Long-Term Monitoring of Vegetation Expansion and Trials In the Dust Control Treatment Areas of Revelstoke Reach – Upper Arrow Reservoir

March 2002

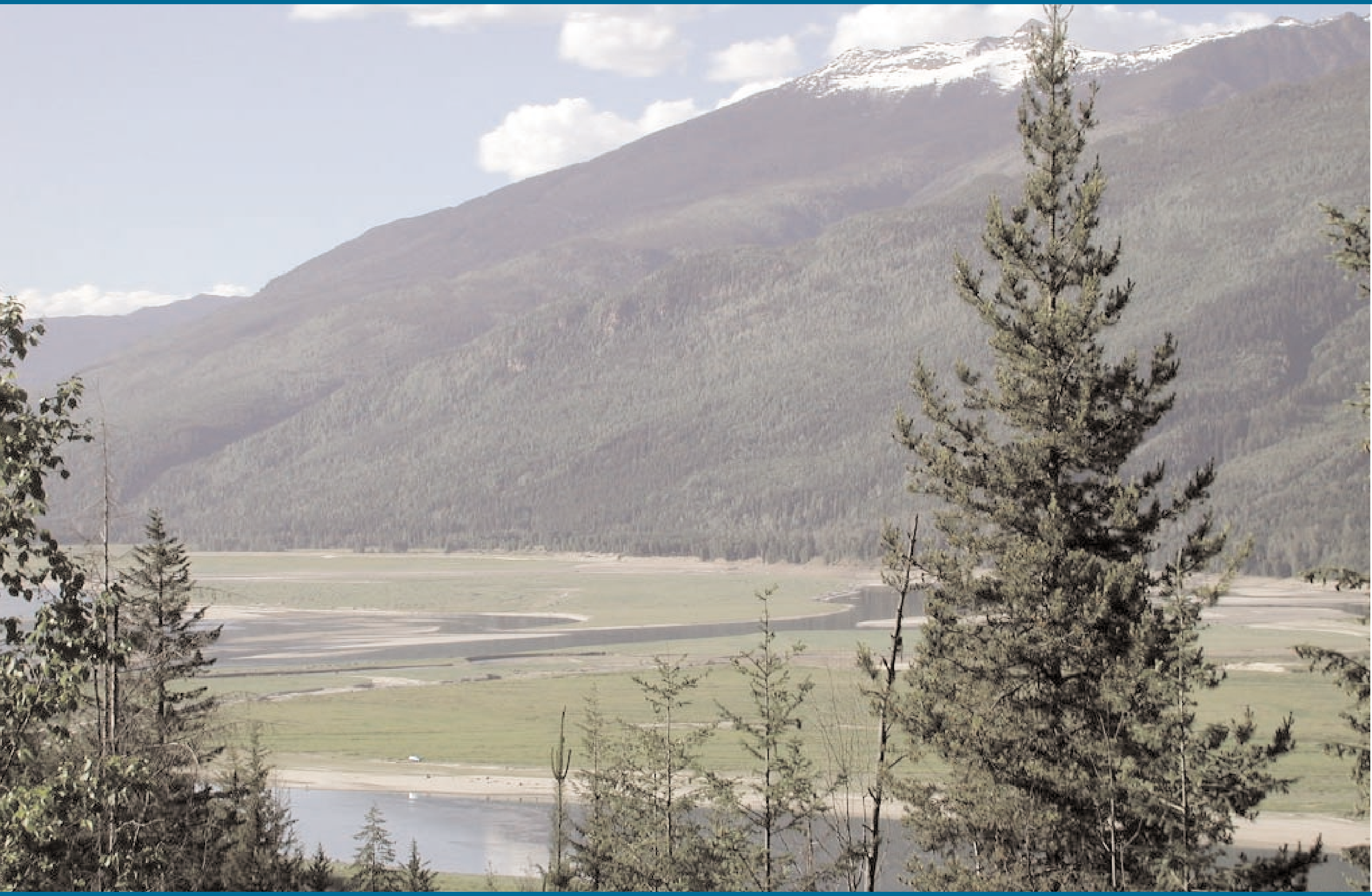

Photo courtesy of Wendy Beauchamp

Prepared by: Anne I. Moody, AIM Ecological Consultants Ltd.

Prepared for: BC Hydro Strategic Environmental Initiatives Program
Evaluation of the Ancillary Benefits of Upper Arrow Reservoir Drawdown Zone Revegetation Project

BC hydro

B.C. Hydro

Strategic Environmental Initiatives Program
Evaluation of Ancillary Benefits of Reservoir Shoreline Revegetation Project

Long-Term Monitoring of Vegetation Expansion and Trials in the Dust Control Treatment Areas of Revelstoke Reach - Upper Arrow Reservoir.

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Executive Summary

Since the late 1980's, significant portions of the Revelstoke Reach of Arrow Reservoir have been repeatedly seeded with fall rye for wind erosion control and dust abatement. The seeding has continued for dust control annually, with the program modified each year in response to projected water levels, shifts in dust source locations, and the progression of perennial native vegetation development on previously seeded areas. Wetland trials, including a total of 21 wetland species, were planted in 1991 to 1993, to examine the feasibility of establishing a perennial cover of native wetland species for dust control in the draw down zone. Monitoring of the survival and expansion of these seedlings has occurred on an annual basis. The second monitoring program, that of the naturally expanding native vegetation, was initiated when it was first perceived that the native species were beginning to expand their range in conjunction with fall rye seeding. Permanent monitoring plots were established at the lowest limit of plant growth, in 1991, at approximately 435m.

An objective of the BC Hydro Strategic Environmental Initiatives Program (SEIP): Evaluation of Ancillary Benefits of Reservoir Draw down Zone Revegetation, is the quantification of aquatic and terrestrial resource contributions arising from the vegetation development associated with the Arrow Dust Control Program. Although the wetland plant trials and long-term vegetation monitoring were initiated under the Arrow Dust Control Program, the summary fell within the SEIP mandate.

At the conclusion of a decade of growth, four species of sedge remain of the plants established in 1991:

- water sedge (*C. aquatilis*),
- slough sedge (*C. obnupta,*)
- beaked sedge (*C. rostrata*), and
- lenticulate sedge (*C. lenticularis*)

Dramatic differences are apparent in the survival of these plants at the various elevations. The greatest survival has been at 436m with a large proportion of the sedges surviving. All of the plants present at 436m, with the exception of beaked sedge were noted as being very vigorous, producing seed and spreading widely beyond their original plugs. Of these species, the most successful has been slough sedge (98% survival) followed by water sedge (64%), lenticulate sedge (32%) and beaked sedge (14%), Survival numbers, size and seed production declined by the 435m elevation and continued to decrease with depth.

Annual continued growth is evident, until the plants reach their limits of tolerance. This varied according to species and year The ultimate objective of a vegetation establishment program is to achieve surface area coverage. This can best be expressed by the combination of survival and expansion of the original plants (Figure 7). Plant growth and survival at elevation 436m has resulted in more than a 2000% increase in vegetated area over the initial planting at the site. At 435m, there was a maximum 700% increase in five years until inundation stresses produced a decline in the vegetated area.

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1 INTRODUCTION

This report presents a summary of vegetation monitoring at Upper Arrow Reservoir from 1991 to 2001. Two types of vegetation monitoring were undertaken during that period. The first consisted of annual monitoring of vegetation trials established to evaluate the success of several vegetation species planted in the draw down zone of the reservoir. The second approach assessed naturally expanding native vegetation by means of large permanent plots.

An initial vegetation overview was conducted in 1990 to establish the species composition and elevation range of native wetland plants within Revelstoke Reach, Upper Arrow Reservoir (Figure 1). At that time, very few wetland species were present in the upper draw down zone. These species, which occurred predominantly between 436 meters and the full pool level of 440 meters, consisted of reed canary grass (*Phalaris arundinacea*), bluejoint (*Calamagrostis canadensis*), lenticulate sedge (*Carex lenticularis*), Columbia sedge (*Carex aperta*), scouring rush (*Equisetum hyemale*) and water horsetail (*Equisetum fluviatile*). Other species, such as isolated small patches of beaked sedge (*Carex rostrata*), water sedge (*Carex aquatilis*), small flowered bulrush (*Scirpus microcarpus*) and several weedy annuals, (which were found to vary annually in composition and occurrence), were noted as very minor elements in the area. In general, plant diversity and density increased with elevation and only one or two sparse species were found at the lowest limits of growth.

The wetland trials, planted in three successive years from 1991 to 1993, were designed to examine the feasibility of establishing a perennial cover of native wetland species for the purpose of dust control in the draw down zone. A dust control program, consisting of mechanically drill-seeded fall rye, was initiated in the reservoir in 1990. Limitations of the seeding program were recognized as; a lack of vegetative cover in the late winter - early spring (prior to seeding) and the need to repeat the planting annually. The establishment of a perennial vegetation cover was identified as a potential method for achieving long-term dust control.

The second monitoring program, that of the naturally expanding native vegetation, was initiated when it was first perceived that the native species were beginning to expand their range in conjunction with fall rye seeding. Permanent monitoring plots were established at the lowest limit of plant growth, which at the time of plot establishment, was dominated by lenticulate sedge at approximately 435m. Since that time, the vegetation has continued to infill at the 435m elevation and has progressed to lower elevations in the draw down zone. The natural vegetation distribution and elevation relationships are addressed in the recent report regarding the vegetation mapping program (Moody 2002).

The initial objectives of the vegetation trial program were to determine:

- perennial plant species capable of surviving both extended inundation and exposure; and
- lowest tolerable elevations for perennial plant species in the reservoir.

After the first year of trial planting and field studies, the program was expanded to include components which would help to determine:

- the rate of natural sedge colonization within the reservoir,
- how sedge colonization could be enhanced, and
- the optimal method(s) for establishing plants in the reservoir draw down zone

Further details of the Arrow Dust Control program appear in the annual monitoring reports (Carr 1992, Carr & Moody 1992, Carr et. al. 1993, Moody 1998).

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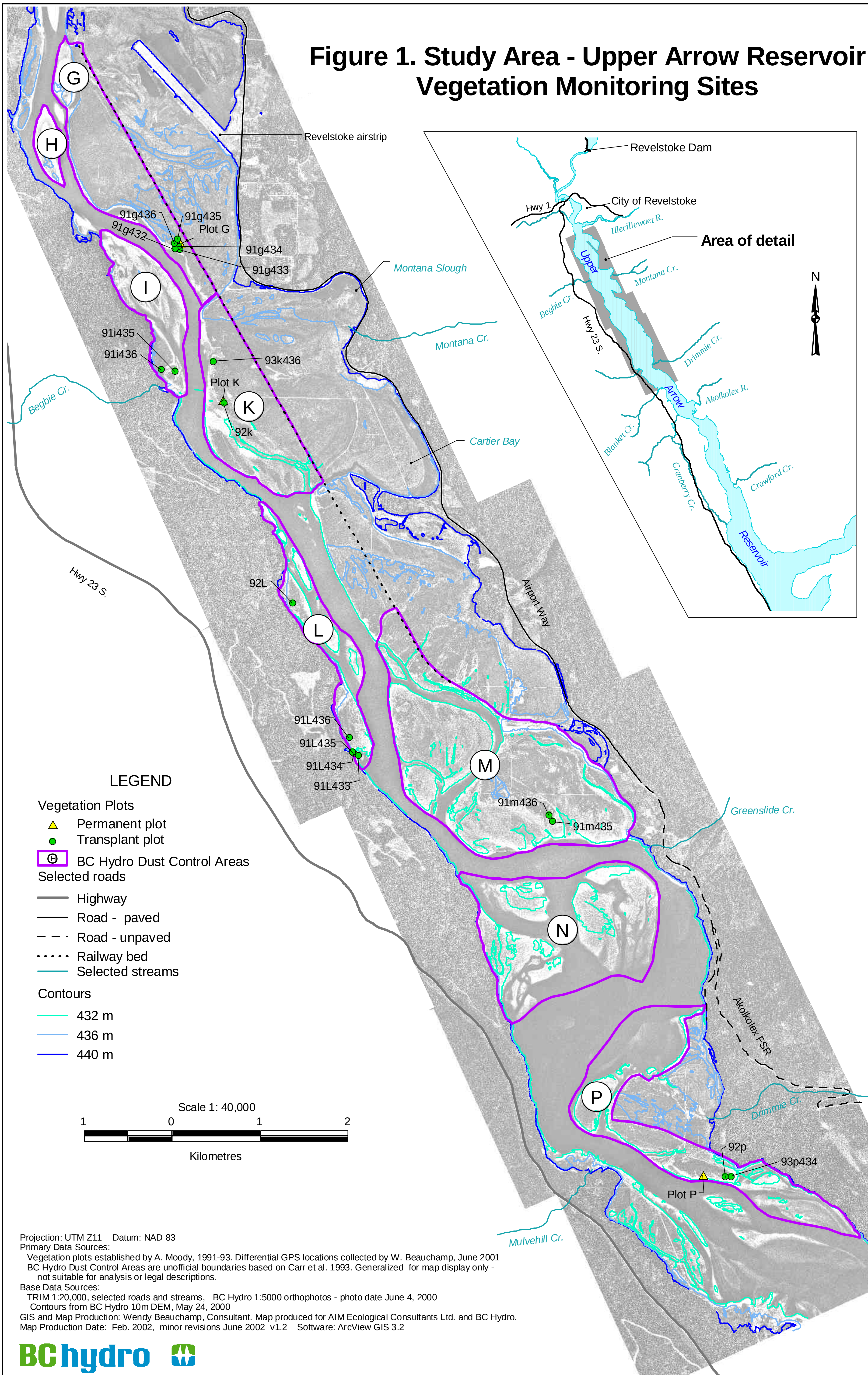


Figure 1. Study Area - Upper Arrow Reservoir Vegetation Monitoring Sites

1.1 SPECIES CULTIVATED FOR VEGETATION TRIALS

Based on the vegetation overview in 1990 and a literature search of North American reservoir shoreline re-vegetation projects, there appeared to be a potential for the expansion of vegetation cover to lower elevations in the reservoir by cultivation and planting of select wetland species. Since water levels at Upper Arrow Reservoir peak before wetland seeds normally mature, a province wide search was undertaken for suitable native wetland species which were tolerant of highly variable environments and which were successfully producing seed.

In the fall of 1990, seeds were collected from a variety of native B.C. wetland sites, stratified and cultivated in a greenhouse to a mature plant stage for planting in the spring of 1991. Most of these seeds were from species which occurred naturally in the reservoir or in the surrounding areas (Table 1). Two notable exceptions were wild rice, which was included at the request of local community members and slough sedge (*Carex obnupta*), which had been tested by the U.S. Army Corps of Engineers in Pacific Northwest reservoirs and which showed great promise for tolerance of inundation. Seed for wild rice was obtained from Alberta and slough sedge seed was collected from the Stave River area (Lower Mainland, B.C). Although reed-canary grass and bluejoint were observed in the draw down zone, a decision was made to not include them in the vegetation trials initially due to their reputations as a "weedy" and invasive species. However, at the request of BC Hydro, reed-canary grass was included in the 1993 trials for comparison with the other species.

In 1991, the water levels remained low long enough to allow for the maturation and collection of seed in the Arrow Lake draw down zone, enabling utilization of local seed for the 1992 trials. The subsequent 1992 trials consisted of a total of 13 species, with 6 of the less successful species from 1991 replaced by other suitable candidates, including the source material from the local environment. In addition, reciprocal trials were undertaken with lenticulate sedge seed obtained from Campbell Lake (Vancouver Island) and with lenticulate sedge seed native to Arrow Lake. In 1993 the number of species was reduced to 8 but the trial included 3 types of propagules for each species (Table 1). Testing of various propagules was undertaken in 1993 in conjunction with the evaluation of elevation tolerances as indicated above. Seeds, sprigs and greenhouse grown seedlings of 8 species were planted to assess the relative success of the propagation techniques.

Table 1: Plants Cultivated For Upper Arrow Reservoir Test Plots

		1991	1992	1993
Red top	*Agrostis alba*	-	seedlings	seedlings, seed & sprigs
Water foxtail	*Alopecurus aequalis*	seedlings	seedlings	
Columbia sedge	*Carex aperta*	sprigs	seedlings	seedlings, seed & sprigs
Water sedge	*Carex aquatilis*	seedlings	seedlings	seedlings, seed & sprigs
Slough sedge	*Carex obnupta*	seedlings	seedlings	seedlings, seed & sprigs
Beaked sedge	*Carex rostrata*	seedlings	seedlings	seedlings, seed & sprigs
Lenticulate sedge Central B.C.	*Carex lenticularis*	seedlings	-	-
Lenticulate sedge U. Arrow L.	*Carex lenticularis*	seedlings	seedlings	seedlings, seed & sprigs
Lenticulate sedge Van. I. seed	*Carex lenticularis*	-	seedlings	-
Tufted hairgrass	*Deschampsia caespitosa*	-	seedlings	seedlings, seed & sprigs
Creeping spike-rush	*Eleocharis palustris*	rhizome		-
Soft-rush	*Juncus effusus*	-	seedlings	-
Mertens rush/fowl blue grass mix	*Juncus mertensianus* / *Poa palustris* mix	-	seedlings	-
Reed Canary Grass	*Phalaris arundinacea*	-	-	seedlings, seed & sprigs
Smartweed	*Polygonum sp.*	rhizome	-	-
American bulrush	*Scirpus americanus*	rhizome	-	-
Soft-stemmed bulrush	*Scirpus lacustris (acutus)*	rhizome	seedlings	-
Seacoast bulrush	*Scirpus maritimus*	seedlings	-	-
Small flowered bulrush	*Scirpus microcarpus*	seedlings	-	-
Arrowgrass	*Triglochin maritima*	seedlings	seedlings	-
Wild rice	*Zizania aquatica*	germ. seed	-	-

1.2 VEGETATION TRIAL LOCATIONS

Test plots were established among the major areas identified as sources of wind-blown silt in Revelstoke Reach (Figure 1). The naming of the geographic areas (Area "G", "P" etc.) follows terminology established for the dust control units (dust source areas) identified for the Upper Arrow Dust Control Program (Table 2) (Carr et. al. 1993).

Table 2: Geographic Distribution of Plots

YEAR	LOCATION			
1991	"G"	"I"	"L"	"M"
1992	"I"	"K"	"M"	"P"
1993	"K"	"M"	"N"	"P"

Specific plot locations were chosen each year based on water levels and site conditions at the time of planting. Criteria for site selection included:

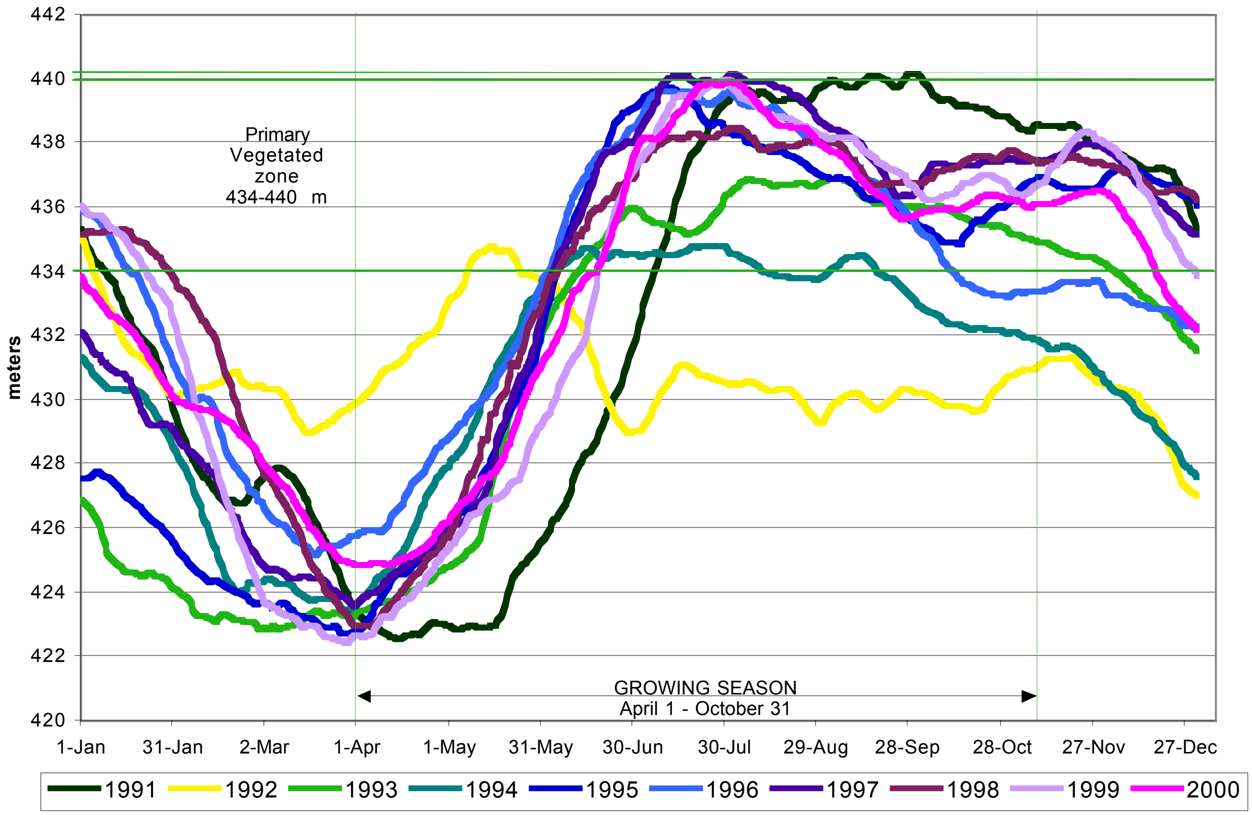
- range of elevation zones
- relatively uniform substrates
- relatively inaccessible, to prevent vehicular damage or vandalism of the plots.

In 1991, the first year of planting, elevations were surveyed and test plots were installed as close as possible to elevations 432m, 433m, 434m, 435m, and 436m. Plots were arranged in a block layout; each block included 50 replicates of each species (25 cm spacing). A departure from the block layout was necessary in 1992 due to high and rapidly rising water levels during the planting period. Plants were installed in linear rows (1 row per species, 25 cm spacing) extending from approximately 434.5m to 435.5 m in elevation. A block layout was resumed in 1993 following an elevationally stratified randomized block design. Since successful establishment had been recorded for the 1991 trials at all elevations, and since the 1992 trials were only able to test a narrow range of upper elevations, the 1993 trials were established at lower elevations, from 430 to 434 m. Monitoring of the wetland trials and test plots has been ongoing since 1991.

1.3 WATER LEVELS

Annual water levels at Arrow Lake follow a general pattern of high water levels during the summer, a gradual decline over the fall and winter period to a low at the onset of the growing season (April), then a steady rise to maximum levels by mid-to late June (Figure 2). Occasionally, the water level reaches the vegetated zone only briefly (1992) or not at all (2001). During such years, climatic factors such as temperature and rainfall may be the most significant factors influencing plant establishment and survival.

Figure 2: Arrow Lake Water Levels (Nakusp) 1991-2001



Inundation of the vegetated zone usually occurs over a 4 week period with the lower elevations being submerged as early as the beginning of June (1998), or as late as July (1991). The median water levels by July 1 are 437 m. Peak water levels are usually reached by mid to late July. Over the past decade, the average water rise during the late June-early July period has been 0.3 m per day but has peaked at 0.5 m per day (Table 3).

Table 3: Maximum water level change per day June 1-30

YEAR	MAX. WATER RISE PER DAY (METERS)
1991	0.33
1992	0.03
1993	0.20
1994	0.16
1995	0.42
1996	0.37
1997	0.50
1998	0.37
1999	0.51
2000	0.47
2001	0.19

2 METHODS

Annual repeat monitoring methods included plant counts (presence or absence) and measurement of stem height, and basal diameter. This type of plot monitoring allowed documentation of individual plant changes over time. Changes in size of the species in the wetland trials as well as the naturally occurring caespitose sedges were primarily monitored by measuring basal diameter of the plant (where the stems meet the ground). The basal diameter measurement became the main focus for repeated measurement because in herbaceous plants, unlike trees, crown cover can vary dramatically during the growing season, depending on the height of the plant[1]. At the outset of the growing season, the ratio of crown cover to basal area may be 1:1 whereas at the peak of growth it may be as great as 50:1. As an example, a 15 cm diameter plant with a drooping 50 cm length of stem would result in a crown cover approximately 24 times that of the basal area (Figure 3). An additional consideration was that basal diameter was not as susceptible to alteration by grazing.

The basal diameter measurements were later converted to basal area[2] and ultimately to total vegetated area[3]. This same methodology was not applicable to the spreading rhizomatous species such as reed canary grass. However, due to vertical growth habit, the crown cover estimates for reed canary grass tend to be a more accurate measure than for caespitose species such as the lenticulate sedge.

2.1 MONITORING OF PLANTED WETLAND TRIALS

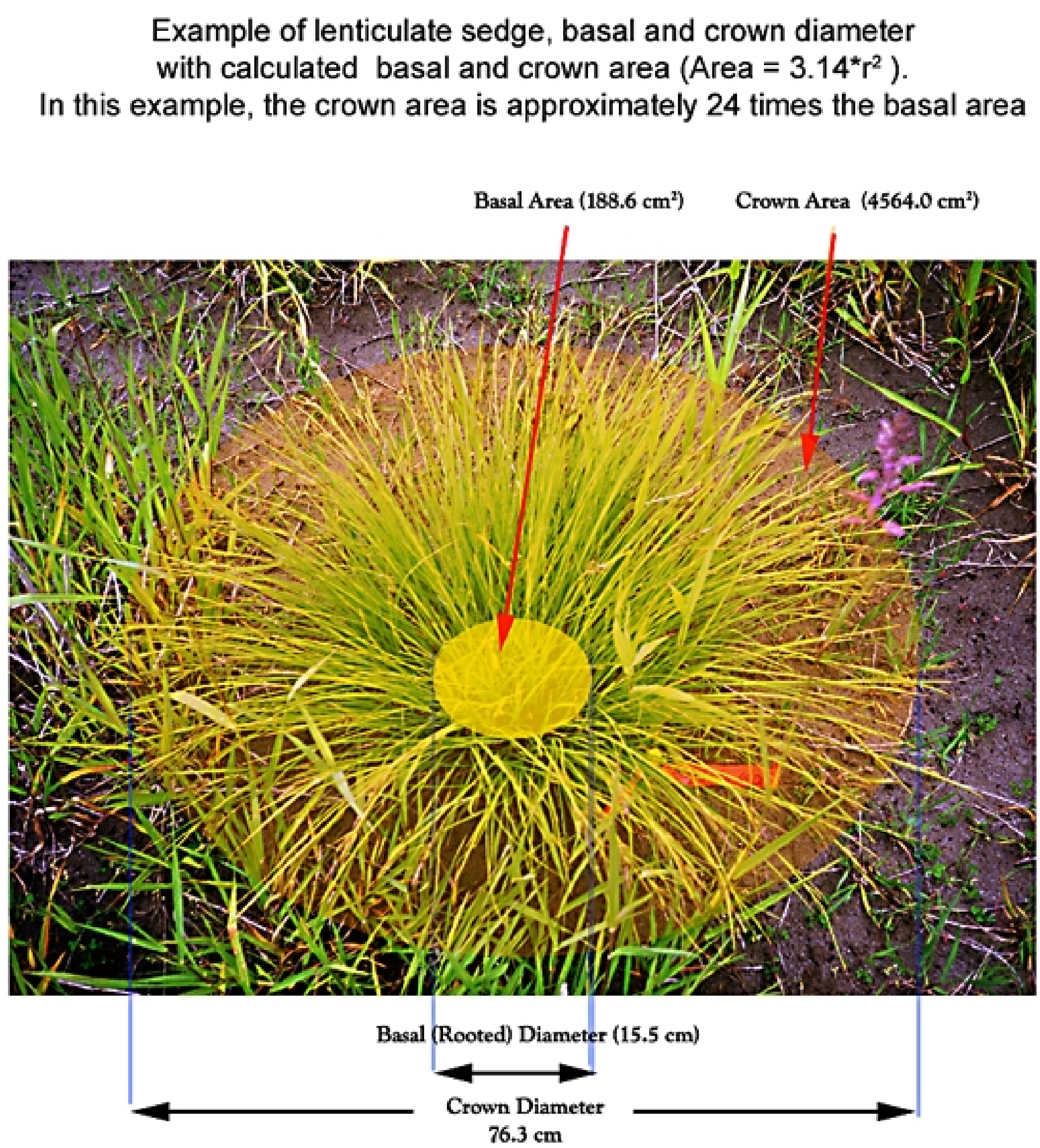
The 1991 and 1992 the test plots were monitored 60 days after planting and on an annual basis thereafter. Monitoring of 1993 plants could not be carried out until the following year due to rapid water level rise. Survival was recorded during each site visit on a presence or absence basis. Detailed monitoring, including: shoot counts, stem height, and basal diameter was carried out at Plot 91"M" in August and September 1992, June 1993, May 1994 and at all sites in June 1996. Partial monitoring occurred in subsequent years (due to time, water level and access limitations) but was consistently undertaken at Plots 91“M” and 92“P” with a complete monitoring undertaken in 2001. Stem height measurements and shoot counts were discontinued after 1996 since a consistent monitoring date could not be maintained between years.

[1] *“Measurements of basal area are more reliable than aerial cover because foliage cover fluctuates with seasonal changes resulting from climatic fluctuations and other perturbations. The basal area of plants remains fairly constant during a season and may increase or decrease over a period of years. However, in shrubs, forbs and single-stemmed grasses, basal area is not the best measure because the stem is usually small in comparison with the aerial spread. Basal area measurements have practical application in permanent plots where vegetation changes are to be monitored for several years.”* Bonham, C.D. 1989. Measurements for Terrestrial Vegetation. J. Wiley & Sons, Toronto.

[2] Basal area of the plant at ground level was calculated using the formula $pi*r^2$, where r equals 1/2 of the basal diameter of the plant.

[3] Total vegetated area per plot was calculated from the mean basal area per plant * number of plants per plot.

Figure 3: Plant size and cover relationships in a caespitose sedge



2.2 MONITORING OF NATURALLY COLONIZED PERMANENT PLOTS

As a result of perceived changes in the native plant distribution over time, permanent plots were established in 1992 at four different locations to determine the nature and rate of native plant colonization. Two types of permanent plots were established.

2.2.1 PERMANENT LINE TRANSECTS

Linear transects were established at areas G (6 transects), N (4 transects), and P (2 transects). The transects consisted of two permanent stakes, 20 m apart, between which a metric tape was stretched during the survey. All of the plant species touching the tape at 10 cm intercepts were enumerated. To facilitate documentation of the plant cover, an 8mm video-camera was used to record the entire length of each transect. The monitoring of the permanent plots was repeated annually using an 8mm video-camera to record the entire length of each transect. All of the plants touching the tape at 10 cm intercepts were enumerated and recorded in the computer database. Initial results were reported in earlier reports (Carr et. al. 1993) but are not repeated in this document since the line transects were discontinued in 1994 (due to vehicle activity and stump removal damage).

2.2.2 CARTWHEEL PLOTS

Permanent circular plots, 5 m in radius (78.5 m^2), were selectively established at areas “G”, “K”, “N” and “P” at the lowest limits of plant growth. Wooden stakes were used to mark the center and 1 m intervals of the outer perimeter of each plot. This resulted in a pattern referred to as a "cartwheel". All of the sedges occurring within the plot were documented according to location and species. In addition, several sedges were chosen at random, marked with coloured plastic tags (inserted into the ground adjacent to the plant) and the plants were measured for height, basal diameter and number of shoots. Monitoring of the area “N” plot was discontinued in 1994 when the plot was destroyed by explosions at nearby stump removal activity.

At the cartwheel plots, all of the sedges occurring within the plot were documented according to location and species; tagged plants were measured for height, basal diameter and number of shoots. As a result of changes observed in the plots, monitoring was amended in 1994 to include basal diameter measurements of all of the plants within the plots. The basal diameters were eventually used to calculate the total vegetated area of the plot.

2.3 ESTABLISHMENT OF FERTILIZER TRIALS

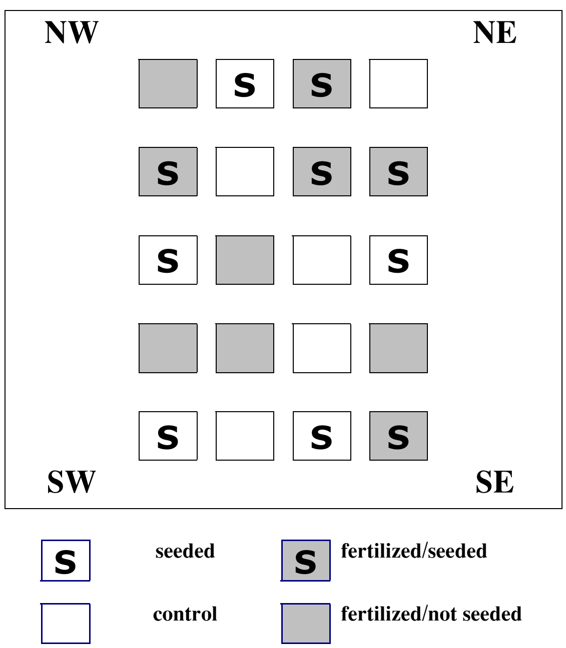
2.3.1 Fertilizer Trials 2000

Fertilizer input to the draw down zone from the fall rye seeding program, has been suggested as factor in the rapid spread of natural vegetation over the past decade. In order to explore this issue, preliminary fertilizer trials were established at area “P” in 2000 using naturally occurring and planted specimens of lenticulate sedge, planted water sedge and tufted hairgrass. Matching pairs of plants (with similar basal diameter and vigour) were selected for the trial. All plants were numbered and labeled with metal tags. One plant out of each pair was fertilized with commercial fertilizer spikes, the other was not. Basal diameters were recorded for each plant during the monitoring session in 2000. Follow-up monitoring was conducted one year later, to re-measure basal diameters.

2.3.2 Fertilizer Trial 2001

A separate vegetation trial was initiated in 2001 to test the value of fertilizer at the seedling emergence stage. A randomized block experiment was established at area “G” 432m[4], utilizing freshly collected lenticulate sedge seed and granular fertilizer used in the fall rye seeding program. Blocks were laid out and corners were marked with yellow plastic tent pegs. Blocks were seeded and controls were not; treatments included fertilized/seeded and fertilized/not seeded, with five replicates of each (Figure 3). A one meter wide gap was left between blocks to avoid cross-contamination with adjacent blocks. Seed was inserted into the substrate using a manual seed-drill. Fertilizer was applied similarly to incorporate it into the substrate. The site of the trial was chosen at Area “G”, from among very few possible options (areas which had not been fertilized and seeded in 2001 for dust control). Although water levels were far below the elevation of the trial location at the time of planting, power generation during the course of the trial set-up resulted in a local water level rise. Over half of the block was inundated by the time the seeding and fertilization were completed. Monitoring of this plot has not yet been conducted but has been proposed for June 2002.

Figure 4: 2001 Fertilizer Plot Layout At Area "G" 432



4 GPS fix for this site is the same as the previously established 1991 “G” 432m plot

3 RESULTS

3.1 VEGETATION TRIALS

Vegetation test plots utilizing greenhouse grown plant material (Table 1) were established over three consecutive years (1991, 1992 and 1993) in a number of locations within Revelstoke Reach (Figure 1). The long term results from the test plots reflect the dramatically different water regimes in which the plants were established.

3.1.1 1991 PLOTS

The 1991 plots were planted in May and were able to grow for 60 days prior to being inundated continuously for the remainder of the growing season (119 days). The 1991 plots, planted over a 5 m elevation range, showed early responses to water level stresses. Although these plots had a longer growing period than normal (water levels did not rise until July), once inundated they were covered by up to 8.2 meters of water (depending on the elevation of the plot) for the remainder of the growing season.

Of the initial 5 elevations tested at each site, the lowest plots (432m) were all lost as a consequence of erosion. In all cases these elevations were closest to the river channel and had the greatest potential for erosion. Unfortunately, these were the only suitable sites available at these elevations at the initiation of the program. Two of the 433m and 434m elevation plots have also been subject to erosion (M and G).

3.1.1.1 SURVIVAL

At the conclusion of a decade of growth, four species of sedge remain of the plants established in 1991:

water sedge (*C. aquatilis*),
slough sedge *(C. obnupta,)*
beaked sedge *(C. rostrata),* and
lenticulate sedge *(C. lenticularis)*

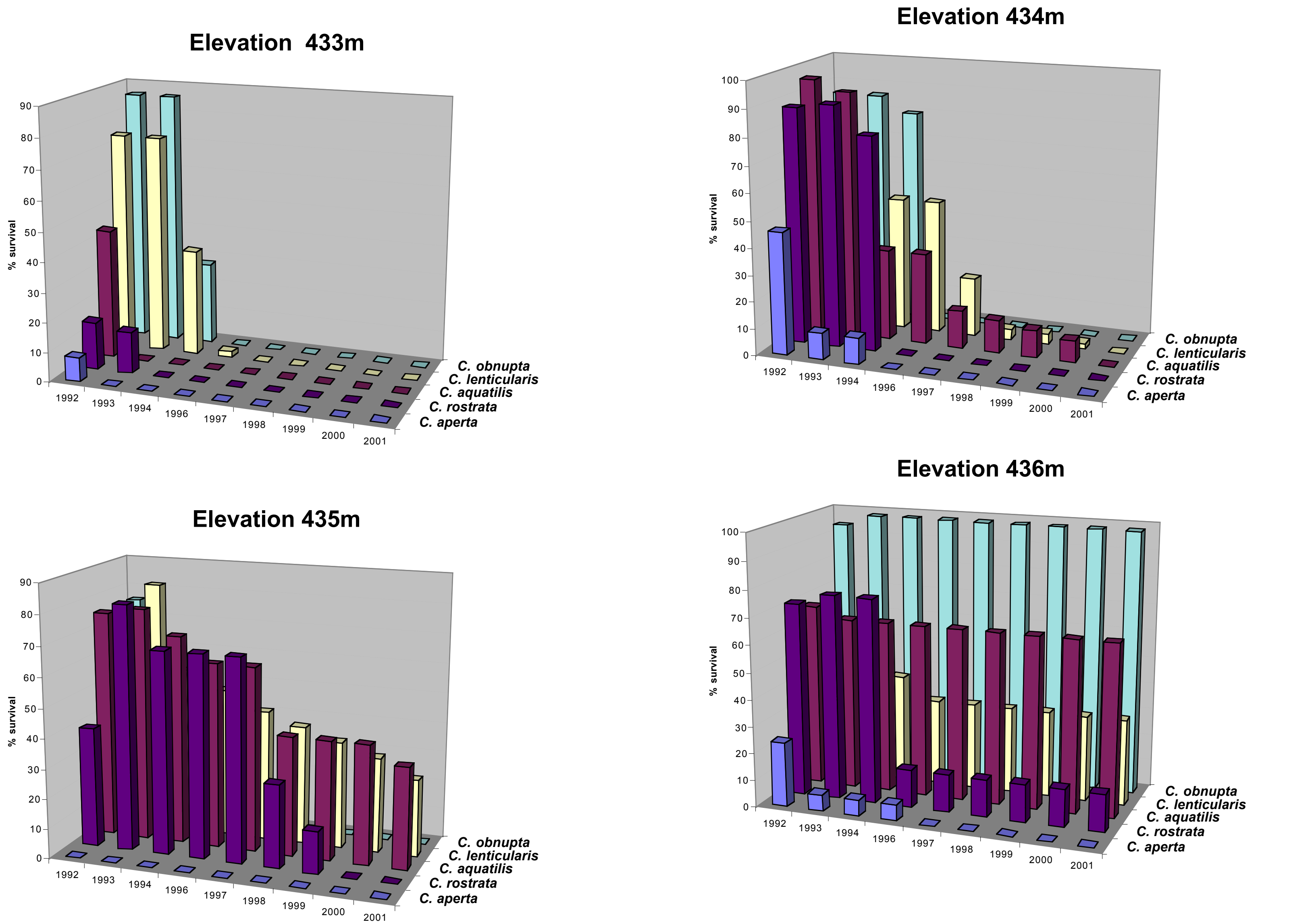
The only exceptions are a few individuals of perennial smartweed, which have persisted at 436m at Areas "I" and "G".

Dramatic differences are apparent in the survival of these plants at the various elevations. The greatest survival has been at 436m with a large proportion of the sedges surviving. All of the plants present at 436m, with the exception of beaked sedge were noted as being very vigorous, producing seed and spreading widely beyond their original plugs. Of these species, the most successful has been slough sedge (98% survival) followed by water sedge (64%), lenticulate sedge (32%) and beaked sedge (14%), (Figure 5). Despite success at 436m, slough sedge and beaked sedge planted in 1991 have not been able to survive at the lower elevations.

Survival numbers, size and seed production declined by the 435m elevation and continued to decrease with depth. Long-term (10 year) survival of the 1991 plants at elevation 435 has been limited to water sedge and lenticulate sedge. These sedges survived longer than any other species at the 433 and 434m elevations. However, persistent high water levels in 1995-1997 appear to have taken their toll on the 1991 plant trials. Of the four 433 sites, only one plant, a heavily grazed lenticulate sedge was observed at Area L. At the same site, 4 individuals of water sedge were present at 434m. Further details concerning the early survival of other species are available in previous monitoring reports.

In most cases, expansion of reed canary grass (except at area "M") has resulted in the test plots being obscured by vegetation cover. At the time of the initial planting, the plots were the only green present in the vicinity, now they are very difficult to find. Vegetation growing within the plots has spread beyond plot boundaries and has intertwined with other planted and invading species to form a solid vegetative cover. Original plugs will be almost impossible to distinguish in the near future.

Figure 5: Percentage survival of 1991 plants at Area "M"



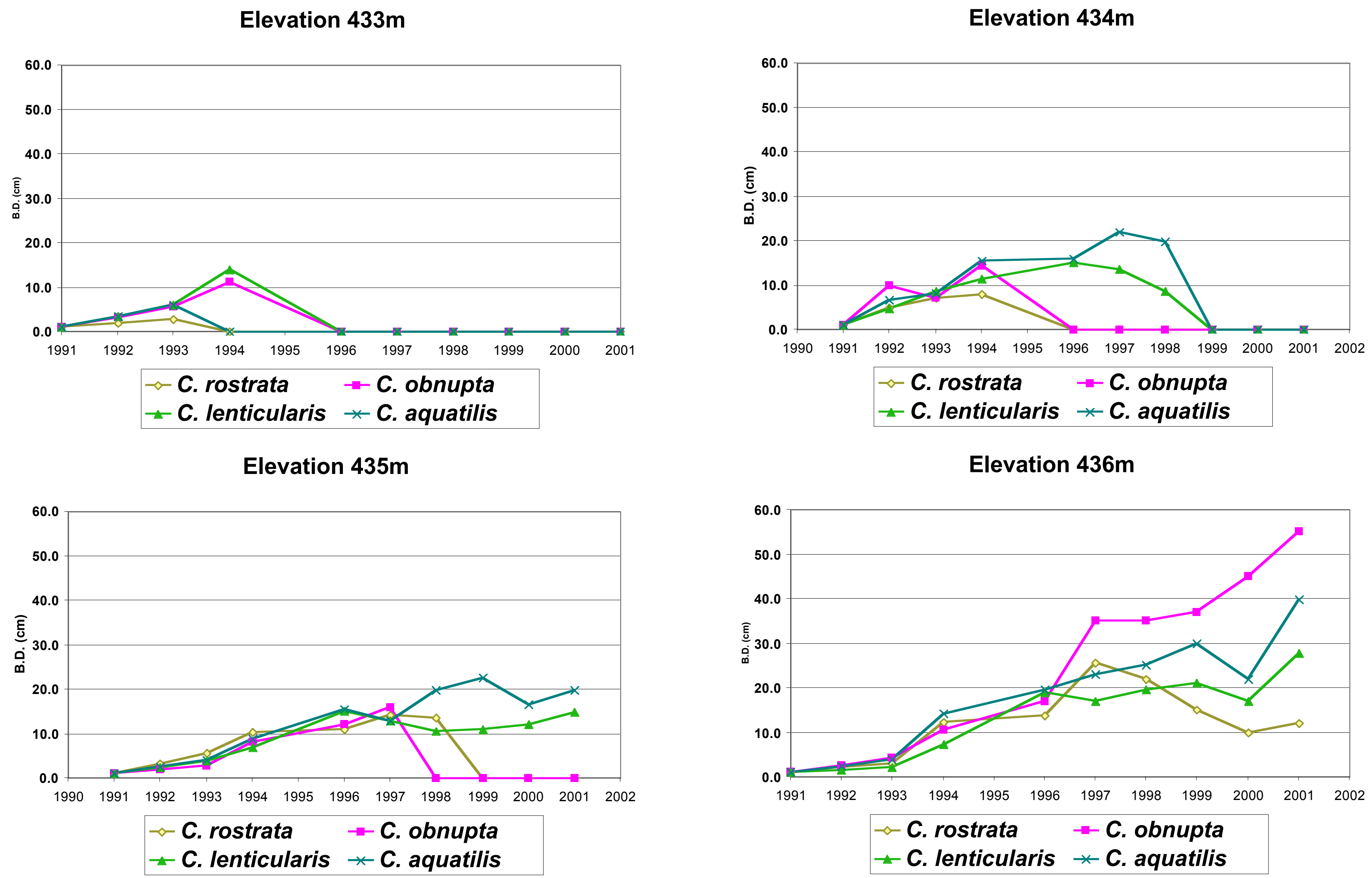
3.1.1.2 Plant size and growth

The normal pattern of plant growth is a gradual increase in the area occupied by the plant (in this case measured by basal diameter) over time. This rate of increase is influenced by the environmental stresses experienced by the plant. These may include nutrient limitations, climatic conditions, or competition, but in the draw down zone, the duration and depth of inundation appear to be the prime factors influencing plant growth and survival. A decline in the basal diameter of the plant reflects not just a slowing or halt in growth, but is indicative of depletion of underground reserves which have been utilized while the plant is in survival mode (inundated). Any decline in basal diameter is therefore an indication of very stressful conditions. When the duration of the stress exceeds the plant's reserves, it dies.

The pattern of plant response to annual stresses is very apparent in the charts of mean basal diameter between 1991 and 2001 (Figure 6). Increases in plant size were initially quite similar across the elevation range except at 434m, where greater than average growth was apparent in all species. The reason for this is unclear but may have been related to moisture availability during the atypically low water year in 1992.

Annual continued growth is evident, until the plants reach their limits of tolerance. For beaked and water sedge at 433m, this occurred by 1994 whereas the other sedges were able to continue growth for at least one more year. At 434m, slough sedge and beaked sedge declined after 1994 but lenticulate sedge persisted until 1996 and water sedge until 1997 before they showed declines. At 435, the growth pattern was quite stable for all species until 1996 following which, slough sedge died, lenticulate sedge declined, beaked sedge began a decline followed by a crash in 1998 and water sedge increased. At this elevation, lenticulate sedge and water sedge both showed the capacity to recover after major declines; lenticulate sedge began recovery in 1998 and water sedge in 2000. All 4 species displayed this pattern of decline and response at 436m, revealing the lower stress load on the plants and consequently a greater capacity to recover. Even beaked sedge, which had been steadily declining since 1997 has started to show some recovery since 2000 at elevation 436m.

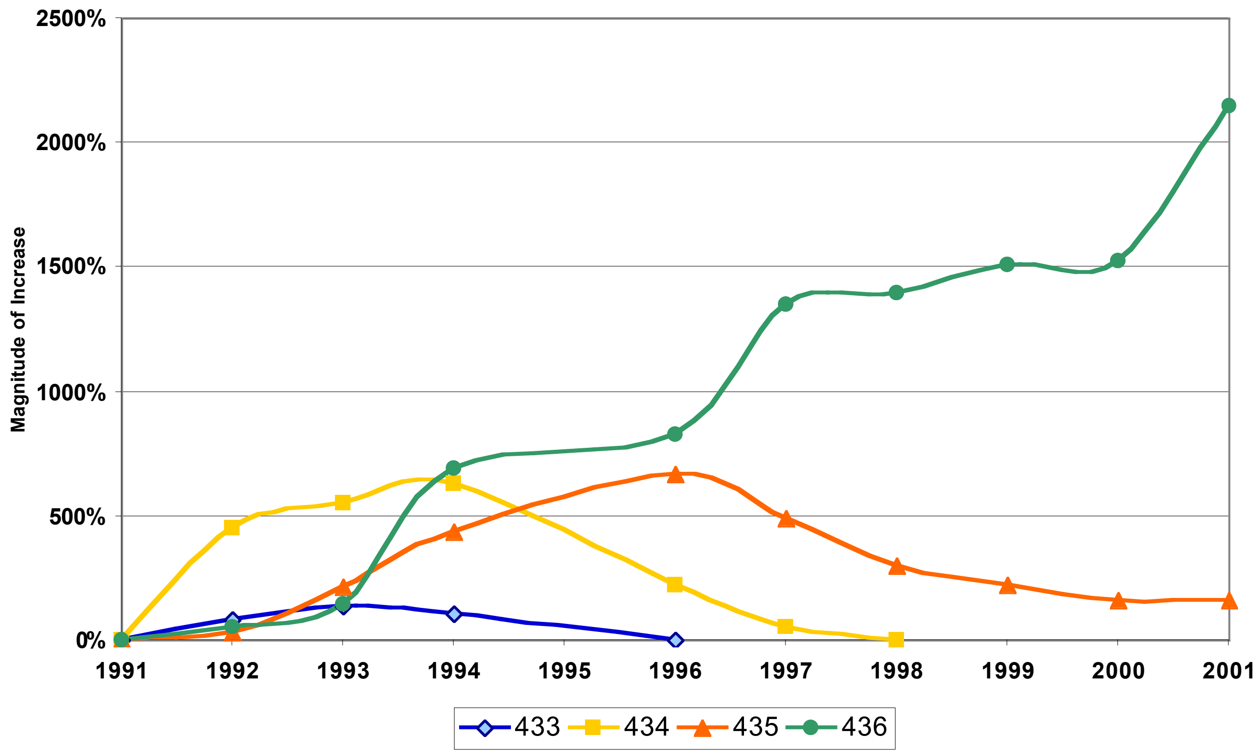
Figure 6 : Mean Basal Diameter Change at Area "M"



3.1.1.3 TOTAL VEGETATED AREA

The ultimate objective of a vegetation establishment program is to achieve surface area coverage. This can best be expressed by the combination of survival and expansion of the original plants (Figure 7). Plant growth and survival at elevation 436m has resulted in more than a 2000% increase in vegetated area over the initial planting at the site. At 435m, there was a maximum 700% increase in five years until inundation stresses produced a decline in the vegetated area. At 434m, a similar pattern was reached two years earlier. The plants at 433m only managed to double their area coverage in two years before starting to decline.

Figure 7: Increase (%) in Vegetated Area Coverage – 1991 Trials



3.1.2 1992 PLOTS

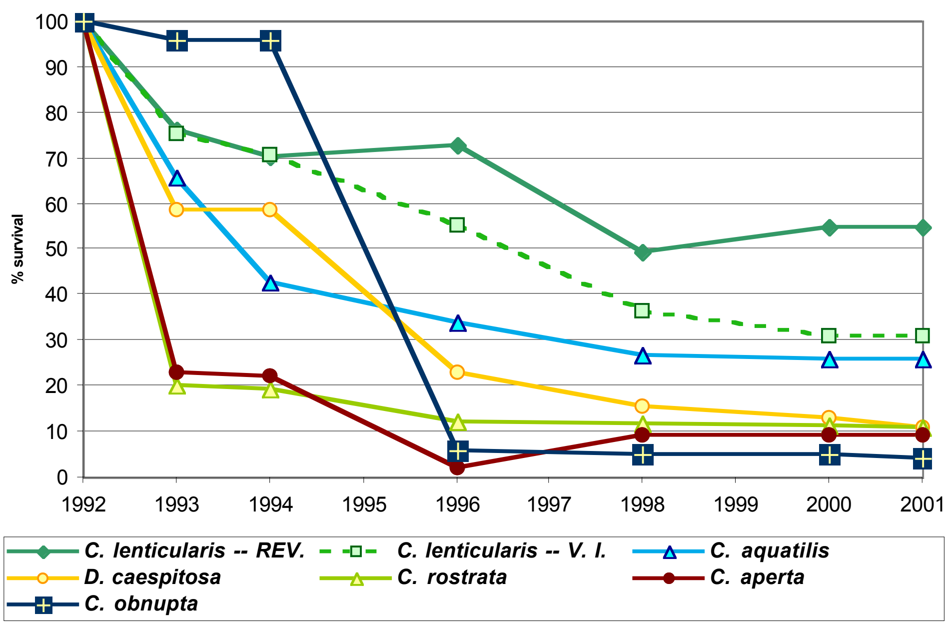
The 1992 plots were planted in May at an elevation of approximately 434.5 to 435.5m in anticipation of a projected continued water level rise, which did not occur. After May, the water levels declined and remained low for the remainder of the growing season. The 1992 plots have shown the best survival of the three planting years. Planting occurred at an elevation around which the water levels fluctuated for much of the growing season. This resulted in perfect growing conditions for establishment of the plants.

3.1.2.1 SURVIVAL

The 1992 planting results are not directly comparable to the 1991 results, in part due to the more limited elevation range in which they were planted (434.5-435.5m) and due to changes in species. As a consequence of the low water levels in 1992 these plants received the benefit of an extended growing season during their first year. Seven of the species tested survive to date (Figure 8). The lenticulate sedge originating from Arrow reservoir has shown a better than 50% survival whereas the one from Vancouver Island has only shown 30% survival, comparable to the non-native lenticulate sedge in the 1991 trials. Water sedge has shown a 25% survival, comparable to the 1991 trial results at elevation 435. The remainder of the species have all shown approximately 10% survival.

As in the 1991 trials, declines were noted for the 1996 to 1998 period. An interesting observation occurred following the decline in lenticulate sedge counts in 1999. Plants which had been enumerated as dead that year had recovered and showed renewed growth from belowground reserves by the following year.

Figure 8: Survival (%) of 1992 Trial Species

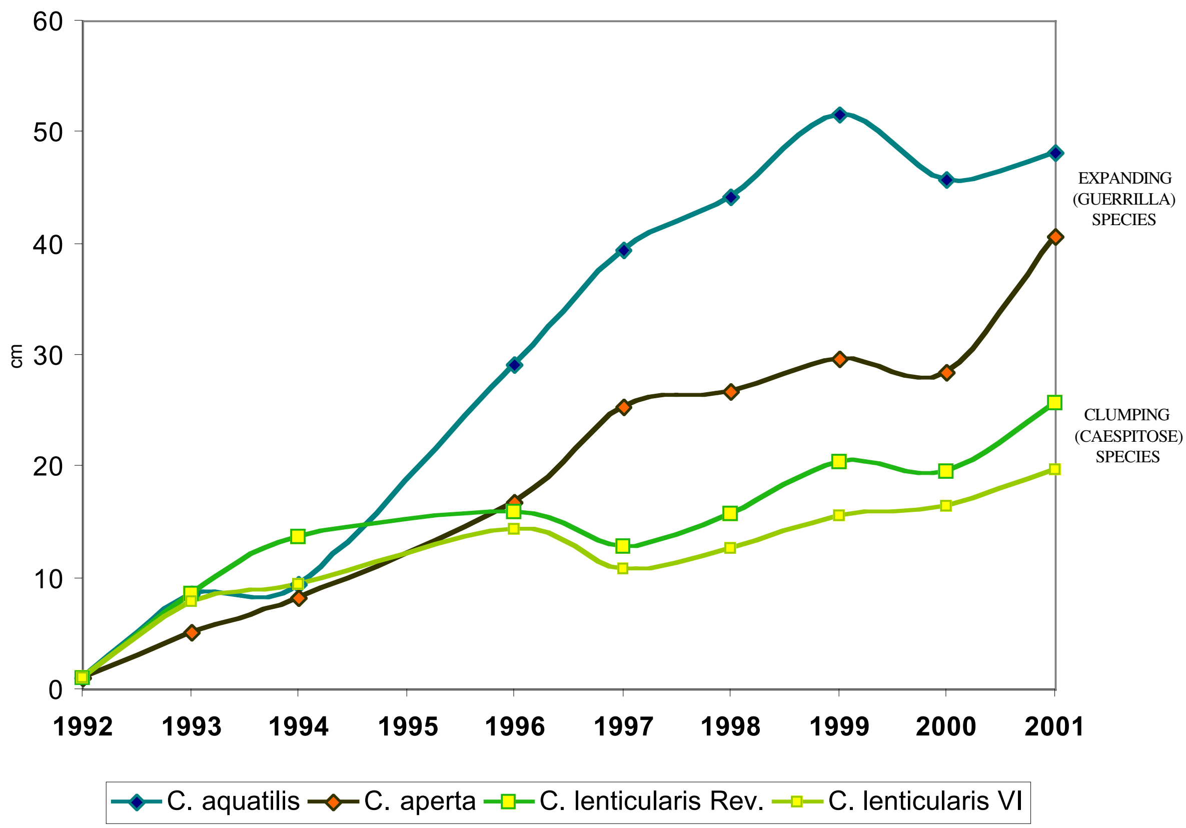


3.1.2.2 Plant Size and growth

Basal diameter measurements of 1992 trial plants show generally steady growth of the major surviving species (Figure 9). The spreading growth forms of water and Columbia sedge showed a slowing of growth following the 1997 monitoring whereas both ecotypes of lenticulate sedge showed a reduction in plant size following 1996. All of the sedges showed size reductions following the 1999 monitoring and recovery between 2000 and 2001. Similar trends were observed in the 1991 plants at the 435 and 436m elevations.

In comparisons between 1991 and 1992 plant size, overall, the 1992 plantings tend to be larger than the 1991 plants at similar elevations, despite the year's difference in growth.

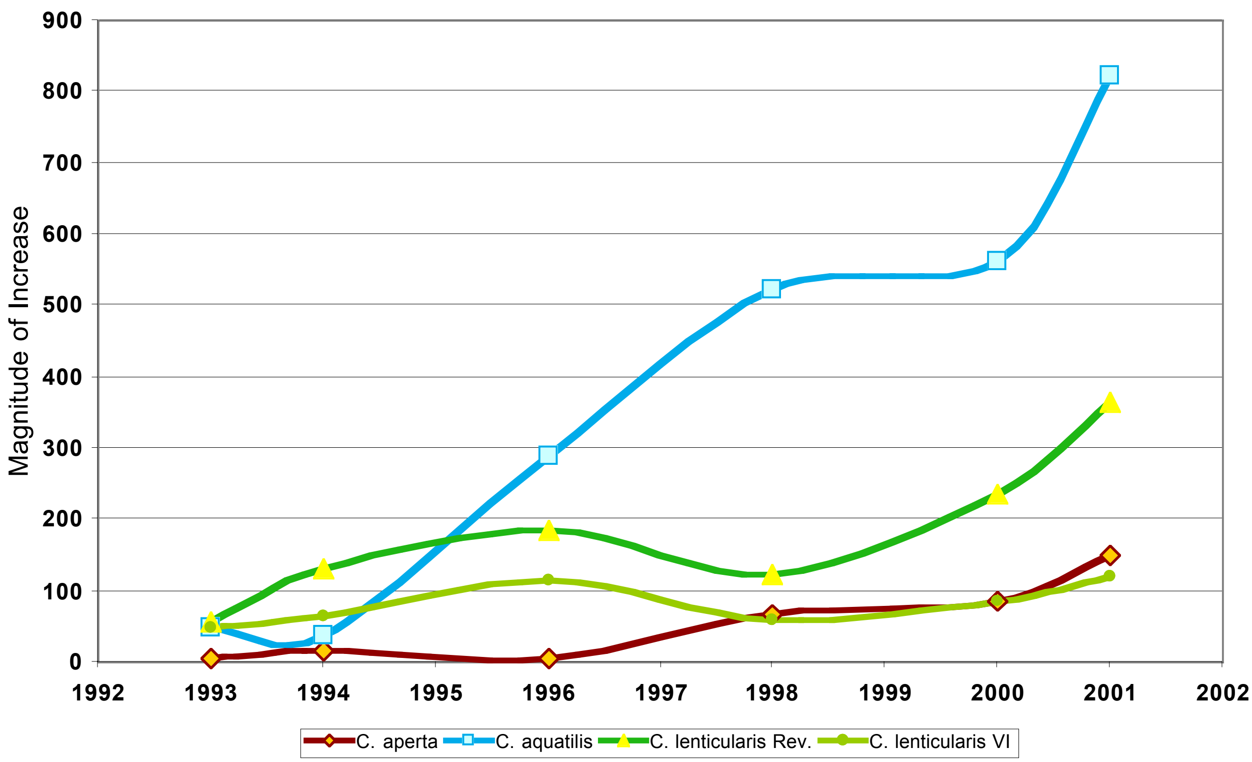
Figure 9: Mean Basal Diameter of 1992 Trial Plants



3.1.2.3 TOTAL VEGETATED AREA

As in the 1991 trial results, the total vegetated area resulting from the combination of survival and expansion of the original plants has been calculated[5] for the 1992 test plots (Figure 10). Due to the lack of elevation variation, the following figure examines the 1992 plantings based exclusively on species. Although the number of surviving plants of water sedge was less than lenticulate sedge, the capacity of water sedge to expand has resulted in an over 800 percent increase in vegetated area over a period of 9 years. Both ecotypes of lenticulate sedge have exhibited parallel growth patterns, but the local variety has consistently performed better than the non-native variety. Despite having a caespitose (clumping) growth habit, lenticulate sedge from Arrow Lake has produced a vegetation cover, over 365 times that of the original planting. Even Columbia sedge, which has struggled over the years has now reached a 150 percent increase.

Figure 10: Increase (%) in Vegetated Area at 1992 Test Plots according to species.
(based on surviving plants x mean area coverage)



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5 Total vegetated area of plot = average basal area of plants (pi*r^2) * number of plants in plot

3.1.3 1993 PLOTS

The 1993 wetland trials were designed to test various planting methods and to examine the lower elevation range which had not been tested by the previous trials. The water rose almost immediately after planting and remained continuously above the elevation of the plots for the remainder of the growing season (223 days). The 1993 plots were overwhelmed by high water levels immediately and showed very little long term success. Only the very highest elevations at sites “P” and “K” continue to show isolated remnants of these plantings. The year 1993 had longer than average periods of continuous flooding for elevations 430 – 435m, but higher than average exposure at elevations above 435m.

Due to the rise of water in 1993, quantitative measurements of establishment were not feasible prior to inundation, but qualitative observations were made shortly before flooding. The greenhouse grown plants appeared to be establishing well except for the uppermost elevations where waterfowl grazing was apparent. Germination of planted seeds was not visible prior to flooding. Monitoring of these plots in 1994 revealed that most of the sprigs and greenhouse stock had succumbed to flooding. Only tufted hairgrass, reed canary grass and lenticulate sedge seed were successful at producing seedlings, and only at the highest elevations. Germination of seed of lenticulate sedge had occurred at the highest elevation tested (434m) and appears to be related to appropriate moisture conditions available for germination and establishment.

Long-term monitoring of these plots has been hampered by aggressive reed canary grass colonization which has made recognition of the planted reed canary grass impossible and has obscured the smaller species in the plots. Shading by the reed canary grass has also restricted light to the smaller plants in the understory. The resulting growth form of the plants (tall but weak) is typical of plants in a light-impoverished environment.

No evidence of the plots was found at any elevation at Areas”M” or “N” in 2001. Both of these plots had been planted along the edge of depressions rather than along the slope to the river as had been the case with other plantings. These sites were chosen to provide the required elevational gradient, but to avoid problems with erosion along the river which had been experienced with previous plots. However, the depressions retained water for longer periods, thereby increasing the duration of inundation and resulting in the demise of the plants.

The plots at elevations 430-433m at Areas “P” and “K” have also completely disappeared. Only the very highest elevation (434m) continues to show isolated remnants of the plantings. The expansion of reed canary grass has resulted in the Area “K” 434m test plot location being completely obscured by vegetation cover. Monitoring of these plots has been discontinued for all but the lenticulate sedge seedling plot at Area”P”. At Area “K”, the effort expended to locate the few remaining plants far outweighs the information which can be gained from further monitoring.

The major notable success of the 1993 plantings has been a one square meter block of lenticulate sedge which emerged in 1994 as a result of seed planted in 1993. This block has been photographically documented over time. In 2000, ten seedlings in this plot were tagged as part of the fertilizer trial.

3.2 NATIVE PLANT MONITORING - PERMANENT PLOTS

Permanent plots were established in 1992 at several locations in order to monitor native plant colonization and expansion. Cursory observation over a period of time had revealed that native species, particularly sedges, were expanding into areas which, based on aerial photographic evidence, had previously been unvegetated. The permanent plot locations were selected in areas which were showing initial signs of vegetation colonization. At the inception of the permanent plot monitoring, plant expansion was only evident at the 435m elevation.

Numerous qualitative changes have been observed at the plots over time. Upon initial establishment, Plot “P” contained an abundance of horsetail and very little sedge (Figure 11). Over the monitoring period, the horsetails and Columbia sedge seedlings have all but disappeared, the lenticulate sedges have become larger and more abundant and the plot has been colonized to a large extent by reed canary grass. The presence of the reed canary grass does not seem to have affected the expansion and growth of the pre-existing sedges. However, it has attracted geese, and their habit of excavating plant rhizomes (“cratering”) in shallow water conditions. The “grubbing” or “cratering” activity of the geese seems to be focused primarily on the shallow and easily accessible rhizomes of reed canary grass rather than the tightly bound sedge rhizomes. The substrate disturbance both in terms of excavations and the subsequent deposition of materials on the adjacent plants has resulted in disruption of the site (Figure 11) particularly in 1996. Although the site presently appears unaffected, the topography is still very uneven (hummocky).

Figure 11: Permanent Monitoring Plot at Area "P" 1992-2001.

1992

1994

1996

2001 (center peg is beneath green flag)

The plot at Area “K” has been subject to much more intense goose “cratering” activity than the plot at “P”. Deposition of sediment over top of the existing substrate has severely hampered sedge seedling establishment in this plot. Reed canary grass has continued to vegetatively re-invade the plot despite annual disruption by geese. The large sedges which are established in the plot have able to continue expansion despite nearby goose digging which occasionally undermines a sedge clump. Even when plants are de-stabilized they may collapse into adjacent “craters” and re-establish stability by root expansion.

The Area “G” plot, in contrast to the others above, has had no disruption by geese, probably because of the lack of reed canary grass in the plot. It is the highest elevation plot of the three and has consistently had the greatest vegetation cover of horsetail and lenticulate sedge as well as some Columbia sedge.

3.2.1 PLANT NUMBERS

Plant numbers have consistently increased at all plots since the beginning of monitoring. Minor reductions in plant numbers were noted at Area “G” between 1992 and 1993 (187 to 180 per 100 square meters) and at area “P” between 1993 and 1994 (178 to 175 per 100 square meters). A major increase in plant density was noted for Area “G” between 1993 and 1996 (Figure 12). Numerous small seedlings of both lenticulate and Columbia sedge were present in the plot in May 1996. This appears to be attributable to water levels suitable for seed germination and establishment at this elevation in 1995 and 1996. In both years the median water level was close to 436 m, which would give the right mix of exposure and moisture for seedling germination. Plant densities more than doubled from 1.8 to 4.1 plants per square meter during that time interval. Areas “P” and “K” did not show the same response, but substantial increases were noted in the 1996-1998 interval. The densities at “K” increased from 0.15 to 0.25 and at “P” from 1.8 to 2.3 plants per square meter. All plots had substantial declines following the 2000 season; “K” a 50% reduction, “P” a 20 % reduction and “G” a 15% reduction in plant densities. Overall plant densities were highest at Area “G” and lowest at Area “K”

The differences in the “G” plot versus the “P” and “K” plots may be related to elevation differences. The area “G” plot is situated at approximately 436m, whereas both of the others are at approximately 435m.

Figure 12: Plant Densities at Permanent Plots

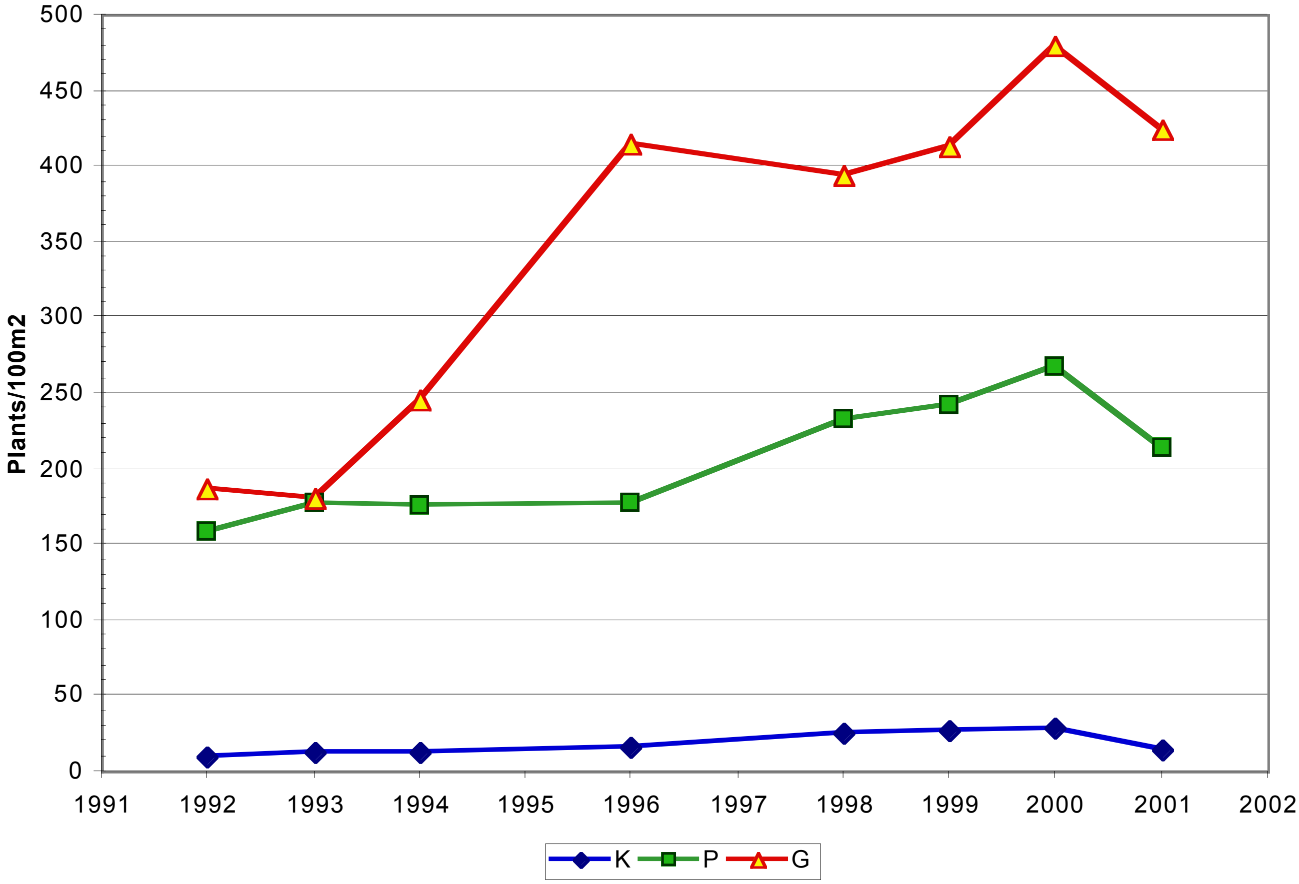


Table 4: Sedge densities at permanent monitoring plots

	Density – total plants per 100 m^2		
	K	**P**	**G**
1992	10	157	187
1993	13	178	180
1994	13	175	245
1995			
1996	15	178	414
1997			
1998	25	232	394
1999	27	241	413
2000	28	267	479
2001	14	213	424

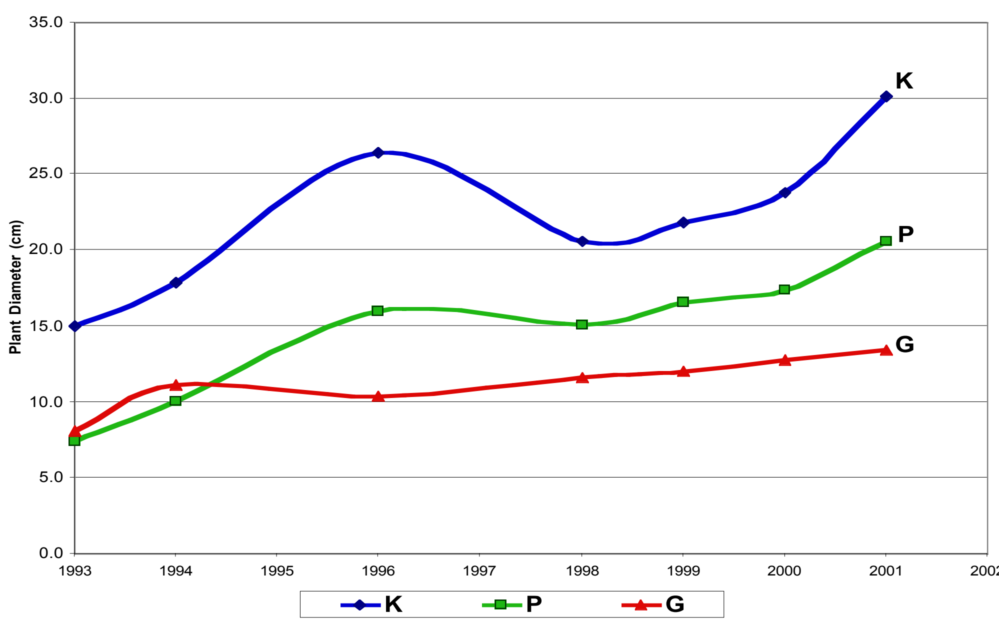
3.2.2 PLANT SIZE AND GROWTH

Changes in caespitose sedge size was monitored by measuring the basal diameter of the plants. Permanent plot results have revealed a general trend for an increase in the size of sedges at all sites. In general, Area "K" has the largest, but fewest number of sedges, whereas Area "G" has the greatest density but smallest sizes of plants (Figure 12, Figure 13). A decrease in the mean size of plants was noted in the 1996-1998 interval at both Area "K" and Area "P", primarily related to the increase in the number of small plants. Area "G" experienced a minor decline after 1994 (Figure 13) again related to increasing plant numbers rather than actual decreases in plant size. Histograms displaying the annual size distribution at the plots are presented in the appendices for each plot (**Error! Reference source not found.**, 7).

Table 5: Mean basal diameter of sedge plants in permanent monitoring plots.

	Mean Basal Diameter (cm)		
	K	**P**	**G**
1993	15.0	7.4	8.1
1994	17.9	10.0	11.1
1995			
1996	26.4	15.9	10.3
1997			
1998	20.6	15.1	11.6
1999	21.9	16.6	12.2
2000	23.8	17.4	12.7
2001	30.2	20.6	13.4

Figure 13: Mean Basal Diameter Changes In Permanent Plots



3.2.3 TOTAL VEGETATED AREA

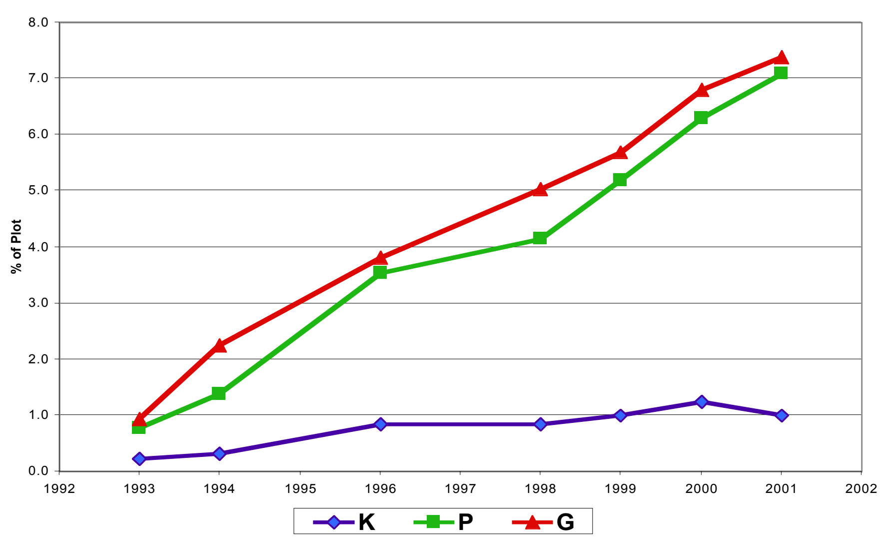
Despite the differences in plant size and density of the plots at Areas “G” and “P”, the expansion of vegetation cover over the past decade has been remarkably consistent (Figure 14). At the onset of monitoring, the basal, or rooted plant cover of all three plots were less than 1%. Vegetation development has proceeded in parallel for the plots at Area “G” and Area “P”, with rooted cover reaching over 7% of the area as of 2001. As indicated earlier, the measured basal or rooted cover is a much smaller value than the crown cover normally presented for ground coverage by the plant (Figure 3). The comparable crown cover values change with increases in plant size during the growing season, and have been estimated as a minimum, 10 times and at a maximum, 50 times that of the basal cover.

Vegetation responses to stresses have been consistent for Areas “G” and “P”, particularly the slow down of growth in the 1996-1998 period. This again coincides with the results from the vegetation trials. In contrast to the rapid vegetation expansion at Areas “G” and “P”, vegetation development at area “K” has been proceeding very slowly, in large part due to the high degree of disruption this plot has been experiencing on an annual basis. Vegetated cover peaked at just over 1.2% in the year 2000, but declined to 1.0% by 2001 (Table 6).

Table 6: Vegetation Cover at Arrow Permanent Plots (% of plot vegetated)

	K	P	G
1993	0.22	0.77	0.93
1994	0.32	1.39	2.24
1995			
1996	0.83	3.54	3.82
1997			
1998	0.85	4.14	4.81
1999	1.00	5.20	5.69
2000	1.24	6.31	6.81
2001	1.00	7.09	7.39

Figure 14: Vegetation Cover at Permanent Plots



3.3 PRELIMINARY FERTILIZER TRIALS

Five separate trials were established to provide an indication of fertilizer effects on vegetation in the draw down zone. Trials 1, 3 and 5 involved lenticulate sedge; trial 2 tested tufted hairgrass and trial 4 tested water sedge. The results of the monitoring show that after one year of growth, the fertilized sedges consistently had an increased basal diameter over those of the controls (Appendix 8). The tufted hairgrass showed no response. The planted sedge showed slightly less response to fertilizer than either the 1993 seedlings or the natural sedge. The water sedge showed less of a response to the fertilizer than the lenticulate sedge. Naturally occurring water sedge was not available for comparison with the planted sedge.

Trial 1
The plants resulting from lenticulate sedge seed planted in 1993 were used for this trial. The seedlings have remained small and dense in this plot. The mean basal diameter of the 6 year old plants was 8 cm at the inception of the trial. Five pairs of plants were tested for fertilizer effects. The plant response ranged from 23 to 57% increase in the size of fertilized plants. The mean increase was a statistically significant 29% increase in basal diameter for fertilized plants over controls.

Trial 2
These plants were the remnants of tufted hairgrass planted for the 1992 vegetation trials. All of the remaining individuals have been struggling with survival for the past five years. Results of the fertilizer trial showed no effect; some plants declined in size while others increased.

Trial 3
Ten pairs of plants of the local variety of lenticulate sedge planted in 1992 were used for this trial. The mean basal diameter of the 8 year old plants was 18.8 cm at the inception of the trial. The plant response ranged from 11 to 38% increase in the size of fertilized plants. The mean increase was a statistically significant 22% increase in basal diameter for fertilized plants over controls.

Trial 4
Five pairs of plants of water sedge planted in 1992 were used for this trial. The mean basal diameter of the 8 year old plants was 42.6 cm at the inception of the trial. The plant response ranged from 9 to 20% increase in the size of fertilized plants. The mean increase was a statistically significant 13% increase in basal diameter for fertilized plants over controls.

Trial 5
Ten pairs of plants of naturally established lenticulate sedge growing in the vicinity of the 1992 plot were used for this trial. A range of basal diameters (5- 23 cm) was chosen for this trial, the mean was 14.7 cm. The plant response ranged from 15 to 57% increase in the size of fertilized plants. The mean increase was a statistically significant 29% increase in basal diameter for fertilized plants over controls.

4 DISCUSSION

The water level fluctuations experienced by vegetation in the Upper Arrow draw down zone, far exceed any fluctuations tolerable by plants reported in the literature to date. Typically, plant tolerances are reported on a scale of centimeters rather than the several meters inundating the vegetation at Upper Arrow reservoir. The establishment of vegetation trials and permanent plots has therefore allowed us to develop an unparalleled understanding of vegetation responses to inundation stress.

Monitoring of the both the permanent plot plants and the wetland trial plants has resulted in a documentation of annual changes in plant numbers, size and area coverage. Plant response, as related to the stresses which they are exposed to, is evident in the decline in numbers and plant size during particularly stressful conditions (1996-1997 and 1999-2000).

The test plots established at Upper Arrow Reservoir have provided information regarding individual species tolerances of water fluctuations within the reservoir. Many of the species tested, showed intolerance of the Upper Arrow Reservoir water regime almost immediately. The remainder, with the exception of the sedges, have declined in size and in number to a point where their potential for revegetation is negligible. However, five sedges have proven to be highly successful at the higher elevations (435 and 436 m). Lenticulate and water sedge appear to have the greatest range of flooding tolerance of the species tested. All of the sedges have shown increasing survival with increasing elevation. Slough sedge has had the greatest overall survival but only at elevation 436m. Growth rate and survival differences between the 1991 and 1992 plantings have been noted for several species at comparable elevations. These differences may be attributable to the superior growing conditions for the 1992 plants in the growing season, following planting. The differences in water levels following planting appear to have immediate and long-lasting effects on the success of the plants.

A number of factors influence initial establishment of the plants including: vigour of the seedlings, and climatic conditions immediately following planting. Establishment and subsequent survival figures are confounded by differences between sites (substrate and moisture conditions) and by differences between years (in the hydrologic regime). During the decade of monitoring plant response, reservoir levels have fluctuated dramatically. Monitoring of the plant responses to these conditions is revealing information not only about the net survivorship but also how the individual species are responding to segments of the varying environmental condition. Species which have experienced extreme stress during some conditions, may rebound and resume vigorous growth when conditions are suitable. As a group, the sedges have shown a greater tolerance than other species, of the range of water level fluctuations. The grasses tested had minimal success in the elevations tested but may offer potential for higher elevations. The rush group had no success at all, probably due to their inability to tolerate the extended periods o exposure and drought. Within the successful group, a mix of species with a range of tolerances appears to be preferable to monocultures in the highly variable reservoir environment. As conditions fluctuate, individual species will flourish or decline depending on their tolerances. A mixed community will allow the persistence of a vegetation cover in spite of environmental fluctuations.

The elevation of a site represents an integration of flooding stresses to which the plants may be subjected. However, these stresses vary dramatically from year to year and the stress levels experienced at any given elevation may be reflected at a different elevation another year. Permanent plots revealed that there is a difference in tolerances of seedlings and mature plants. Assuming average water levels, there is a reasonable expectation of mature plants surviving at or above 434 m in elevation. However, if the water regime changes so that the duration of flooding is significantly different from the average condition, then an altered response in the vegetation tolerance can be expected. Fertilization can enhance the growth rate and therefore should help increase survival and recovery of plants following inundation stress.

The establishment and continued survival of wetland species occurs as a balancing act between the conditions essential for germination and condition essential for growth. These two conditions are not necessarily the same. Sedge colonization varies depending on the annual water level. The greatest increase in seedling numbers occurred in the permanent plots after 1999. Seedling germination and establishment appears to be occurring at the annual median water level, but mortality of sedge seedlings is governed by the subsequent inundation. Monitoring of permanent plots has shown that many of seedlings (but not all) which are able to establish during favourable germination years are able to carry on growth during years when water levels are too high for recruitment of seedlings to occur. Production of seeds from these established plants contributes to the seed supply which, if incorporated into the soil, will germinate during the next favourable draw down period.

Natural plant establishment appears to have been enhanced by the process of drill seeding which incorporates seed into the soil. The annual growth of fall rye accumulates organic material in the substrate. An increase in native plant expansion has been observed in those areas where drill seeding has been occurring regularly. Conversely an absence of natural plant establishment has been noted in sites excluded from drill seeding. There appears to be a relationship between the density of sedge seedlings (found occurring naturally) and the density of vegetation cover in the area (trapping the seed on the site). Therefore, it is likely that natural vegetation expansion has been assisted by the drill seeding program. Fertilization seems to be important in increasing the size of plants, thereby increasing their ability to withstand stress. Numerous options are possible for enhancing natural colonization, including;

- harrowing of areas where a natural seed supply occurs;
- facilitating seed entrapment and incorporation into the soil;
- manipulation of water levels to enhance germination; and,
- fertilization of natural communities to enhance growth and flooding tolerance.

All of these options would need further testing to determine their value.

The median water level is a good approximation of the elevation at which seedling germination and establishment can occur. The degree of flooding exceeding this level dictates the survival of germinated seed. Mortality of sedge seedlings is influenced by flooding as is the mortality of seedlings and sprigs if water levels rise before the plants are able to establish. Tests of seed germination have revealed that lenticulate sedge is the only one of the sedges tested which can be expected to produce viable plants from seed. Reed canary grass is able to expand by seed and vegetatively by rhizome extention as well as stem rooting but is slightly less tolerant of inundation than lenticulate sedge. Other grasses offer potential for establishment by seeding, but are limited in their tolerance of inundation.

Extended draw down periods present cost-effective and efficient opportunities to establish a perennial vegetation cover which may be able to persist even through extended periods of flooding. During extended draw down periods, seeding of several species may be feasible and may allow germination and establishment of seedlings which would otherwise be flooded in the first year. When seedlings have a long enough exposure to allow establishment, the prognosis for the established plants is good, despite average or slightly above average subsequent flooding. If extended draw down conditions can be predicted they may provide the most cost-effective and efficient time during which to establish a self-perpetuating vegetation cover within the draw-down zone. Plants established during favourable growth years appear to have a strong growth advantage over those established in difficult years, as is evident in the plants established in 1992, which have consistently exceeded the growth of those established in 1991.

5 RECOMMENDATIONS

- Monitoring of the 1991 plots be discontinued

  This plot monitoring is no longer viable due to native plant encroachment and intermingling with other species. Detection of the original plants is almost impossible at this point. Qualitative observations could be undertaken periodically to determine if the species are persisting. This would be particularly feasible with slough sedge at the 436m elevation because it is so distinct form the other species.

- Permanent plot (cartwheel) monitoring be scaled down

  Continued monitoring of permanent plots is recommended at a reduced intensity. The plant density has reached a point where continued monitoring is difficult. Subsampling of the plots could be undertaken in the future. New plots should be established in current incipient vegetation establishment areas to provide additional information reagarding newly developing plant responses to a highly variable environment.

- Monitoring of 1992 Plots be continued

  The 1992 plots are capable of providing additional data on plant survival and expansion. Further annual monitoring is recommended to allow a continuation of the established monitoring program to document long-term viability of lenticulate sedge and its capacity for expansion and response to the fluctuating water levels over time. The decade of monitoring has documented responses to a small range of potential reservoir conditions which the plants are exposed to. Additional information will amplify the current understanding of vegetation capacity to tolerate reservoir extremes.

- Fertilizer Trials be continued

  The initial fertilizer trials have yielded very valuable information regarding plant responses to fertilization. This data has implications for future vegetation planting and management decisions. The 2001 fertilizer trial requires monitoring to assess the effects of the treatment and seeding experiment.

- Climatic data be incorporated

  The inclusion of climatic information into vegetation analyses will provide an additional dimension of information for the understanding of plant responses to inundation and exposure stress. This is essential data which needs to be incorporated into the ResVeg model if a dry stress factor is to be included.

- Controlled trials be undertaken to test the effect of drill-seeding and fertilization on native plant expansion.

    All of the evidence presented to date, regarding the benefits of drill-seeding for vegetation establishment is circumstantial. In order to quantify the observed effects, controlled trials are necessary.

- Coordination of reservoir research and maintenance programs be undertaken to avoid conflicting activities (such as stump removal in the vicinity of research plots).

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