ELTR,NAFL,NIsp,POPU
1K*	unkown	unkown	13-May-00	1.0	orange/white	12-Sept-00	
1L*	unkown	unkown	13-May-00	1.1	none	12-Sept-00	ELTR, Nisp

Site 2

Cage #	GPS North	GPS West	Date Installed	Depth (m)	Buoy Color	Date Found	Species
2A	44 59.560'	123 59.033'	6-May-00	1.5	unknown	12-Sept-00	VAAM
2B	44 59.569'	123 59.029	6-May-00	.9	unknown	not found	
2C	44 59.578'	123 59.030'	6-May-00	1.7	unknown	not found	
2D*	44 59.561'	123 59.053'	6-May-00	2.4	unknown	2-July-01	VAAM
2E	unknown	unkown	6-May-00	2.2	unknown	not found	
2F	44 59.580	123 59.046'	6-May-00	2.9	unknown	not found	
2G	44 59.563'	123 59.32'	13-May-00	.5	unknown	12-Sept-00	nothing
2H	44 59.567'	123 59.32'	13-May-00	.5	unknown	12-Sept-00	ELTR
2I	44 59.571'	123 59.017'	13-May-00	.5	unknown	12-Sept-00	nothing
2J	44 59.574'	123 59.010'	13-May-00	.5	unknown	12-Sept-00	nothing
2K	44 59.590'	123 59.45'	13-May-00	3.0	orange/white	not found	
2L*	44 59.45'	123 59.45'	13-May-00	1.6	orange/white	2-July-01	NIsp.

Site 3**

Cage #	GPS North	GPS West	Date Istalled	Depth (m)	Buoy Color	Date Found	Species
3A	44 59.111'	123 59.013'	7-May-00	2.7	unknown	not found	
3B	44 59.123'	123 59.000'	7-May-00	2.0	orange	not found	
3C	44 59.135'	123 59.995'	7-May-00	2.4	green	not found	
3D	44 59.133'	123 59.010'	7-May-00	3.1	orange	not found	
3E	44 59.124'	123 59.019'	7-May-00	3.2	unknown	not found	
3F	44 59.104'	123 59.016'	7-May-00	2.9	unknown	not found	
3G	44 59.171'	123 58.988'	13-May-00	2.9	orange	not found	
3H	44 59.183'	123 58.982'	13-May-00	1.8	none	not found	
3I*	44 59.178'	123 58.977'	13-May-00	1.4	green	2-Jul-01	NIsp.
3J	44 59.147'	123 58.971'	13-May-00	1.6	orange	not found	
3K	44 59.134'	123 58.995'	13-May-00	1.5	green	not found	
3L	44 59.113'	123 59.007'	13-May-00	2.1	orange/white	not found	

Site 4**

Cage #	GPS North	GPS West	Date Installed	Depth (m)	Buoy Color	Date Found	Speices
4A	44 58.068'	124 00.027'	7-May-00	1.5	unknown	not found	
4B	44 58.064'	124 00.038'	7-May-00	1.6	unknown	not found	
4C	44 58.065'	124 00.052'	7-May-00	1.5	unknown	not found	
4D	44 58.100'	124 00.052	7-May-00	2.0	orange	not found	
4E	124 00.029'	124 00.029'	7-May-00	2.0	none	not found	
4F	Petterson's	House	7-May-00	1.1	unknown	12-Sept-00	nothing
4G	44 58.054'	124 00.006'	20-May-00	1.2	orange/white	not found	
4H	44 58/052'	124 00.027'	20-May-00	1.2	orange	not found	
4I	44 58.048'	124 00.053'	20-May-00	1.1	orange/white	not found	
4J	44 58.050'	124 00.070'	20-May-00	1.1	green	not found	
4K	44 58.067'	124 00.065'	20-May-00	1.5	orange/white	not found	
4L	44 58.082'	124 00.077'	20-May-00	1.9	orange/white	not found	

Site 5

Cage #	GPS North	GPS West	Date Installed	Depth (m)	Buoy Color	Date Found	Species
5A	44 58.124'	124 00.528'	7-May-00	2.2	milk jug	not found	
5B	44 58.119'	124 00.538'	7-May-00	2.2	orange/white	not found	
5C	44 58.112'	124 00.552'	7-May-00	2.1	milk jug	not found	
5D	44 58.130'	124 00.571'	7-May-00	1.9	milk jug	not found	
5E	44 58.134'	124 00.552'	7-May-00	2.0	orange	not found	
5F	44 58.138'	124 00.540'	7-May-00	2.1	orange/white	not found	
5G	44 58.143'	124 00.581'	20-May-00	1.3	green	not found	
5H*	44 58.146'	124 00.570'	20-May-00	1.4	green	12-Sept-00	NIsp
5I*	44 58.151'	124 00.549'	20-May-00	1.5	orange	12-Sept-00	nothing
5J	44 58.135'	124 00.590'	20-May-00	1.4	none	not found	
5K	44 58.122'	124 00.579'	20-May-00	1.8	unknown	2-July-01	NIsp
5L	44 58.108'	124 00.570'	20-May-00	2.1	unknown	not found	

Appendix B

Sediment Core Laboratory Data

Species key: ELTR = *Elatine triandra*, NIsp = *Nitella* spp. POPU= *Potamogeton pusillus* ssp. *tenuissimus*
* Soil to flocculent to collect with a core. Sample collected directly into the polyethylene container

Site 1

Core #	Approximate Depth Collected (m)	Date Collected	Pool #	Species	Ocular Cover Estimate (%)
1-1	1.25	20-May-00	4	ELTR	5
1-2	1.25	20-May-00	3	ELTR	80
1-3	1.25	20-May-00	3	ELTR	45
1-4	2.00	20-May-00	4	ELTR	70
1-5	2.00	20-May-00	3	ELTR	65
1-6	2.00	20-May-00	2	ELTR	15
1-7	1.00	20-May-00	1	ELTR	80
1-8	1.00	20-May-00	4	ELTR, NIsp	40

Site 2

Core #	Approximate Depth Collected (m)	Date Collected	Pool #	Species	Ocular Cover Estimate (%)
2-1	2.25	6-May-00	3	ELTR, NIsp	50
2-2	1.50	6-May-00	2	ELTR, NIsp	100
2-3	2.60	6-May-00	1	ELTR	80
2-4	3.00	6-May-00	4	ELTR	35
2-5	0.60	6-May-00	4	ELTR	75
2-6	1.25	6-May-00	3	Nisp, unknown	<5
2-7	1.00	6-May-00	2	ELTR, NIsp	25
2-8	1.00	6-May-00	1	ELTR	15

Site 3

Core #	Approximate Depth Collected (m)	Date Collected	Pool #	Species	Ocular Cover Estimate (%)
3-1	3.35	20-May-00	4	ELTR	35
3-2	1.50	20-May-00	4	ELTR	35
3-3	1.80	20-May-00	3	ELTR, NIsp	20
3-4	1.80	20-May-00	2	ELTR	45
3-5	1.80	20-May-00	1	ELTR	<5
3-6	3.35	20-May-00	1	ELTR	60
3-7	3.35	20-May-00	2	ELTR	20
3-8	1.50	20-May-00	3	ELTR, NIsp	35

Site 4

Core #	Approximate Depth Collected (m)	Date Collected	Pool #	Species	Ocular Cover Estimate (%)
4-1*	1.25	6-May-00	3	none	0
4-2*	1.25	6-May-00	2	none	0
4-3 *	1.50	6-May-00	1	ELTR	50
4-4 *	2.10	6-May-00	4	ELTR	20
4-5	1.00	6-May-00	4	ELTR	100
4-6	1.50	6-May-00	3	none	0
4-7 *	1.00	6-May-00	2	ELTR	90
4-8 *	1.00	6-May-00	1	ELTR	70

Site 5

Core #	Approximate Depth Collected (m)	Date Collected	Pool #	Species	Ocular Cover Estimates (%)
5-1	2.10	5-May-00	3	none	0
5-2	1.00	5-May-00	2	NIsp	35
5-3	1.00	5-May-00	1	POPU	<5
5-4 *	1.50	5-May-00	Lost	-----	
5-5	2.10	5-May-00	4	ELTR	<5
5-6	1.80	5-May-00	3	ELTR, NIsp	<5
5-7	2.10	5-May-00	2	NIsp	15
5-8 *	1.00	5-May-00	1	ELTR	20

Random

Core #	Approximate Depth Collected (m)	Date Collected	Pool #	Species	Ocular Cover Estimates (%)
R-1	0.75	5-May-00	2	ELTR	65
R-2	1.25	5-May-00	4	none	0

Appendix C

Herbarium of Portland State University
Biology Department

Collected from Exclosure Cages

Number	Name	Date
DL001F	*Myriophyllum aquaticum*	9/20/00
DL002F	*Egeria densa*	9/20/00
DL003F	*unknown*	9/20/00
DL004F	*Potamogeton pusillus ssp. tenuissimus*	9/21/00
DL005F	*Vallisneria americana*	9/20/00
DL006F	*Potamogeton richardsonii*	9/20/00

Collected from Core Samples

Number	Name	Date
DL001L	*Elatine triandra*	9/21/00
DL002L	*Nitella spp.*	9/21/00
DL003L	*Potamogeton pusillus ssp. tenuissimus*	9/21/00

Appendix D

Glossary

Abiotic - characterized by the absence of life.

Anthropogenic - pertaining to humans.

Asexual (Vegetative) Reproduction - Mode of reproduction in which offspring arise from a single parent. Tubers and turions are asexual propagules produced by aquatic plants.

Biocontrol - The use of parasites, predators, and pathogens to maintain other pest organism densities at tolerable levels. . Classical biocontrol is the importation and release of exotic agents, that are host-specific, with the expectation that the agents will become established and further releases will not be necessary.

Biomass - Total dry weight of all organisms in a particular population, sample, or area.

Biotic - pertaining to life.

Biovolume - Total dry size of all organisms in a particular population, sample, or area.

Charophyte - large rooted aquatic non-vascular plants (also see macroalgae).

Fragmentation - a form of vegetative reproduction, in which a small segment of a plant can grow into a new population.

Host-specific - A biocontrol that shows preference for only one targeted species.

Macroalgae - large rooted aquatic non-vascular plants.

Macrophyte - large rooted aquatic vascular plants. Can be floating or submersed.

Phototrophic - The capability of plants to convert sunlight to chemical energy (photosynthesis).

Phytoplankton - free floating photosynthetic single celled (typically) organisms suspended in bodies of water.

Propagule - a reproductive bud or shoot typically produced by asexual reproduction.

Species Richness - The number of species in a region, site or sample.