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Annual Macrophyte Survey of Penrith Lakes for 2008

Biosis Research Pty Ltd

Natural & Cultural Heritage Consultants 15-17 Henrietta St Chippendale NSW 2008

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Report for

Penrith Lakes Development Corporation

Annual Macrophyte survey of Penrith Lakes for 2008

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- Anne Rutlidge (Biosis Research)
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ABBREVIATIONS

DPI	NSW Department of Primary Industries
GPS	Geographic Positioning System
MDS	Multi-Dimensional Scaling
PLDC	Penrith Lakes Development Corporation
sp.	Species (singular)
spp.	Species (plural)
ssp.	Subspecies
var.	Variety

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1 SUMMARY

Biosis Research was commissioned by the Penrith Lakes Development Corporation to undertake the 2008 survey of macrophytes in the main lakes and detention basins of the Penrith Lakes System. A total of nine water bodies in the Penrith Lakes System were surveyed for macrophyte species composition and density, including the main recreational lakes of the Sydney International regatta Centre.

A wide variety of macrophytes were recorded from transects in the lakes and random meanders in the lagoons. A total of 430,149 m^2 of macrophytes were mapped across the nine lakes that were surveyed, compared with over approximately 350,000 m^2 in 2007. In general, the increase in cover from 2007 was contributed to by growth of submerged macrophytes. Emergent macrophyte cover tended to decrease for most lakes and most species.

The majority of lakes had macrophyte communities that were in good condition with some areas of moderate grazing or dieback that may have been associated with weed control activities. The exceptions to this were Duralia Lake, where macrophyte beds in the deeper areas had declined, and Final Basin, where emergent macrophyte beds along the lake's edge have declined sharply.

A total of 34 species of aquatic plants and two taxa of macroalgae were recorded in the surveyed lakes. The majority of these taxa were emergent (20 taxa) or submergent (15 taxa) with only seven taxa of floating macrophyte present. The suite of aquatic macrophyte species present within the Penrith Lakes system includes species with a range of hydrological requirements and tolerances. This endows the community with some resilience to changes in water level. This was evident particularly in the colonisation of new areas of Duralia Lake by macrophytes in response to changing water levels at lakes, despite a decline in populations in other sections that are now assumed to be too deep for macrophytes to persist.

There have been large increases in the cover and extent of submerged macrophytes at the two recreational lakes, Regatta Lake and Warmup Lake, mostly driven by expansion by *Hydrilla verticulata*. This creates a potential management issue, since this long-leafed water plant can interfere with the operation of boats. Weed matting laid to prevent the growth of submerged aquatic plants including *Vallisneria gigantea* in critical areas of the lakes was previously effective, however *H. verticulata* has now expanded at these lakes and covers 59 % and 36 % of the lake areas of Regatta and Warmup Lakes respectively.

The control of the two noxious species *Eichhornia crassipes* (in West Wilchard Wetland) and *Salvinia. molesta* (in Warmup Lake and Northern Pond) continues.

S. molesta was not found on any transects in Northern Pond in the 2008 survey, which suggests that the control methods have successfully eradicated the species from the lake. However, control measures at the other two lakes have not been as effective. The proliferation of *S. molesta* at Warmup Lake is a problem, with the lake experiencing a six-fold increase between 2007 and 2008. Similarly, *E. crassipes* was recorded for the first time at West Wilchard Wetland in 2007 and its cover has since expanded more than seven-fold between 2007 and 2008, despite spraying. Duck Pond, where *S. molesta* was recorded in 2007, was not surveyed in 2008. It is possible that spraying of *S. molesta* amongst *Typha* sp. beds within Warmup Lake has inadvertently been killing *Typha* sp. as well, thereby increasing available habitat for *S. molesta.* Recruitment may therefore be exceeding mortality in this case, hence the use of a different control method utilising calcium dodecylbenzene sulfonate has been recommended. This herbicide works mechanically by causing *S. molesta* plants to sink and drown and has no effect on surrounding reeds and rushes.

Increases in water level at Duralia Lake have resulted in a reduction in the extent of submerged macrophyte communities, however emergent macrophytes have begun to flourish. Although submerged macrophytes remain important to regulate water quality and trap sediments, the growth in emergent macrophytes should compensate somewhat for their loss. At the end of 2007, Duralia Lake began to be used for wakeboarding. The continued influence of wakeboarding on macrophyte communities (and vice-versa) should continue to be monitored. Speedboat activity in the lake could mechanically damage established macrophyte communities or prevent colonisation, hence excessive growth of macrophytes in sensitive areas can hinder recreational boating activities.

Blooms of an unknown algae were observed in Final Basin (and have also been observed on previous occasions). Whilst this may not represent a health concern at the moment, it may still be pertinent to take steps to prevent future blooms. One approach to this would be to establish fast growing macrophytes in the lake, thus greatly reducing the available nutrients for algal growth. This could also lead to additional benefits in the lake such as reduced turbidity. Potential candidate species for colonising Final Basin would be *Hydrilla verticulata* or *Potamogeton perfoliatus,* both of which are abundant in the adjoining Regatta Lake. This would have to be carefully considered, however, as considerable effort is made to control these species in the Regatta Lake and it would be ill advised to create a potential invasive population in Final Basin.

Recommendations for the continued management of macrophytes at Penrith Lakes include

- Continuation of monitoring;

- Continuation and evaluation of methods of control for noxious macrophyte species, with particular attention given to techniques that can reduce incidental damage to surrounding species;

- Investigation into the colonisation patterns of macrophytes after increases in water level;

- Introduction of new herbicide treatments for *S. molesta* that work mechanically rather than chemically in order to reduce accidental damage to neighbouring vegetation;

- Development of planting plans;

- Establishment of mandatory protocols to ensure that any boats entering the lakes (particularly Duralia Lake) are free from fragments of unwanted aquatic macrophytes;

- Continued monitoring to quickly detect the presence of any unwanted species;

- Investigate vegetation plans for Final Basin with fast growing species in order to mitigate against future algal blooms;

- A reduction of sampling effort in Northern Pond, Final Basin, Warmup Lake and Regatta Lake; and

- Enhanced integration of water level and water quality (turbidity) data with macrophyte monitoring data for future surveys.

2 INTRODUCTION

Biosis Research was commissioned by Penrith Lakes Development Corporation (PLDC) to undertake the third annual survey of aquatic macrophyte communities within the major lakes and detention basins of the Penrith Lakes System. This survey follows on from previous surveys that assessed fifteen different water bodies within the system between 2006 and 2007.

Macrophytes in the Penrith Lakes system serve a number of beneficial functions including regulation of water quality, bank protection, enhancing the aesthetic quality of the lakes and providing aquatic habitat for wildlife. Dense beds of macrophytes are not always beneficial, however, as they can create management or conservation issues if excessive growth disrupts recreational activities and water flow, or if exotic macrophyte species are inadvertently introduced into the system. The Penrith Lakes macrophyte survey programme has therefore been developed in order to provide PLDC with the necessary information to successfully manage this important aspect of the lakes ecosystems.

2.1 Aims

The broad aim of the current study was to revisit specific locations within selected Penrith Lakes water bodies and collect survey data about macrophyte diversity, abundance and range. These results were then compared to previous years' surveys in order to explore patterns and identify any trends that may be of significance to ongoing management.

The major tasks of the study were to:

1. Survey selected major lakes in the PLDC area;
2. record and identify all species and augment the existing PLDC aquatic plant herbarium;
3. map the densities and growth habits of macrophyte communities in each selected lake;
4. compare changes in macrophyte communities between years and between lakes;
5. identify exotic weeds, record their location and assess the effectiveness of control actions to date and;
6. provide recommendations on the future management of macrophyte populations.

2.2 Study Area

The Penrith Lakes System is a series of artificial lakes on the historic floodplain of the Nepean River below Penrith Weir. The lake system is being developed by PLDC as the rehabilitation of ongoing sand and gravel quarrying in the area.

At present, some of the lakes are utilised for recreational activities and water storage. They also provide aesthetic, environmental, water quality control and recreational functions that include the International Rowing Centre and White Water Centre.

The system currently contains two major lakes, a series of water quality control ponds, several offline ponds and several retarding basins within the quarry and public areas of the Penrith Lakes Scheme (see Figure 1). The overall system of lakes, their connectivity, total volume, shoreline structure and design continue to change as the project is developed by PLDC.

Whilst there are fifteen water bodies within the Penrith Lakes System, only nine of these were surveyed during the 2008 season. Table 1 provides a summary of the survey history for each of the lakes and ponds to date.

Table 1: Penrith Lakes Assessed in the 2006, 2007 and 2008 Study

Lake	2006 Survey	2007 Survey	2008 Survey	Survey type
Warm-up Lake	✓	✓	✓	Transect
Rowing Lake (also referred to as Regatta Lake)	✓	✓	✓	Transect
Final basin	✓	✓	✓	Transect
Middle Basin	✓	✓	✓	Transect
Northern Pond	✓	✓	✓	Transect
Cranebrook Lake	✓	✓	✓	Transect
Duralia Lake (previously referred to as Boyces Lake)	✓	✓	✓	Transect
West Wilchard Lagoon	X	✓	✓	Transect
Escarpment Lagoon (previously referred to as Castlereagh Pond)		✓	✓	Transect
Main Lake A	✓		X	Transect
Duck Pond	X	✓	X	Transect
Quarry Lake	X	✓	X	Transect
Boyces Lagoon	X	✓	X	Random meander
Cranebrook Lagoon	X	✓	X	Random meander
One Tree Lagoon	✓	✓	X	Random meander

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Figure 1: Overview of the Study Area.

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Scale: 0 0.25 0.5 0.75 1.0 kilometres

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3 METHODS

The current survey was undertaken during March and April 2008 by two aquatic ecologists. As indicated in Table 1, mapping of macrophyte beds was undertaken in the nine larger lakes and ponds. Weather during the surveys was generally sunny with occasional overcast conditions and showers. Approximately 35 mm of rainfall was recorded within the seven days prior to the start of, and during the survey.

3.1 Taxonomy

The plant taxonomy field guides used to classify macrophytes in this report were based on information from the NSW Herbarium and identification guides developed by Robinson (2003) and Sainty and Jacobs (1994). Macrophytes were always identified to species level if possible, although macroalgae was identified to genus level. The taxonomy of many macrophyte species is unclear or currently under revision, for example, *Vallisneria* species within NSW are considered by the NSW Herbarium to be *Vallisneria gigantea*, however other authors (e.g. Sainty 1994) describe the species as *Vallisneria americana*. *V. gigantea* is used in this report, but it should be noted that this species may contain several similar taxa and the taxonomy of this group is by no means clear.

For some species, the fruiting or flowering bodies are required for positive identification. During the time of the survey, not all species were fruiting or flowering and therefore some species could not be definitively identified. Where this was the case, these species have been given a provisional identification only. In the body of the report, plants are referred to by their scientific names only.

3.2 Macrophyte Survey

Biosis Research designed a methodology for the monitoring and mapping of macrophytes in the Penrith Lakes, based on King and Barclay (1986), (Biosis Research 2005). This methodology was used in the 2006, 2007 and the current survey.

Due to their size and volume, a complete survey of the Penrith Lakes was not feasible. Instead, a transect approach was used to survey as much area as possible in each lake. This approach involved subdividing the shoreline of each lake into discrete shoreline units of between 100 m and 500 m in length, as shown in Appendix 1. The number of shoreline units was roughly proportional to the size of each lake. Within each shoreline unit, three randomly located transects were laid perpendicular to the shore and all macrophytes along the transect were recorded. Transects were continued out from the shoreline until macrophyte growth was no longer encountered, the mid-point of the lake was reached (i.e. the point at which transects from opposite shores would reach each other) or, in the case of smaller ponds, the opposite shore was reached. The shoreline position of each transect was recorded using a GPS.

Transects were undertaken by the following means:

- direct observation whilst wading or from a boat;
- snorkelling close to or along the lake bottom;
- raking with a long handled rake and/or;
- dredging with a heavy weighted tow line behind a boat.

Due to the small relative sizes of Boyces Lagoon, Cranebrook Lagoon and One Tree Lagoon, these had been sampled in previous surveys with a random meander approach that did not involve mapping, placement of transects or division of the into shoreline units. In 2008, these three lagoons were not surveyed (as mentioned in Table 1).

Along each transect, macrophytes were classified into a vegetation zone that described both the composition of species and their density. For each zone, the start and end distance along the transect was recorded, along with the ‘abundance’ (density) and ‘sociability’ (growth form) of each species in the zone, after the classifications of King (1986). A cover index resulting from the combination of each abundance and sociability score was assigned, using the matrix detailed in Table 2. These cover indices allowed for assessment of both the health and density of macrophyte beds, rather than restricting monitoring and analyses to simple measures of area (Biosis Research 2005). As can be seen from Table 2, higher ratios are assigned to higher density patches.

Table 2: Definitions of abundance and sociability ratings, and cover indices which result from a matrix between these (after King 1986).

		COVER INDEX		
		Sociability Rating		
		a Individual strands or clumps	b Patches of growth up to 10 m	c Beds of relatively even distribution
Abundance Rating	1 Sparse growth (<15 % cover)	0.05	0.10	0.15
	2 Moderate growth (15-30 % cover)	0.15	0.25	0.35
	3 Abundant growth (>30 % cover)	NA	0.60	0.65

3.2.1 Herbarium Specimens

A herbarium of aquatic plants was developed for Penrith Lakes from samples taken during the 2006 and 2007 surveys. The herbarium is designed to assist PLDC staff to identify macrophytes encountered during management activities.

Small samples of macrophytes were taken, identified to species level and then pressed and dried for inclusion in the herbarium. The growth form and lakes in which the species occurred was recorded and noted next to the sample.

3.2.2 Macrophyte Condition Assessment

The general condition of macrophytes was noted and included:

- flowering;
- detachment of emergent and submergent species;
- rotting of fronds or discolouration;
- epiphytes and:
- grazing.

Any evidence of planting or control of macrophytes was recorded. Observation was also made of the lake substrate as changes in the type of substrate can effect the distribution and growth of submergent macrophytes.

3.3 Mapping

Mapping of the macrophyte communities in a lake provides a visual representation of the extent and area of macrophyte beds. Mapping also allows the calculation of area and coverage for analysis of the extent and change in macrophyte communities.

In order to map the macrophyte beds, a series of spatial guides were created. A general lake boundary was drawn based on available aerial photography and digital contour data for the Penrith Lakes area. Each transect was recorded using GPS during the field survey and then overlaid onto the digital lake boundary. GPS waypoints were used to identify the points at which macrophyte zones changed in species composition, abundance and/or sociability. All transects were assumed to be perpendicular to the shoreline.

Using the waypoints as a guide, polygons were created to represent the boundary of each macrophyte species. For each species an individual polygon was created for each change in abundance and sociability indices, which allowed for improved analytical evaluation of the data. Where possible, polygons of matching species abundance and sociability were given common boundaries to create a homogeneous coverage for each species. The shape of each polygon was determined by whether the species appeared along adjoining transects as well as the general lake boundary. The limits to which a polygon extended along the shoreline was determined by either major changes in the shoreline or by arbitrarily ending the polygon if a matching species coverage was not identified on adjoining transects. Typically, a midpoint between transects was chosen as the end of a polygon, unless indicated otherwise from the field survey or examination of aerial photography.

Where multiple species were located in the same area, individual polygons were created for each species and further subdivisions made if the one species had different abundance and sociability indices. These polygons were overlaid on top of one another in order to reduce the complexity of the graphical presentation.

3.4 Analyses

To characterise and compare macrophyte communities within and between lakes, and between survey years a number of analyses were performed using the abundance and sociability data.

In the analyses, “area” referred to the area within the mapped boundary of macrophyte species, regardless of abundance or sociability indices. “Cover” referred to the approximate density of the macrophyte species by taking into account both the abundance and sociability recorded.

3.4.1 Quantitative differences in macrophyte communities

The following calculations were made for each lake to describe the macrophyte communities:

- Total area of macrophytes- the total area covered by all macrophyte species (maximum possible value was 100 % of the lake area).

- Total cover per species- a measure of cover that incorporated both total area (in square metres) and abundance/sociability (density and growth form). For each patch of a species, the area of the patch was multiplied by the cover index (from the abundance-sociability matrix: Table 2) and these values of all patches are summed. In this way, for two patches of equal area in square metres, a sparse patch received a lower cover index than a dense patch. Total cover per species was expressed in square metres and, due to the cover index, was a proportion of (i.e. was lower than) total area for that species.

The following graphs were prepared from the above data:

- A comparison of changes in macrophyte species composition within each lake over time and total cover of each species for the 2006, 2007 and 2008 surveys.

- A comparison of changes in dominance of submerged, emergent and floating macrophytes. Similar graphs were prepared using the species' cover values pooled between species that shared the same vegetation (submerged, emergent and floating). As species/life forms often overlapped in their mapped area, the sum of covers for every species could be greater than 100 %.

At each lake, there was high variability (typically several orders of magnitude) in cover between the most abundant and least abundant species. In order to compensate for this graphically, a $\log_{10}$ scale was used for y-axes. This approach allowed data to be displayed at both ends of the scale. Because it is not possible to take the log of zero, a data transformation was required (the cover value in metres squared plus one metre squared, or x+1) to enable data to be graphed. See

3.4.2 Comparisons of macrophyte community composition

Non-metric Multi Dimensional Scaling (MDS: Clarke and Warwick 1994) ordinations were used to visually represent the similarity of macrophyte communities between lakes and between years. MDS ordinations provide an easily interpreted image of the relationship of study sites to each other that takes into account species composition and density. No statistical expertise is needed to interpret the ordinations as, in essence, the most similar survey sites are located close together on the MDS and the least similar are furthest apart.

MDS ordinations can be presented in either a 2-dimensional (2D) or 3-dimensional (3D) format, with the choice guided by how well each format represents the true relationship between points. How well the ordination fits the relationship is described by a measure called "stress value". In general, stress values of 0.2 or less indicate that a format provides a good representation and, wherever possible, 2D formats are used to simplify interpretation.

MDS ordination analysis of the 2008 data was undertaken to determine the relationship of macrophyte communities between the lakes. A comparison between the current and previous years' surveys was used to display any change in relationships within and between the survey years.

The variables chosen for analysis by MDS ordination were Relative Cover and Presence/Absence of each species in each lake. Relative Cover takes into account the cover of the macrophyte patches as well as lake area, allowing more valid comparisons between lakes of different sizes.

Relative Cover is the cover of each species per square metre of lake area, expressed as a percentage:

$$RC_{xy} = \frac{(\sum A_{xi} C_{xi}) \times 100}{L_y}$$

where RC_{xy} is the Relative Cover of species X in Lake Y; A_{xi} is the area of the i^{th} patch of species x in Lake Y; C_{xi} is the cover index for the i^{th} patch of species x ; and L_y is surface area of Lake y.

Assessments using the presence or absence of species in each lake removes the effect of species density, an example of which is large dense patches of one species, common in many lakes, which would otherwise skew the relationships. That is, this variable focuses solely on the relationships between the diversity of the macrophyte communities in the lakes.

In addition, of emergent and submergent communities were examined separately. The advantage of this approach is that the management of emergent species and submergent species differs between lakes. Lakes such as Rowing Lake, for example, have minimal emergent diversity and cover to facilitate the lake's recreational uses.

3.5 Limitations

This study was designed to provide the best possible representation of macrophyte communities with limited time and resources. Due to the random placing of transects, some small patches of macrophytes or species may not have been intersected and therefore are not represented on the overall mapping or species lists. In addition, small patches of macrophytes were generally intersected by only one transect and therefore the exact size of the patch was probably not determined. Where possible, when plants or species that were known to be new to a given lake were observed either singularly or outside a transect, they were included as opportunistic observations in the species lists.

4 RESULTS AND DISCUSSION

A total of 430,149 m^2 of macrophytes were mapped across the lakes, with different lakes displaying various macrophytes communities.

4.1 Species

A total of 34 species of aquatic plants and two taxa of macroalgae were recorded in the surveyed lakes. The majority of these taxa were emergent (20 taxa) or submergent (15 taxa) with only seven taxa of floating macrophyte present. Three exotic macrophytes were observed, including two noxious species: *Salvinia molesta* and *Eicchornia crassipes*. The species recorded in each lake can be found in Appendix 3: Species List.

Two new species were recorded in the Penrith Lakes during the 2008 surveys, both of which are Australian natives. The first of these was *Phylydrum lanuginosum*, a small emergent perennial, that was recorded in West Wilchard Wetland. The second was *Triglochin microtuberosum*, an emergent that was recorded in Cranebrook Lake and West Wilchard Wetland.

4.2 Overview of lakes

The macrophyte cover in the lakes varied from 5 % to 79 % of the total area. The deep, turbid lakes which form the treatment system for water entering Regatta and Warmup Lakes had the lowest cover of macrophytes (5-21 %). Regatta and Warmup Lakes had moderate coverage of macrophytes (39-56 %), with the highest cover occurring in the shallow Escarpment Lagoon (referred to in previous reports as ‘Castlereagh Pond’) (63 %) and in West Wilchard Wetland (79 %), which is comprised of two deep ponds connected by a narrow channel (Table 3).

Table 3: Macrophyte cover of survey lakes

Lake	Area (m^2)	Macrophyte cover (m^2)	Macrophyte cover (% lake area)	Description
West Wilchard Wetland	4,125	3,257	79	Two deep ponds connected by a narrow channel
Escarpment Lagoon	26,745	16,793	63	Shallow, long, narrow
Cranebrook Lake	28,770	6,042	21	Deep, turbid retention basin

Duralia Lake	121,316	18,090	15	Deep, generally clear, lake conditions changed in 2008
Northern Pond	69,894	4,991	7	Deep, turbid retention basin
Final Basin	87,487	6,022	7	Deep, turbid retention basin
Middle Basin	141,271	6,886	5	Deep, turbid retention basin
Rowing Lake	385,927	215,004	56	Recreation, boating
Warm Up Lake	395,002	153,066	39	Recreation, boating

4.2.1 Warmup Lake

Warmup Lake provides a venue for a wide variety of recreational activities including boating, fishing and white water rafting. The lake also serves as a marshalling area for events on Regatta Lake. The substrate of Warmup Lake is predominantly silt, with some areas of gravel and cobble in the boat launching areas, such as near the White Water Centre and the management building. As the lake is managed for boating, there was some evidence of substrate scouring observed and laying of weed matting to reduce the growth of macrophytes. A total of 17 species of macrophytes were identified in the Warmup Lake representing a well developed community of both emergent and submergent macrophytes.

Aquatic vegetation at Warmup Lake covered 39 % of the lake area. Since monitoring began, the community has been dominated by beds of submerged macrophytes, which have typically covered three to five times more area than emergent macrophytes. Floating macrophytes are present at much lower levels (approximately one order of magnitude lower than emergent macrophytes), yet still cover a substantial portion of the lake area. (Chart 1).

The cover of submerged macrophytes at Warmup Lake has increased consistently over the period of monitoring. From 2006 to 2007 there was an expansion in the width of bands of submerged macrophytes all around the shoreline, and in 2008 the increase in cover was due mainly to proliferation in the eastern corner of the lake. (Where beds of *V. gigantea* in 2007 extended to approximately 20 m from the eastern bank, there are now beds of *Hydrilla verticulata* and *Potamogeton* spp. extending approximately 190 m from the eastern bank). These increases have been driven mainly by the consistent and rapid increase in *H. verticulata* (2,448 m^2 in 2006; 7,530 m^2 in 2007; and 31,244 m^2 in 2008). *Chara* sp., *Nitella* sp. and *Potamogeton ochreatus* have also increased consistently over the three years of study. *H. verticulata* has overtaken *V. gigantea* as the dominant species of submerged macrophyte in the lake, with the latter experiencing a slight decline from last year and now covers 18,569 m^2. In contrast, some submerged macrophyte species have declined in cover, including *Potamogeton crispus* and *Potamogeton perfoliatus*, the latter being absent from transects in 2008 (Chart 2).

After expanding between 2006 and 2007, beds of emergent macrophytes have contracted slightly between 2007 and 2008, mostly because of a contraction of the width of bands around the lake edge. This pattern is largely contributed to by the dominant species *Typha* sp. Between 2006 and 2007, beds of *Typha* sp. around the edge of the lake expanded substantially (despite being impacted by herbicide spraying to control *S. molesta*), but by 2008 these beds have again receded to a cover similar to that observed in 2006 and now cover 9,826 m^2. This decrease may be due to further applications of herbicide. Other emergent macrophytes have shown varying patterns of change over the three years of monitoring. Most species experienced a decrease in cover between 2007 and 2008, including (in order of dominance) *Juncus usitatus, Cyperus eragrostis, Persicaria decipiens* and *Baumea articulata*. The only species that experienced an increase in cover between 2007 and 2008 is *Phragmites australis* (Chart 2).

Despite efforts to control it through chemical spraying the noxious floating macrophyte *S. molesta* continues to proliferate and expand its cover across the lake. Again, this species was found along the shoreline amongst stands of emergent macrophytes, particularly *Typha* sp. The species was not recorded at the lake in 2006 surveys, but had established itself by 2007 and chemical spraying took place to control it. The 2007 monitoring occurred shortly after this spraying and *S. molesta* was recorded over an area of 221 m^2. By 2008, despite a further herbicide application, *S. molesta* had expanded by more than a six-fold increase from 2007, to cover 1,470 m^2. This expansion has occurred mainly by a linear extension of the range around the lake shore, rather than an increase in the width of patches. At the time of survey in 2008, the species had expanded along both the southern and northern shorelines, but remained absent from the western shoreline. The large increase in cover of *S. molesta* has been the driver of increases in the total cover of all floating macrophytes throughout the three years of monitoring. Other floating macrophytes (*Azola* sp., *Marsilea mutica* and *Myriophylum varifolium*) have experienced varying patterns of change in cover over the three years of study. It was previously reported that competition with *S. molesta* (and herbicide spraying) may have resulted in a decline in *Azola* sp., however there has been a concurrent increase in both of these species between 2007 and 2008 (Chart 2).

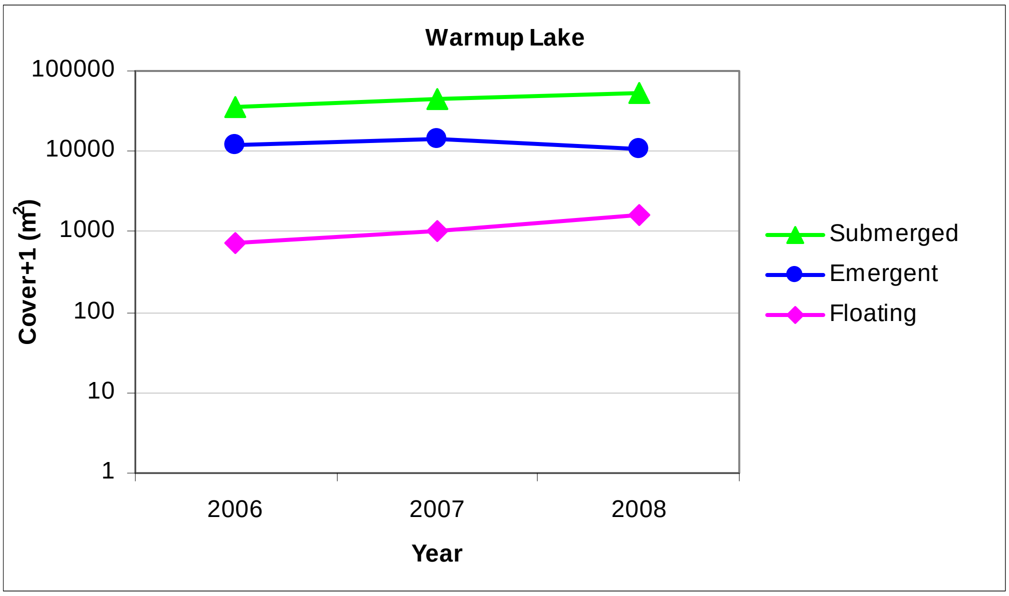

Chart 1: Changes in the cover of submerged, emergent and floating aquatic macrophytes at Warmup Lake from 2006-2008. Note logarithmic scale of y-axis (Appendix 2).

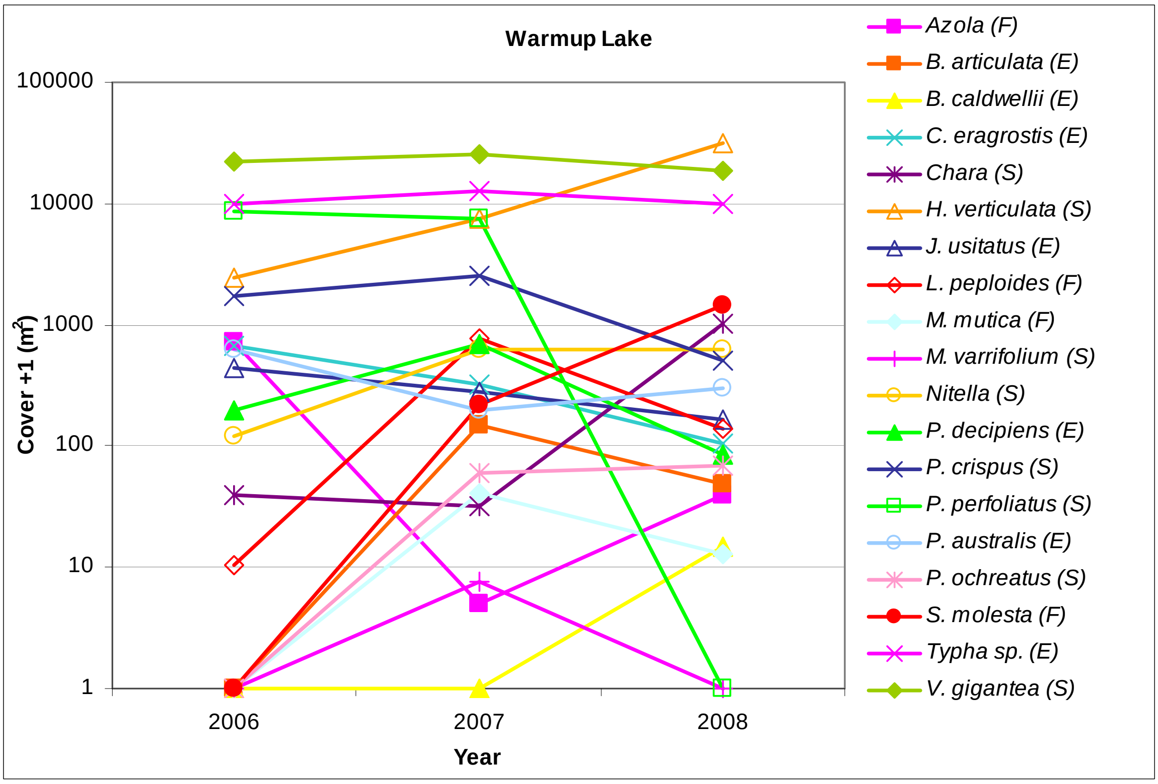

Chart 2: Changes in the cover of aquatic macrophyte species at Warmup Lake from 2006-2008. Note that the logarithmic scale of y-axis (Appendix 2).

4.2.2 Regatta Lake

Regatta Lake is specifically designed for sport and recreational activities. It has a rock cobble bank and several pontoons and wharfs. The substrate in the rowing lanes is lined with weed matting and macrophytes are harvested to prevent disruption of rowing events.

Aquatic vegetation is prolific and expanding at Regatta Lake, now covering 56 % of the lake area. The aquatic vegetation community is dominated by submerged macrophytes, with cover of these species being two orders of magnitude higher than that of emergent macrophytes. Floating macrophytes have not been recorded at the lake over the three years of monitoring (Chart 3).

Submerged vegetation has consistently increased in cover over the monitoring period, driven by patterns of change in the three dominant species, *H. verticulata*, *V. gigantea* and *P. perfoliatus*. These species now cover 103,581 m^2, 29,158 m^2 and 14,703 m^2 respectively. The expansion of these species has occurred through a widening of the band of submerged macrophytes towards the centre of the lake, in both monospecific patches of *H. verticulata*, or two to three species assemblages consisting of *H. verticulata* with *P. perfoliatus* and/or *V. gigantea*. Snails (species not identified) were noted feeding on *V. gigantea*. Where submerged vegetation previously occurred between 2-30 m from the shore, this distance has now increased to 62 m. The other submerged macrophyte species have experienced varying directions of change in cover over the three years of monitoring. The alga *Nitella* sp. was a dominant member of the community (covering 1,030 m^2 and 2,255 m^2 in 2006 and 2007 respectively) but has contracted and now covers only 26 m^2. *M. varifolium*, *P. perfoliatus* and *Potamogeton ochreatus* have all declined in cover between 2007 and 2008. The alga *Chara* sp. was recorded only in 2007 (Chart 4).

Due to the cleared and heavily cobbled shore, there are relatively few areas of emergent macrophytes, restricted to narrow bands on the southern shore, composed of (in order of dominance) *Typha* sp., *P. australis* (recorded for the first time in 2008), *Schoenoplectus mucronatus*, *Cyperus eragrostis* and *J. usitatus*. *P. decipiens* were recorded in 2007 but were not found in 2008. The area of emergent macrophytes has declined slightly since 2007 (Chart 4).

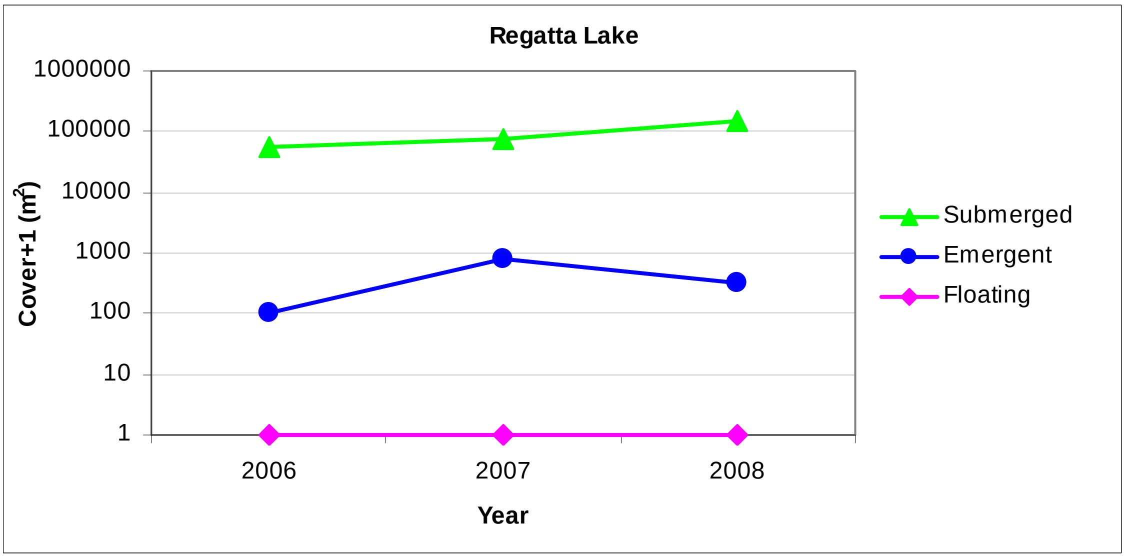

Chart 3: Changes in the cover of submerged, emergent and floating aquatic macrophytes at Regatta Lake from 2006-2008. Note logarithmic scale of y-axis (Appendix 2).

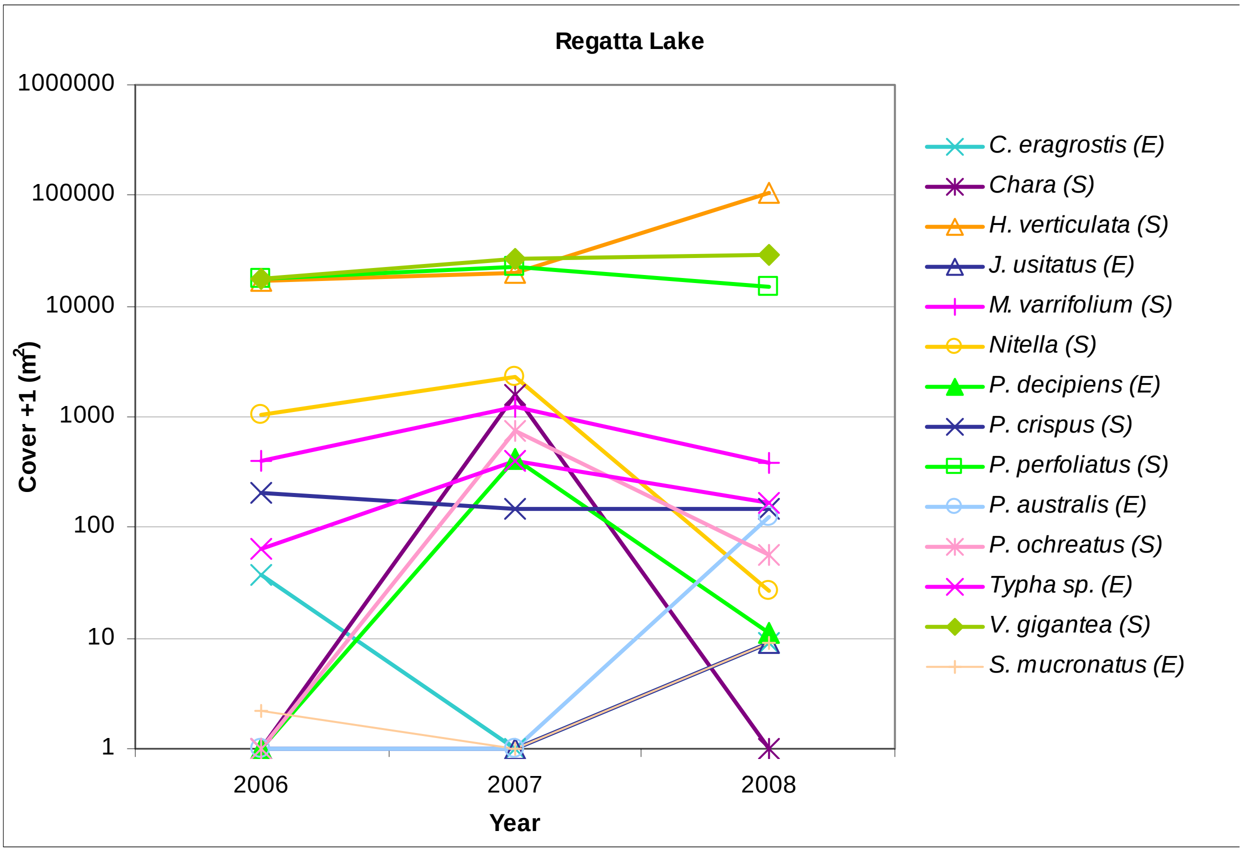

Chart 4: Changes in the cover of aquatic macrophyte species at Regatta Lake from 2006-2008. Note that the logarithmic scale of y-axis (Appendix 2).

4.2.3 Final Basin

Final Basin is part of the water treatment chain for water entering Regatta Lake. It is utilised for infrequent recreational activities, primarily fishing and model boating. The substrate of the lake is generally cobbles near the edge, with sand and silt in the deeper areas.

Since monitoring began, Final Basin has been characterised by a low coverage of aquatic macrophytes (6.9-9.2 % of the lake area over the three years of monitoring; Table 3, data not shown), existing in bands in shallow water around the edges of the lake. High turbidity and subsequently low light penetration probably contribute to this low cover. In 2006, emergent macrophytes were the dominant life form, with submerged and floating macrophytes each covering one third of the area of emergent macrophytes. However, changes in water levels have apparently led to a change in community composition over the three years of study, with submerged macrophytes now forming the dominant component, followed by floating macrophytes. Emergent macrophyte beds that used to occur in a continuous band around the lake up to approximately 10 m wide have contracted and are now absent from parts of the lake shore (Chart 5).

The decline in cover of emergent macrophytes has been continuous since 2006, but has intensified greatly between 2007 and 2008. Emergent macrophytes now cover only 2 % of their 2006 extent. This decline is likely to be due to an increase in water levels. All emergent macrophyte species have been lost from the lake except for *Baumea articulata*, which now persists as two small patches on the south-western and northern banks. *Baumea articulata* now covers 92 m^2. Species present in 2007 and absent in 2008 include *J. usitatus*, *P. decipiens*, *S. mucronatus* and *S. validus*. Although *J. usitatus* and *S. mucronatus* initially showed greater tolerance to high water levels than *C. eragrostis* and *P. decipiens* (the former two persisted into 2007 despite inundation), they have now succumbed to high water levels (Chart 6).

Submerged macrophytes experienced an increase in cover between 2006 and 2007, followed by a decrease in cover between 2007 and 2008. Final Basin is now dominated by submerged macrophytes, with the dominant species being *V. gigantea* which now covers 531 m^2. There has been a slight contraction of the cover of *V. gigantea*: in 2007 it was recorded as patches in the sediment and protection traps for the inlets on the southern, northern and eastern banks, in 2008 it was mostly clear from these areas. *P. crispus* and *P. perfoliatus* both cover 17 m^2. The alga *Nitella* sp. was found only in 2006. Only one species of floating macrophytes was present at the lake in 2008, this being *Marsilea mutica*, which now covers 393 m^2 in the south-east and north-east corners of the lake (Chart 6). The persistence of both *V. gigantea* and *M. mutica* is presumably due to the tolerance of these species to varying water levels, particularly *M. mutica* which has a floating leaf attached to creeping rhizomes on the substrate.

Several algal 'blooms' have been observed in Final Basin, including during the most recent survey.

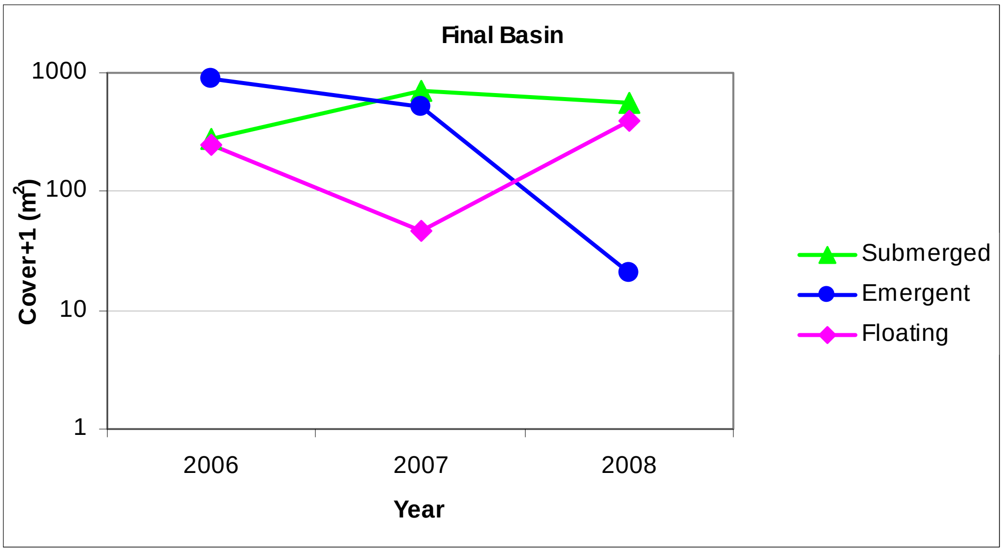

Chart 5: Changes in the cover of submerged, emergent and floating aquatic macrophytes at Final Basin from 2006-2008. Note logarithmic scale of y-axis (Appendix 2).

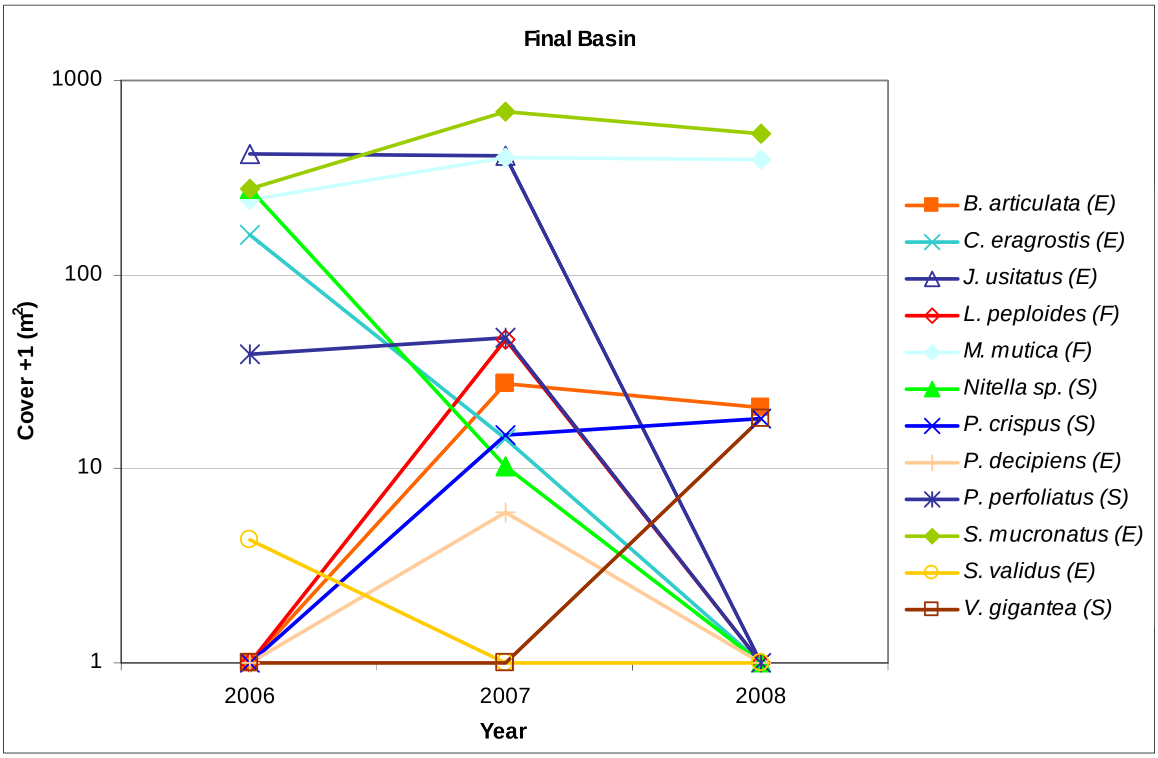

Chart 6: Changes in the cover of aquatic macrophyte species at Final Basin from 2006-2008. Note that the logarithmic scale of y-axis (Appendix 2).

4.2.4 Middle Basin

Middle Basin is part of the water treatment chain for catchment water entering Regatta Lake and is currently located within the quarry area. As such, it has no acknowledged recreational uses. The substrate of the lake is predominantly silt.

Middle Basin is characterised by low cover of aquatic macrophytes, which underwent a four-fold increase between 2006 and 2007 (2 % of the lake area to 9 %), before halving between 2007 and 2008 (5 %; Table 3, data not shown). Emergent macrophytes have consistently been the dominant vegetation at the lake over the three years of monitoring, forming narrow (mostly up to ~3 m) bands of a mixture of species around the lake shore and on shallow banks in the north of the lake. Submerged and floating macrophytes have shown opposite trends to each other, with submerged macrophytes increasing over the three years of monitoring, whilst floating macrophytes have declined and were not recorded in 2008. The cover of submerged macrophytes is now approximately half the cover occupied by emergent macrophytes (Chart 7).

Changing water levels at Middle Basin have apparently had a substantial influence on the aquatic vegetation community, resulting in changing dominance of different macrophyte species and changes in the distribution of vegetation around the lake. An increase in water level occurred between 2006 and 2007, followed by a slight decrease at the time of the 2008 monitoring, however during the 2008 surveys there was evidence of recent higher water levels, including dead emergent macrophytes on the shoreline. This has affected the habitat suitability for species occurring on shallow banks and an island in the north of the lake.

Over the three years of monitoring, the dominance of different species of emergent macrophytes has changed the community structure of Middle Basin. The once-dominant *Typha* sp. was found at moderate levels in 2006 and by 2007 it had experienced a six-fold increase in cover, but by 2008 had declined to approximately half of its 2006 levels. It remains as a large bed on a small island 40 m from the north-western bank. Concurrent with the decline in *Typha* sp., *B. articulata* experienced an increase in cover to 315 m^2 and is now one of the three dominant species of emergent macrophyte at the lake, along with *P. australis* (274 m^2) and *J. usitatus* (224 m^2). *B. articulata* is now established in mixed-species bands and patches along the south-western shoreline and in the southern corner of the lake (Chart 8).

Submerged macrophyte cover expanded rapidly between 2006 and 2007 and has remained relatively stable between 2007 and 2008. This stability is not reflected in the patterns of individual species. *V. gigantea* is the dominant species and has increased steadily over the three years of monitoring, now covering 328 m^2. Whereas *V. gigantea* in 2007 occurred as narrow bands immediately adjacent to emergent vegetation on the shoreline, in 2008 it was recorded in broader bands of varying distance from the lake shore, particularly along the western and southern shorelines. Four species of submerged macrophyte (*M. varifolium*, *P. crispus*, *P. perfoliatum* and *P. tricarinatus*) were recorded only in 2007. *H. verticulata* has approximately halved since 2007 (Chart 8).

Floating macrophytes declined between 2006 and 2007 and were not recorded at the lake in 2008 (Chart 8).

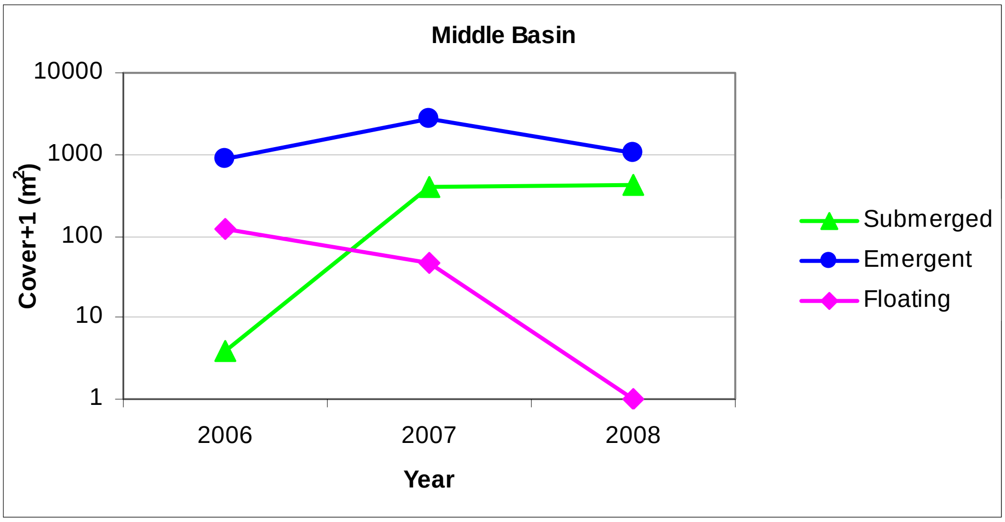

Chart 7: Changes in the cover of submerged, emergent and floating aquatic macrophytes at Middle Basin from 2006-2008. Note logarithmic scale of y-axis (Appendix 2).

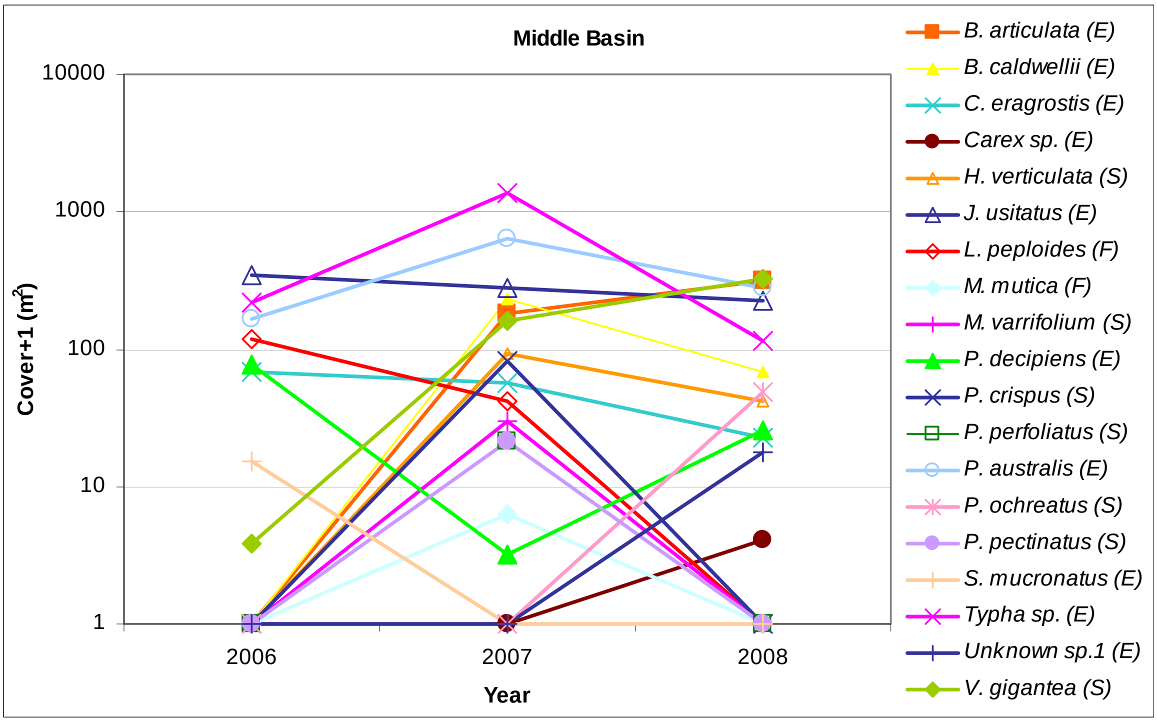

Chart 8: Changes in the cover of aquatic macrophyte species at Middle Basin from 2006-2008. Note that the logarithmic scale of y-axis (Appendix 2).

4.2.5 Northern Pond

Northern Basin is one of the initial water bodies of the water treatment chain for water entering Regatta Lake and is currently within the quarry area with no recreational uses. As in 2007, the lake's turbidity was high and the substrate silty.

The cover of aquatic vegetation at Northern Pond was low compared with most of the other monitored lakes (probably due to high turbidity and low light penetration) and the community has remained very stable in cover and composition over the monitoring period. In 2008, macrophytes covered 7 % of the lake area and this has varied between 6-8 % over the period of monitoring. Emergent macrophytes have consistently been the dominant life form of aquatic vegetation at Northern Pond, with cover remaining stable. The cover of submerged macrophytes has declined over the three years of monitoring, with cover now lower than that for floating macrophytes (Chart 9).

The emergent macrophyte community is quite diverse, comprised of 13 species with similar levels of cover (mostly 10-100 m^2). The exception is *Typha* sp. which dominates the community, consistently exceeding 1,000 m^2 cover since 2006 (currently at 1,209 m^2). *Typha* sp. occurs in a continuous band (mostly up to 3 m width, but up to 15m on the western shore) around the lake. The patch noted in 2007 at the weed curtain in the south-western outlet of the lake has receded substantially. After a decline between 2006 and 2007, *B. articulata* has experienced an increase to more than seven times its 2007 cover, to 149 m^2. It occurred mostly on the western edge of the eastern arm of the lake. Other species have experienced minor fluctuations in cover and dominance over the three years of monitoring (Chart 10).

Of the three floating species previously recorded at the lake, only two species remained at Northern Pond in 2008. The dominant species, *Ludwigia peploides* spp. *montevidensis* covered 63m^2, and *M. mutica* covered 5 m^2. The introduced *S. molesta* was the target of a spraying program in 2006 and has now not been found in surveys since 2006. *S. molesta* previously occurred associated with the emergent *Typha* sp. within the weed curtain on the south-western outlet of Northern Pond (Chart 10).

The cover of submerged macrophytes declined sharply between 2006 and 2007 and continued to decline between 2007 and 2008. *V. gigantea* is the only species remaining, covering only 10m^2 and co-existing with a patch of *Typha* sp. on the western shoreline. Both *Potamogeton crispus* and the alga *Nitella* sp. were absent from transects in 2008 (Chart 10).

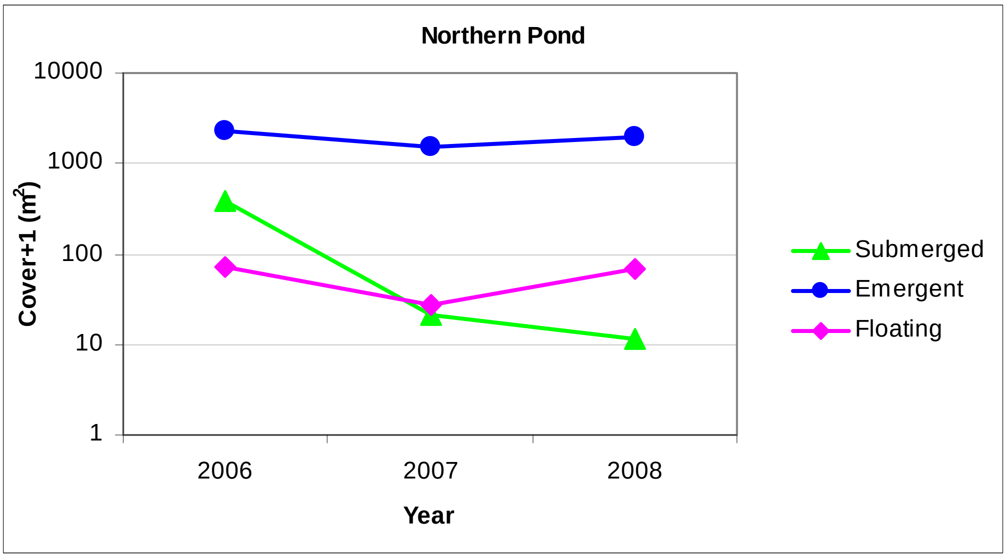

Chart 9: Changes in the cover of submerged, emergent and floating aquatic macrophytes at Northern Pond from 2006-2008. Note logarithmic scale of y-axis (Appendix 2).

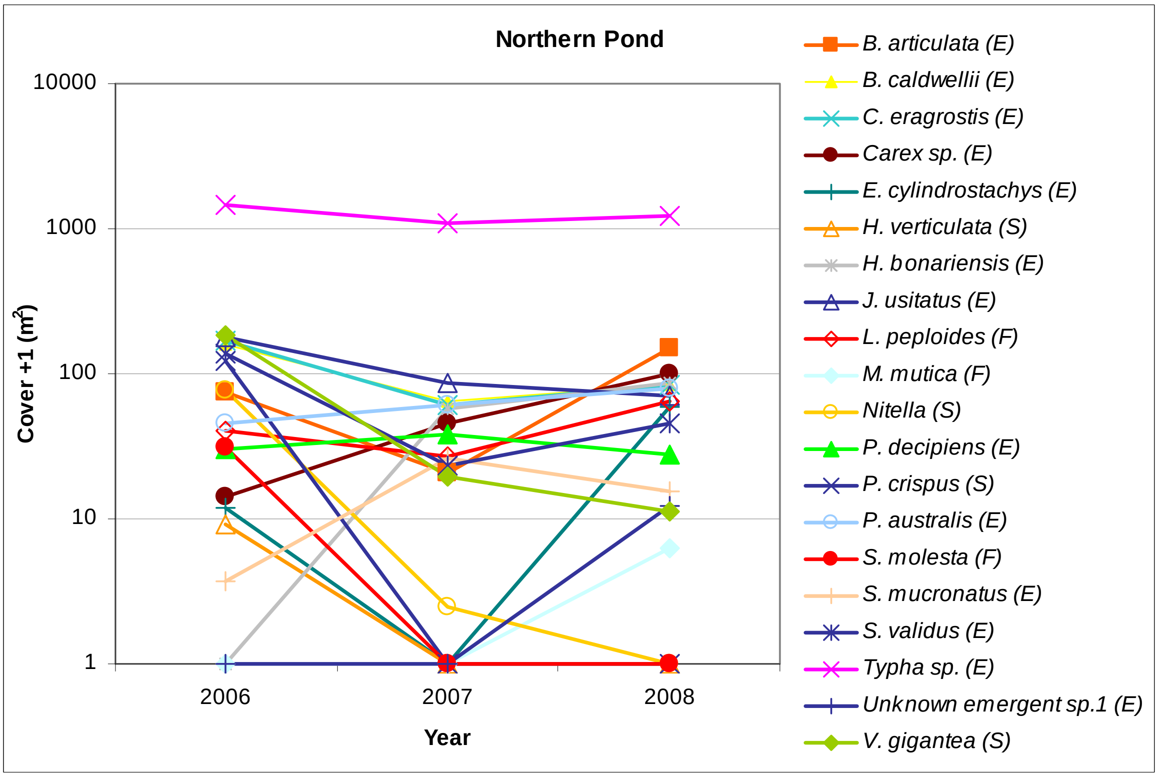

Chart 10: Changes in the cover of aquatic macrophyte species at Northern Pond from 2006-2008. Note that the logarithmic scale of y-axis (Appendix 2).

4.2.6 Escarpment Lagoon

Escarpment Lagoon is a long, narrow, shallow lake which was recently formed during the realignment of Castlereagh Road. The substrate is comprised of very soft soil and silt. It was surveyed for the first time in 2007. The northern half of the lake was almost completely covered by aquatic vegetation, whilst the southern half maintained some areas of open water with no vegetation. As the aquatic vegetation community has continued to develop, the lake has experienced changes in both the dominance of different patch types of macrophytes and species composition.

When the lake was first monitored in 2007, floating macrophytes were the dominant vegetation, however floating species have now declined and submerged species cover the greatest area (Chart 11). Although the cover of emergent macrophytes in 2008 is lower than submerged macrophytes, they have experienced a rapid establishment between 2007 and 2008, and may continue to expand in area in future, as bank vegetation continues to become established.

The cover of submerged macrophytes has increased almost four-fold since 2007, driven mainly by large increases in the cover of the two currently dominant species, *V. gigantea* and an unknown aquatic species. Each now covers approximately 3,700 m^2 in the deeper, central parts of the northern half of the lake (Chart 12).

Emergent macrophytes have increased most rapidly. No species were recorded at the lake in 2007, however a relatively diverse assemblage has now developed, including seven species, all occurring at covers of 30-320 m^2. Emergent macrophytes are now present in a continuous band around the lake shore, with the exception of a small sector in the northern corner. In contrast, the cover of floating macrophytes has experienced a forty-fold decline, mainly due to the loss of the previously-dominant *Ottelia ovalifolia* ssp. *ovalifolia* from the northern parts of the lake (cover of 5,424 m^2, in 2007; and 133 m^2 in 2008) (Chart 12). The noxious floating macrophyte *E. crassipes* was present at the lake in 2007 as scattered submerged plants and patches close to the banks. Control methods applied to the floating growth phase of this weed appear to have been successful, as the species was not recorded in 2008.

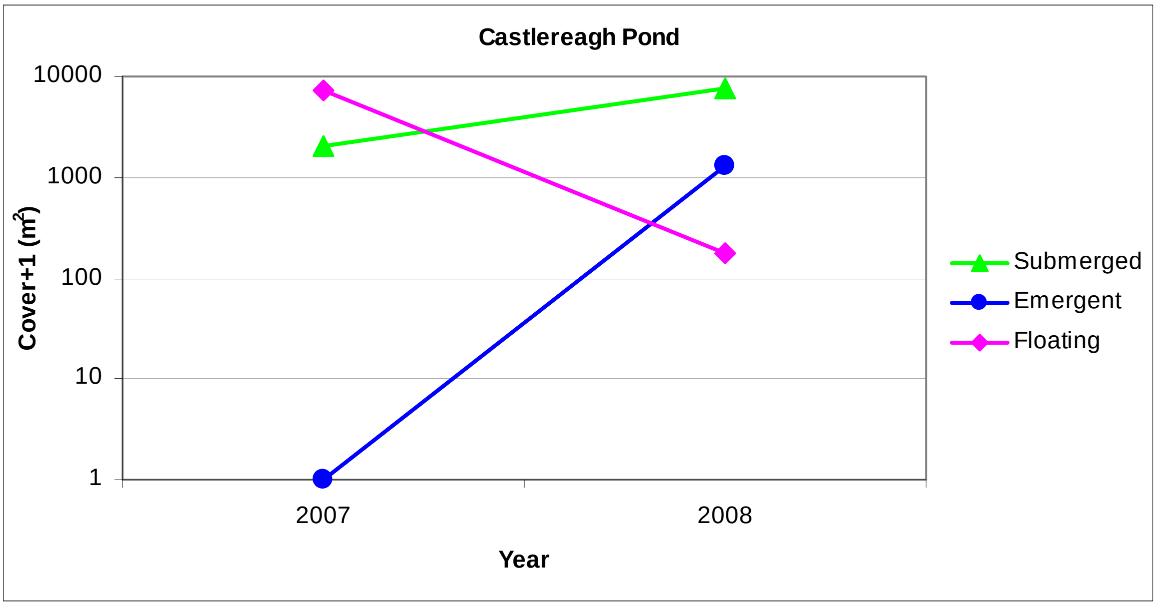

Chart 11: Changes in the cover of submerged, emergent and floating aquatic macrophytes at Escarpment Lagoon (formerly Castlereagh Pond) from 2006-2008. Note logarithmic scale of y-axis (Appendix 2).

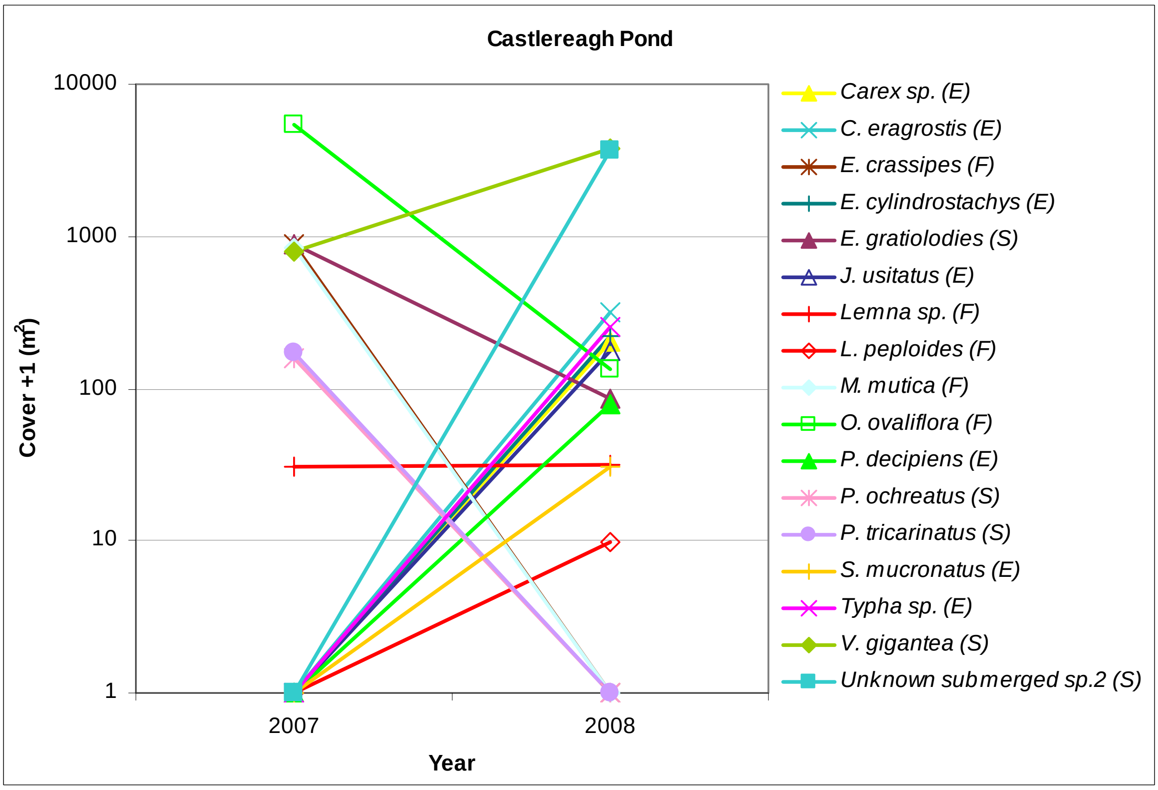

Chart 12: Changes in the cover of aquatic macrophyte species at Escarpment Lagoon (formerly Castlereagh Pond) from 2006-2008. Note that the logarithmic scale of y-axis (Appendix 2).

4.2.7 Cranebrook Lake

Cranebrook Lake forms part of the treatment system for catchment waters entering the recreation lakes. The lake is deep and generally turbid, with areas of macrophyte growth limited mostly to the shallows and edges.

As aquatic vegetation at Cranebrook Lake has continued to establish and mature, the percent coverage of macrophytes has increased from 2 % in 2006, to 3 % in 2007 and 21 % in 2008. Both submerged and emergent macrophytes have shown a consistent increase in the three years since 2006. Floating macrophytes decreased in 2007 followed by an increase in 2008 (Chart 13).

V. gigantea was the only species of submerged aquatic macrophyte to be recorded at Cranebrook Lake. The density and cover of submerged aquatic macrophyte beds continued to increase since the last survey. In 2007, a dense bed of *V. gigantea* up to 6 m from the shore was recorded in the south-eastern corner of the lake. This was the only area supporting submerged macrophytes in the lake. This year, the band of *V. gigantea* has encircled the entire lake in shallow waters near the bank, with the exception of the south-eastern corner of the lake. It has increased from an area of 3 m^2 in 2007 to 1,928 m^2 in 2008 (Chart 14).

A band of emergent macrophytes has also remained present around the lake bank and continued to increase in area (Chart 14). This has generally been a multi-species bands with floating macrophytes interspersed. The emergent *Eleocharis cylindrostachys* has experienced the greatest increase in area, from 4 m^2 in 2007 to 559 m^2 in 2008. It is now found in continuous monospecific and multi-specific stands around the northern half of the lake shoreline, with several other occurrences on the south-western and southern shorelines. *J. usitatus*, the third most prolific species, has also expanded, now covering 186 m^2. In contrast, *C. eragrostis* has declined in cover and is now confined to a narrow band on the north-western shoreline. After experiencing an initial increase in cover (to 159 m^2 in 2007), it has now receded to cover only 10 m^2 in 2008. Other species of emergent macrophytes recorded in the 2008 survey included *Carex* sp., *Eleocharis acuta*, *P. decipiens*, *Triglochin microtuberosum* (new to Cranebrook Lake in 2008) and *S. mucronatus* (Chart 14). Dead, inundated stems of *Carex* sp. were observed during the 2008 survey, suggesting that previous declines in the species' extent (presumably the steep decline recorded from 2006-2007) may have been due to increased water depth.

Floating macrophytes were the least prolific members of the aquatic vegetation community, with total cover an order of magnitude lower than that of emergent and submerged macrophytes. Compared with the latter two, floating macrophytes have maintained a relatively stable cover over the three years of monitoring (Chart 13). They occurred in multi-species assemblages along the same shoreline areas of the lake as the emergent macrophyte bands. As in previous years, *L.*

peploides spp. *montevidensis* was by far the most prolific of the floating macrophytes, covering 80 m^2. The other two species were *M. mutica* (new to Cranebrook Lake in 2008) and *Azola* sp. (Chart 14).

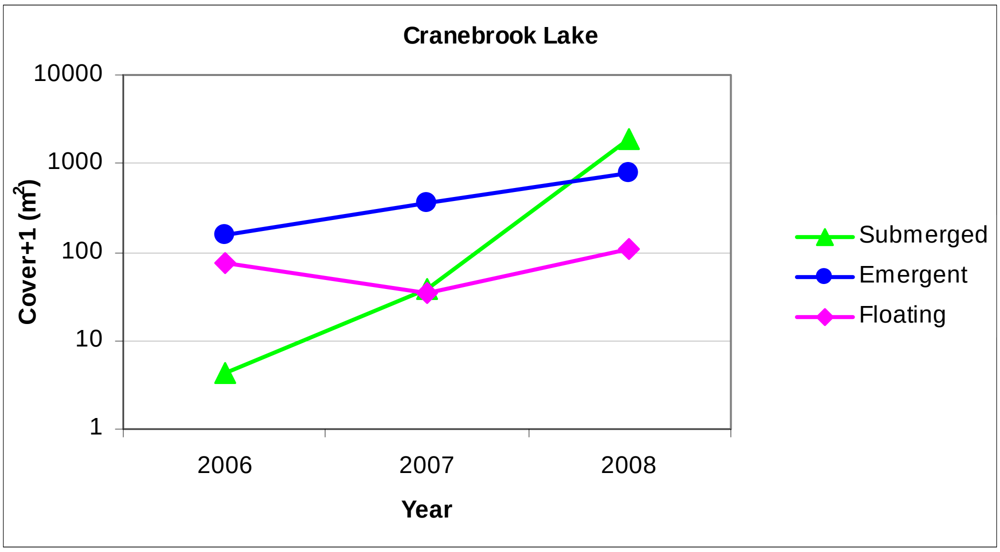

Chart 13: Changes in the cover of submerged, emergent and floating aquatic macrophytes at Cranebrook Lake from 2006-2008. Note logarithmic scale of y-axis.

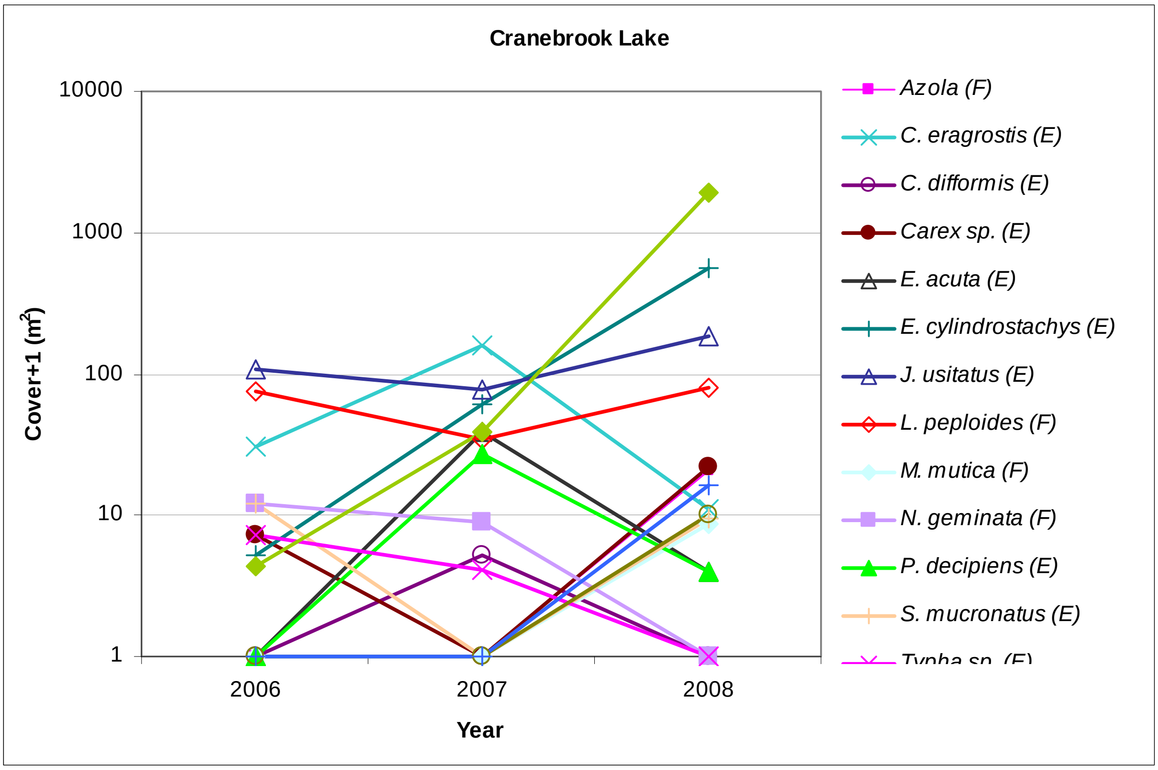

Chart 14: Changes in the cover of aquatic macrophyte species at Cranebrook Lake from 2006-2008. Note that the logarithmic scale of y-axis required a data transformation (x + 1) to eliminate zero values which could not have been plotted otherwise.

4.2.8 Duralia Lake

Duralia Lake (referred to in previous reports as Boyces Lake) is located to the west of Cranebrook Lake. Since 2007, the lake has been made available for recreational wakeboarding.

In the first year of monitoring (2006), the central and shallower parts of the lake were dominated by large beds of submerged macrophytes, primarily mixed beds of the alga *Chara* sp., *P. ochreatus* and *V. gigantea*, covering 87 % of the lake area. Lake levels increased by approximately 4 m between 2006 and 2007, leading to decreased light penetration across central parts of the lake. Substantial changes in the macrophyte community have resulted, principally the die back of submerged macrophyte beds distributed across the lake bed and the complete loss of *Chara* sp. from transects. Overall this has resulted in the 2007 level of macrophyte cover reducing to 26 %, with occurrences only around the shoreline and in the shallower parts of the lake adjacent to the shoreline, and are absent from the deepest centre parts.

In late 2007, Duralia Lake changed from being a water quality control lake with no recreational activity into a venue for recreational and competitive wave boarding. In addition to this new use, there has been a rapid increase in the lake's water level. The water level in the lake rose a further ~3 m in the 12 months to September 2007. This increase was due to water being pumped into Duralia Lake from Lake A. A large area of newly inundated shoreline was created with a concurrent reduction in the overall macrophyte area and diversity as deep macrophyte beds died off.

Macrophyte cover in the 2008 survey was recorded at 15 % of the lake area (compared with 26 % in 2007).

The macrophyte community has continued to be dominated by submerged macrophytes, with cover consistently one to two orders of magnitude higher than emergent macrophytes over the three year period of study (Chart 15). Floating macrophytes have made up a very small proportion of the aquatic macrophyte community, being present at very low levels in the first year of monitoring (2006) and not recorded in either 2007 or 2008.

The cover of submerged macrophytes has declined ten-fold over the three years of monitoring. The two consistently dominant species are *P. ochreatus* and *V. gigantea* which cover 20,988 m^2 and 12,563 m^2. The covers of both of these species are an order of magnitude lower in 2008 than in 2006. However, of the submerged macrophytes, only *V. gigantea* has shown a consistent decline over the period of study. Most other species (including *P. ochreatus*) showed a steep decline in cover from 2006 to 2007, but have increased in cover between 2007 and 2008. Of these species, three declined to zero cover in 2007, before reappearing in 2008 (including *Myriophyllum* sp., *Chara* sp. and *Nitella* sp.). This indicates a marked ability of these species to recolonise new areas of the lake that are more suitable. In contrast, *Potamogeton tricarinatus* declined to zero in 2007 and failed to reappear in 2008.

As lake levels rose in 2007, emergent macrophyte communities also experienced a sharp decline in cover. Although water levels have continued to rise between 2007 and 2008, the increase in water level has apparently been slower and has allowed a recovery of emergent macrophytes between 2007 and 2008. This trend of decline followed by recovery was driven by four species; *C. eragrostis*, *J. usitatus*, *P. australis* and *Typha* sp. These species did not appear on transects in 2007, but reappeared in 2008. The largest increase was in the cover of *J. usitatus*, which now covers 50 m^2 and was the only species of emergent macrophyte to occur at a cover of more than 20m^2. Both of the *Schoenoplectus* species were recorded only in 2006 and no new species of emergent macrophytes were recorded in 2008. In contrast to these fluctuations, cover of *P. decipiens* has remained relatively stable throughout the three years of monitoring (Chart 16).

The only species of floating macrophyte recorded was *M. mutica* which was recorded at a cover of 3 m^2 in 2006 and not recorded since.

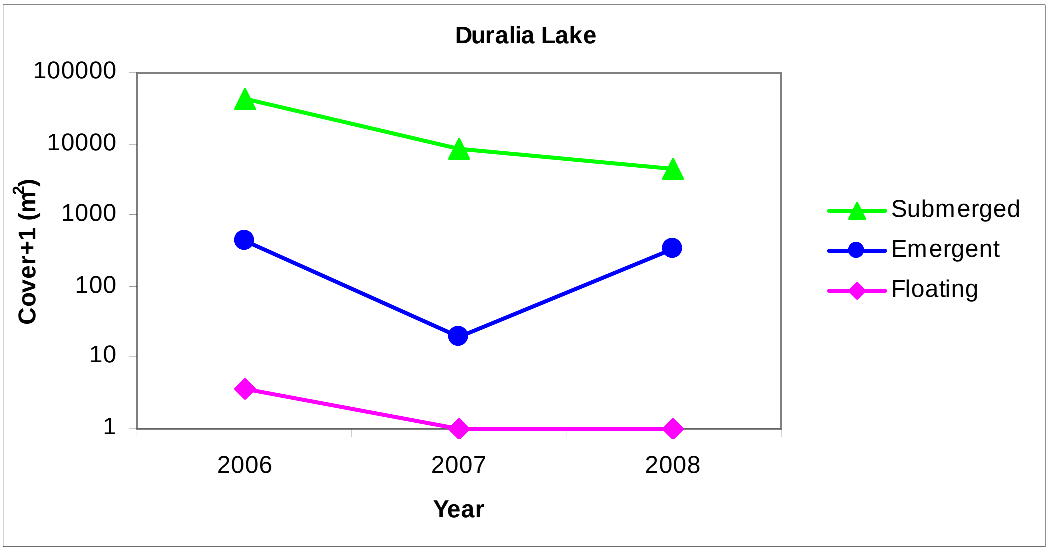

Chart 15: Changes in the cover of submerged, emergent and floating aquatic macrophytes at Duralia Lake from 2006-2008. Note logarithmic scale of y-axis (Appendix 2).

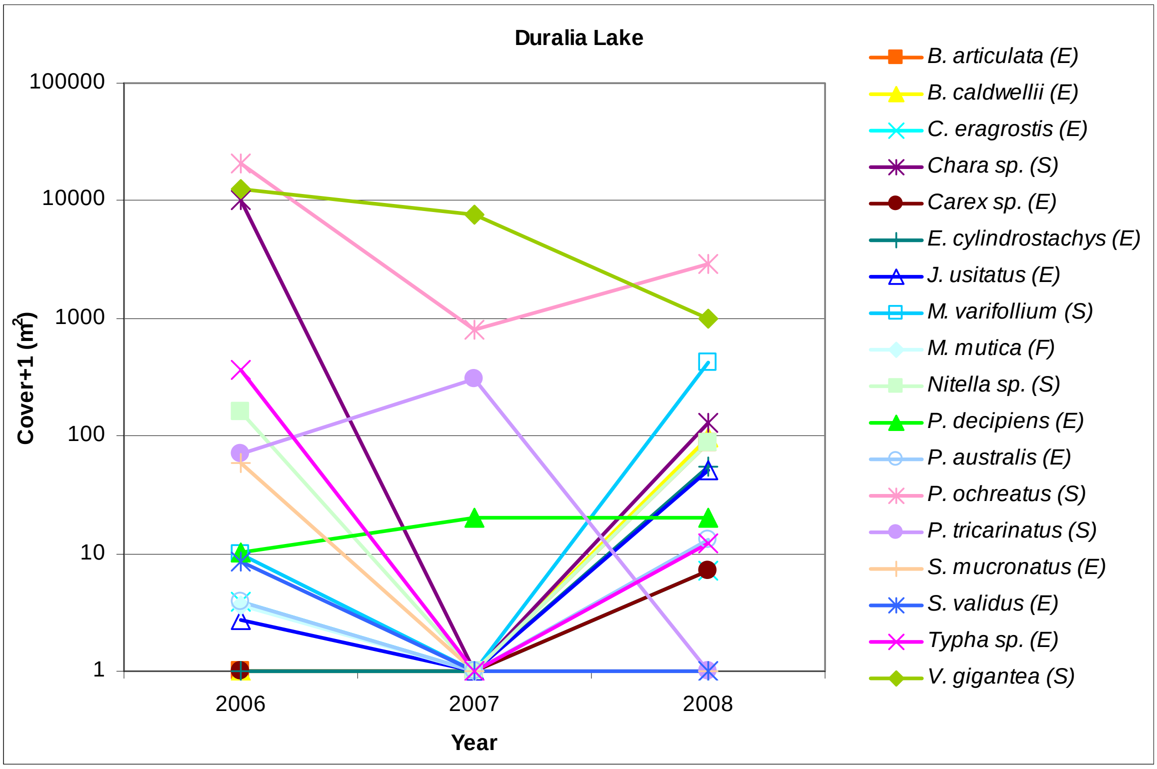

Chart 16: Changes in the cover of aquatic macrophyte species at Duralia Lake from 2006-2008. Note logarithmic scale of y-axis (Appendix 2).

4.2.9 West Wilchard Wetland

West Wilchard Wetland consists of two ponds connected by a narrow channel and is located in the north of the Penrith Lakes Area. The ponds are deep and, when the lake was first monitored in 2007, the water was heavily tannin-stained, resulting in poor light penetration and the absence of submerged macrophytes. In 2008, however, tannin staining was diminished and submerged macrophytes had established in the lake. The substrate of the northern pond was primarily silt with a deep covering of particulate matter, such as branches and woody debris.

Floating macrophytes were the dominant vegetation at the lake, with more than three times the cover of emergent macrophytes. Five of the six species of floating macrophytes increased in cover between 2007 and 2008, and three new species established in the same period. The dominant species in the 2008 survey, *Azola* sp. was newly established in West Wilchard Wetland and covered 892 m^2 of the lake area. Only *Lemna* sp. had declined in cover during the same period.

O. ovalifolia subsp. *ovalifolia* occurred only in the northern pond, however aside from this difference, both lakes shared very similar species composition.

Emergent macrophytes were the second most prolific vegetation at the lake. Although there had been a slight reduction in cover, the species richness had increased and there were 12 species established at the lake, compared with 7 in

2007. The dominant species were *Carex* sp. and *E. cylindrica*, which each covered more than 150 m^2 of the lake area.

The noxious weed *E. crassipes* was recorded at both ponds, and had increased more than seven-fold since the 2007 survey to a cover of 118 m^2, despite herbicide spraying of floating and emergent growth.

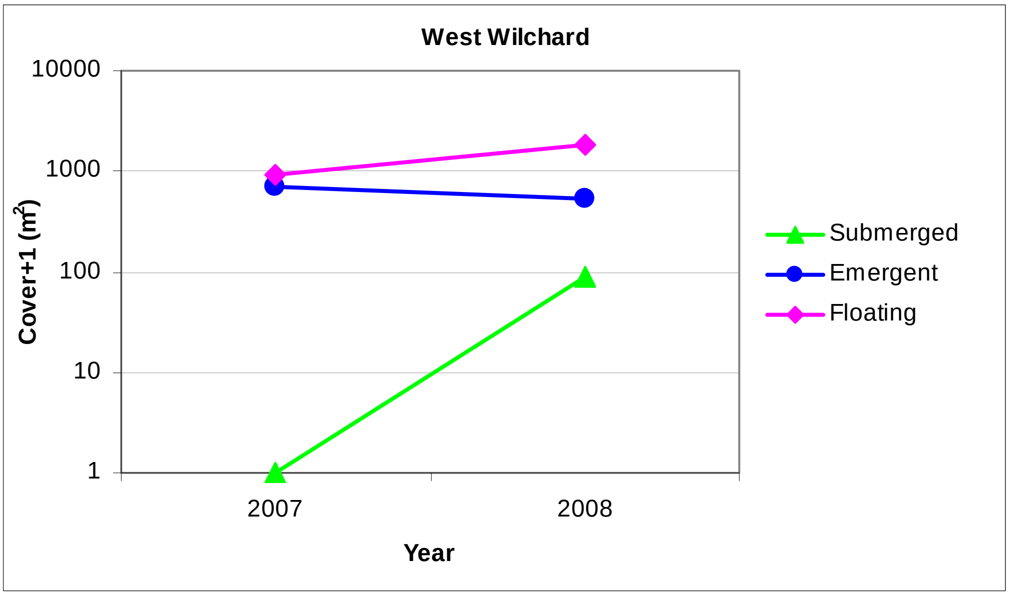

Chart 17: Changes in the cover of submerged, emergent and floating aquatic macrophytes at West Wilchard Wetland from 2006-2008. Note logarithmic scale of y-axis (Appendix 2).

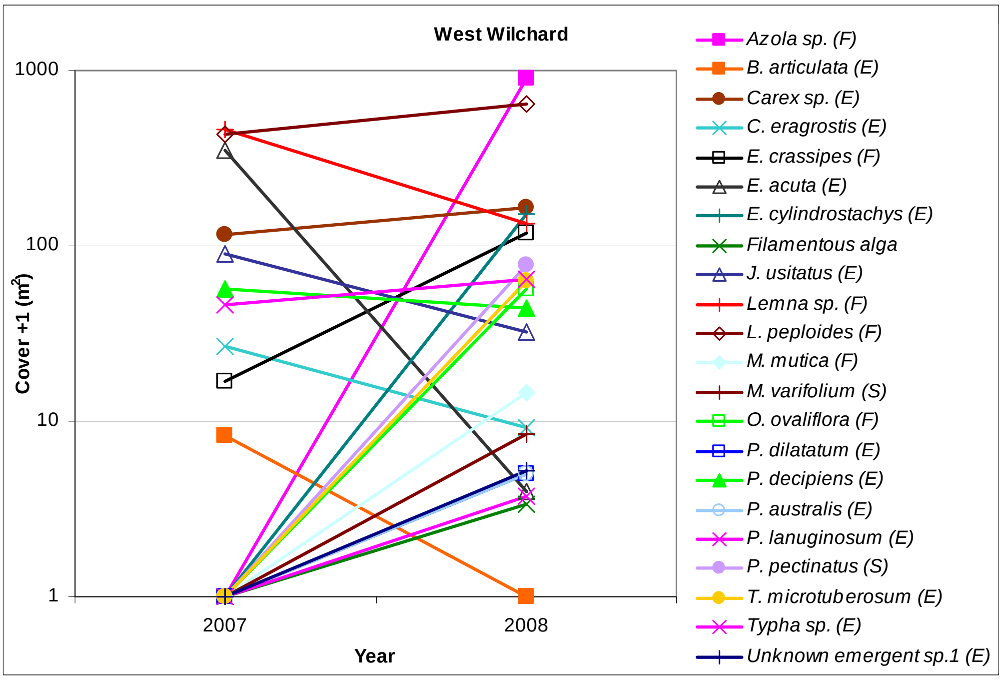

Chart 18: Changes in the cover of aquatic macrophyte species at West Wilchard Wetland from 2006-2008. Note that the logarithmic scale of y-axis (Appendix 2).

4.3 Comparisons between lakes

All MDS 2D ordinations had stress values of less than 0.2 indicating that these ordinations are a good representation of the relationships between samples (lakes/years). All MDS charts showed a scatter of sites throughout the 2D space, indicating that there were a range of different species driving the differences between sites.

In all comparisons, West Wilchard Wetland was consistently different from all other sites. An absence of submerged macrophytes in 2007 played a strong role in driving this difference. In 2008, a high species richness (21 species), the presence of a filamentous alga (not found at any other lake) and the absence of *V. gigantea* (found at every other lake/year) contributed to its uniqueness. When emergent and floating macrophytes were excluded from the analysis, this tendency was enhanced and West Wilchard Wetland was an outlier that caused substantial clustering of all other sites, making it difficult to illicit patterns of similarity between them. This was the case for analyses based on both Relative Cover, and Presence-Absence comparisons. As such, MDS analyses for 2006-2008 were run to exclude West Wilchard Wetland(explained in detail in Appendix 4).

4.3.1 Relative cover

The 2008 MDS of relative cover (chart 19) indicated that four lakes were quite similar, whilst the remainder were evenly distributed around the edge of the ordination, indicating that they each had some degree of distinctness. The four similar lakes were Regatta and Warmup Lakes (both large, deep lakes managed for boating/recreation), Cranebrook Lake (a smaller but also deep lake which is part of the treatment system for catchment waters) and Escarpment Lagoon (which is long, narrow and shallow). Consideration of species data shows that these lakes were similar in supporting a substantial cover (21-63 % of the lake area) of aquatic macrophytes, dominated by submerged species, followed by emergent macrophytes and finally floating macrophytes. The MDS based on submerged macrophytes only (excluding floating and emergent species) supports this grouping of four species also, showing that the submerged macrophyte community is what characterises the aquatic vegetation at these lakes (Chart 20).

The remaining five lakes were relatively evenly separated, with three of the four detention basins (Final Basin, Middle Basin and Northern Pond) all occurring in a broad grouping with Duralia Lake. West Wilchard Wetland was somewhat different from all sites (Chart 19). Again, based only on submerged macrophytes, these five lakes were scattered showing little similarity to each other, with the exception of a close affiliation in the submerged macrophyte assemblages between Middle Basin and Final Basin (Chart 20).

The MDS plot for all years of monitoring indicated that Regatta Lake, Warmup Lake and Northern Pond have had very stable macrophyte communities over the three years of monitoring. Macrophyte cover shows that this stability has been greatest at Regatta and Warmup Lakes, with Northern Pond showing a decline in submerged macrophytes over the three years of study (Chart 21). This is reflected in the MDS plot based only on submerged macrophytes, which shows stability in aquatic vegetation assemblage over the three years at Warmup Lake and Regatta Lake, with temporal changes at Northern Pond (Chart 22).

Lakes showing the greatest change in species composition over time were Cranebrook Lake, Duralia Lake, Escarpment Lagoon and Final Basin. There were no similarities between these lakes in the direction of change (Chart 21). At Cranebrook Lake and Duralia Lake, these changes were driven by changes in the submerged macrophyte community (as visible in Chart 22), however at Escarpment Lagoon and Final Basin, there was stability in submerged macrophyte communities over the three years of monitoring (Chart 22). Examination of the species cover data shows that Escarpment Lagoon experienced declines in floating macrophytes over the monitoring period and Final Basin experienced declines in emergent macrophytes.

These changes over time have led to different groupings of lakes compared with those identified in 2007. In particular, Duralia Lake in 2007 was most similar in species composition to Rowing Lake and Warmup Lake, and Final Basin similar to Middle Basin. However in 2008, Duralia Lake and Final Basin have moved towards each other on the ordination plot and are now most similar to each other. Cranebrook Lake was in 2007 similar to the other detention basins (Final Basin, Middle Basin and Northern Pond) but is now more closely affiliated with Regatta Lake, Warmup Lake and Escarpment Lagoon. Escarpment Lagoon was previously isolated on the ordination plot from other lakes.

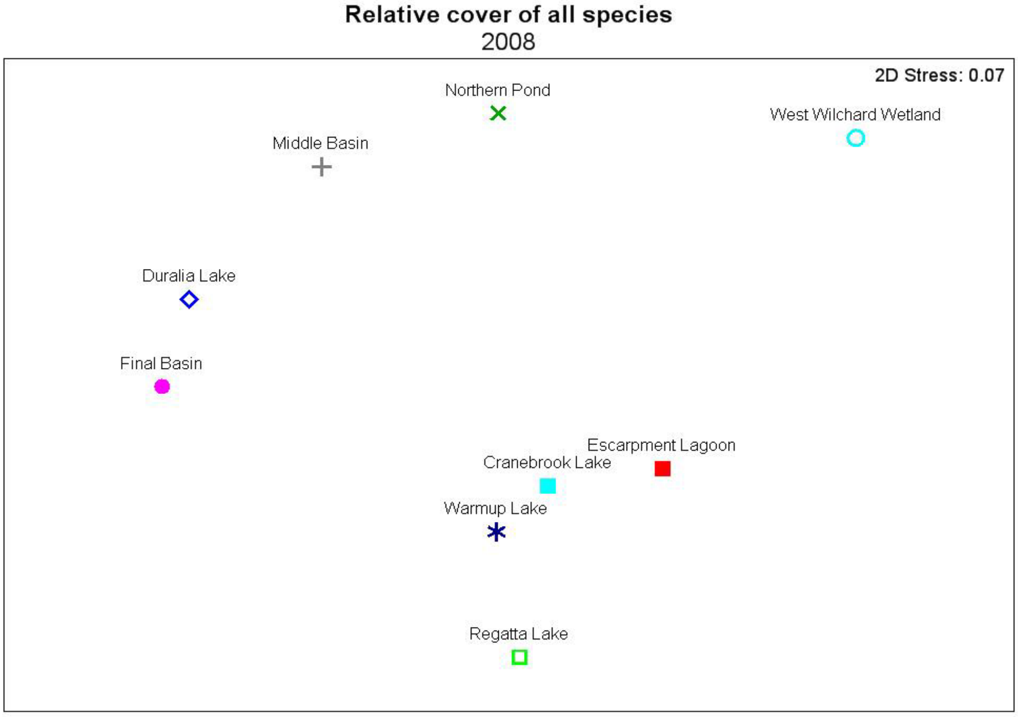

Chart 19: MDS based on relative cover of all species, 2008 only.

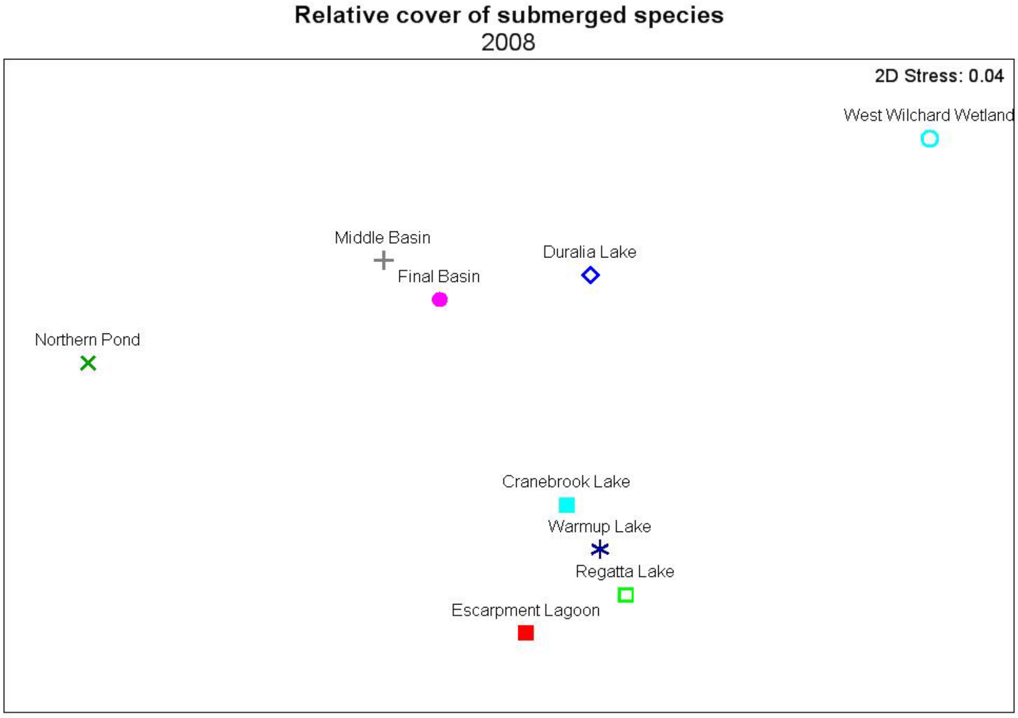

Chart 20: MDS based on relative cover of submerged species, 2008 only.

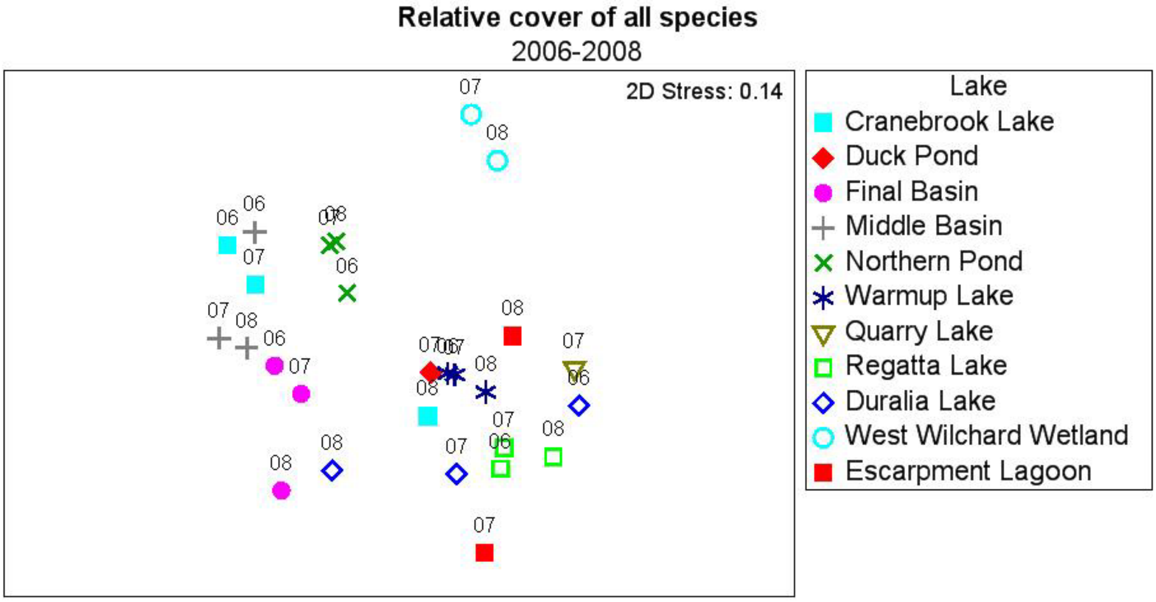

Chart 21: MDS based on relative cover of all species, 2006-2008.

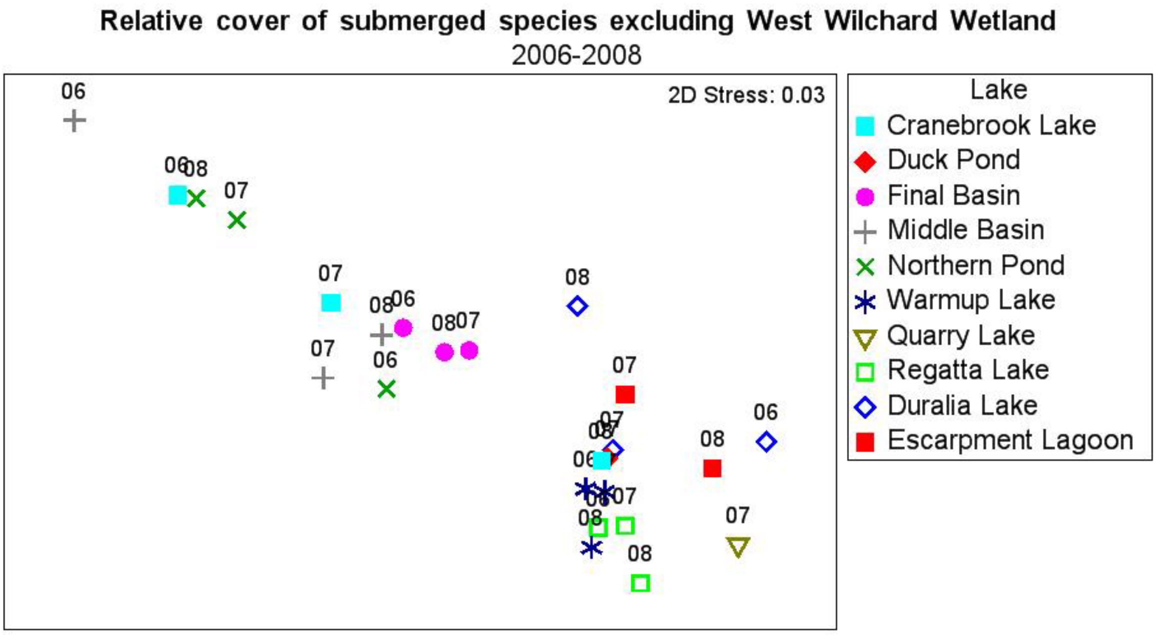

Chart 22: MDS based on relative cover of submerged species, 2006-2008.

4.3.2 Presence-Absence of Species

MDS plots based on species presence-absence (rather than cover of each species) removes the influence of dominant species and focuses the analysis on the suite of species that occur at the sites. This analysis resulted in different groupings of lakes, compared with analyses based on relative cover.

In 2008, there were no tight clusters of sites, indicating that each lake had its own relatively distinct suite of species. The two lakes closest in species composition of all species were Duralia Lake and Middle Basin (Chart 23). These two lakes were also similar when submerged macrophytes only were considered. Warmup Lake and Regatta Lake formed another pair with similar submerged macrophyte communities (Chart 24).

The lakes with the most stable species composition over the three years of monitoring were Cranebrook Lake, Northern Pond and Warmup Lake (Chart 25). This stability was driven by stability in the submerged macrophyte community at Cranebrook Lake and Warmup Lake, however Northern Pond experienced change in its macrophyte community over the three years of study (Chart 26). The other lakes underwent larger changes in the presence and absence of aquatic macrophyte species, in particular Escarpment Lagoon, Duralia Lake, Regatta Lake, Final Basin and West Wilchard Wetland (Chart 25). These large changes were reflected in the submerged macrophyte community also (Chart 26). The changes brought Northern Pond closer in species composition to Cranebrook Lake, however changes in species composition at other lakes tended not to lead to greater similarities with other lakes (Chart 26).

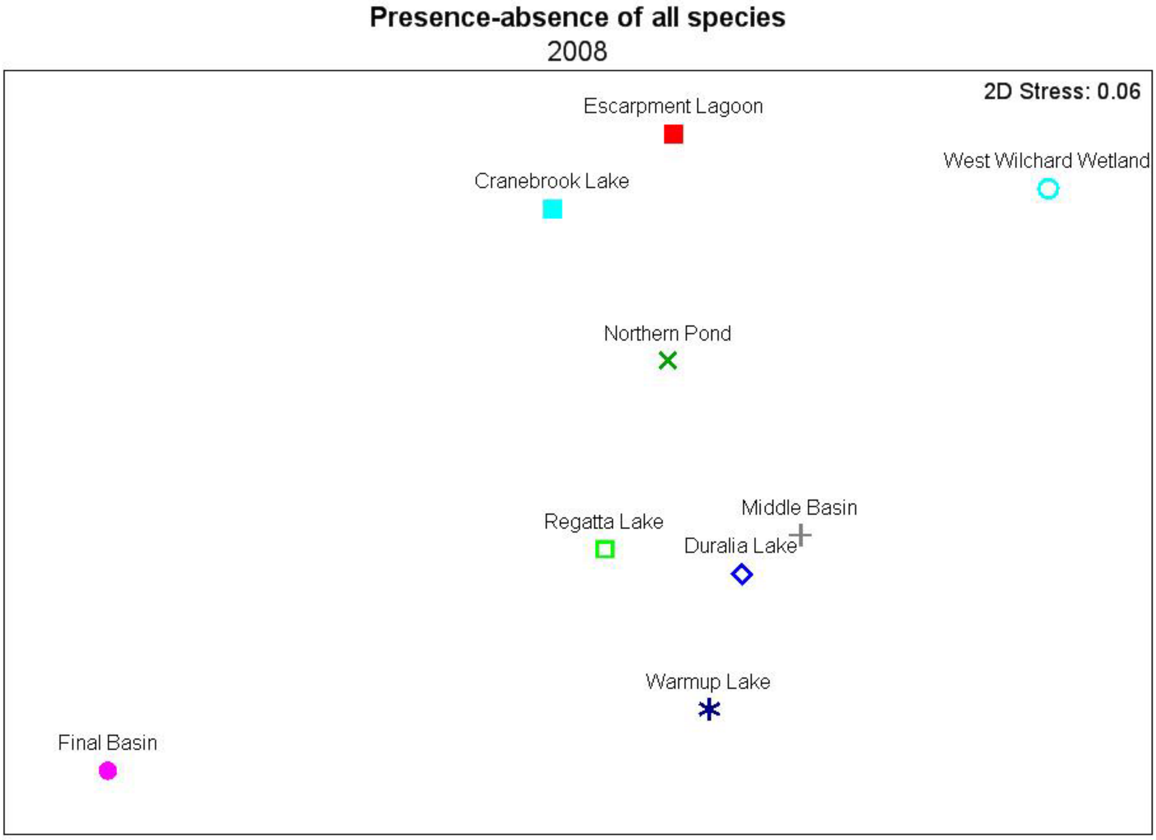

Chart 23: MDS based on presence-absence of all species, 2008 only.

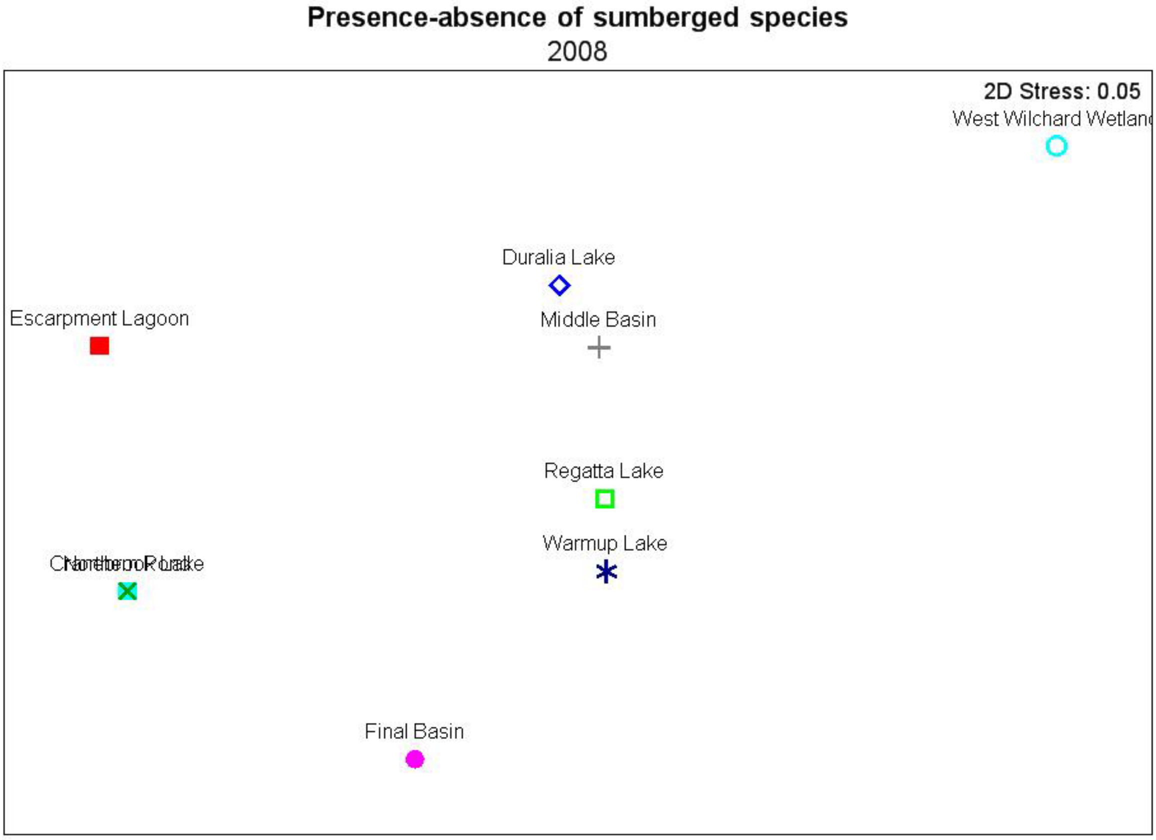

Chart 24: MDS based on presence-absence of submerged species, 2008 only.

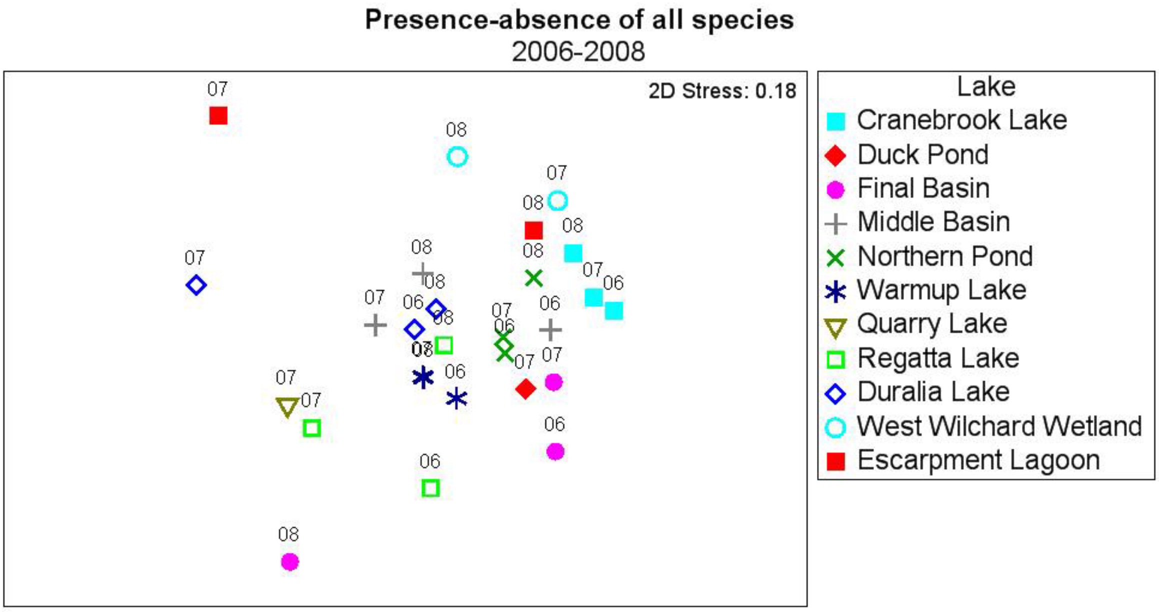

Chart 25: MDS based on presence-absence of all species, 2006-2008.

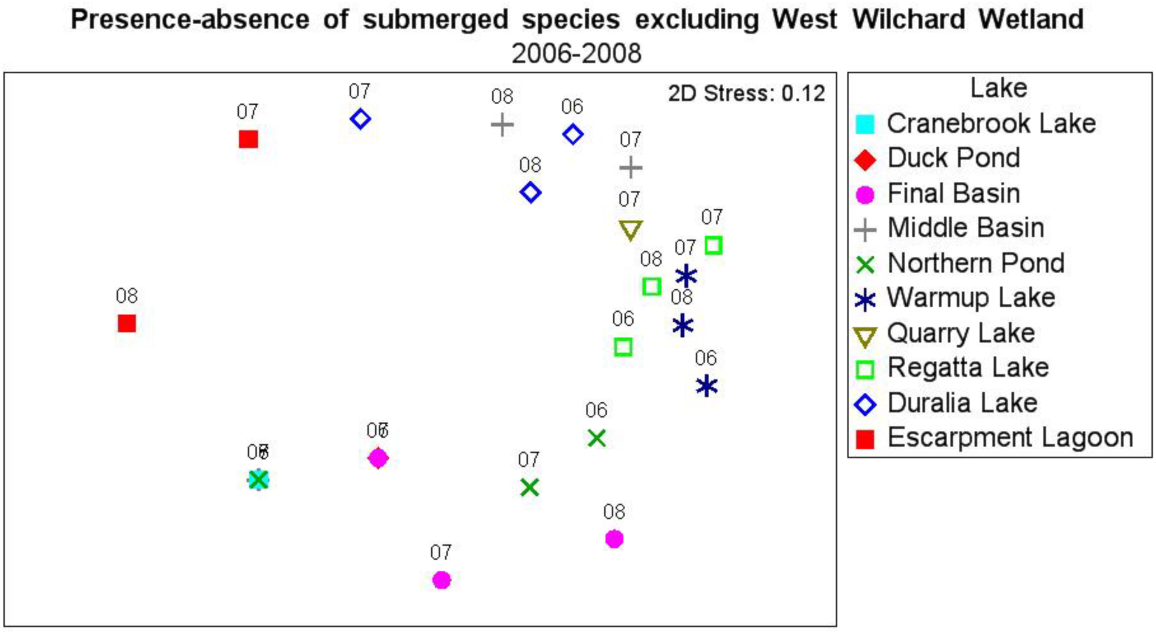

Chart 26: MDS based on presence-absence of submerged species, 2006-2008.

4.4 Macrophyte Identifications

Macrophytes often require flowers, fruiting bodies and tubers for positive identification, which may not be available at the time of survey. Therefore, there are a number of species in this survey that have been given a provisional identification.

Species with a provisional identification and their location included:

- *Elatine gratioloides* (Escarpment Lagoon and Warmup Lake);
- Unknown emergent sp. 1 (Cranebrook Lake, Middle Basin, North Pond and West Wilchard Wetland)
- Unknown submerged sp. 1 (Escarpment Lagoon)

Note that the species that was identified in the 2006 report as *Maundia triglochinoides* was in 2007 identified as *Triglochin microtuberosum.*

4.5 Exotic Macrophytes

Four exotic plant species were recorded during the current survey. This included two shoreline emergent species *Cyperus eragrostis* and *Paspalum dilatatum*, and two declared noxious weed species, *Salvinia molesta* and *Eichhornia crassipes*. The latter two species are targeted as part of a control program in Penrith Lakes.

Salvinia molesta was not found on any transects in Northern Pond in the 2008 survey, which suggests that the control methods have successfully eradicated the species from the lake. However, its proliferation at Warmup Lake is a problem, with the lake experiencing a six-fold increase between 2007 and 2008. Duck Pond, where the species was recorded in 2007, was not surveyed in 2008.

E. crassipes was recorded for the first time at West Wilchard Wetland in 2007, and its cover has expanded more than seven-fold between 2007 and 2008, despite spraying. Unfortunately, the spraying of these weeds has affected emergent vegetation, such as *Typha* sp. and *Juncus* sp. in Warmup Lake, Northern Pond and potentially in Escarpment Lagoon. *Typha* sp. is found in abundance in many of the lakes and can cause its own management problems with its dense beds slowly reducing the size of lagoons through sedimentation. The spraying for S. *molesta* is causing large gaps between the *Typha* bed and the bank. This area is generally sunny, shallow and, due to the surrounding *Typha* bed, is warm and protected from wash and wind. These characteristics make these gaps an ideal place for *S. molesta* to thrive where it is has very little competition or shading.

4.6 Macrophyte management

4.6.1 Increase in submerged macrophytes at Regatta Lake and Warmup Lake,

The maintenance of open water free from aquatic macrophytes is important in Regatta Lake and Warmup Lake, where macrophytes can interfere with recreational and sporting activities. In these lakes, there has been an increase in the density, area and cover of submerged macrophytes, largely driven by increases in *H. verticulata*. Regatta Lake and Warmup Lake now contain 215,004 m^2 and 153,066 m^2 of macrophytes respectively, which cover 56 % and 39 % of the lake area, respectively. Compared with 2007 when weed matting was apparently successful at controlling the growth of these submerged macrophytes, this year the weed matting appears to have diminished in its effectiveness somewhat.

4.6.2 Increase in submerged macrophytes at Cranebrook Lake and Escarpment Lagoon

During the same period, there has been a rapid increase in the cover of *V. gigantea* at Escarpment Lagoon and Cranebrook Lake, with the cover of these species now 3,766 m^2 and 1,928 m^2, covering 50 % and 14 % of their lake areas respectively. This represents nearly a five-fold increase at Escarpment Lagoon and a fifty-fold increase at Cranebrook Lake.

Unlike Regatta and Warmup Lakes, Escarpment Lagoon and Cranebrook Lake are not used for boating. A large healthy macrophyte population can contribute to the maintenance of good water quality. In this role, the macrophytes utilise nutrients within the lake and also trap sediment in the inlets and outlets, improving the water quality for lakes downstream (Melzer 1999). Lakes with a restricted macrophyte community can be turbid and are dominated by algae and plankton. These lakes can experience periodic blue green algal blooms and are generally considered to have poor health and water quality (Scheffer and Van Nes 2007).

4.6.3 Impacts of spraying for *Salvinia molesta* on *Typha* sp. density

Spraying to control *S. molesta* in Northern Pond and Warmup Lake appears to negatively affect the density of *Typha* sp. Because *S. molesta* occurs predominantly within these beds, that the application of herbicides may be increasing the mortality of the nearby *Typha* sp. shoots, leading to a gradual decline in density and ultimately creating more potential habitat for *S. molesta*. A strategy of more precise application of herbicides onto *S. molesta* is likely to be very time intensive, but may also lead to greatly long-term success if an improved density of *Typha* limits further growth of *Salvinia.*

Rather than applying herbicides, with their subsequent impact on neighbouring vegetation, an alternative control method may be to apply calcium dodecylbenzene sulfonate to the *Salvinia* plants. The product is applied similarly to other herbicides (i.e. as a spray) but is a mechanical rather than chemical herbicide, working by reducing surface tension around each *Salvinia* plant’s root system, causing it to sink and drown. This is only effective against floating plants, hence would have no impact on surrounding *Typha* beds or any other emergent vegetation. The product is available domestically under the product name ‘Agricrop Immerse Floating Herbicide’.

Further information regarding application and best practise seasonal approach is available from the NSW DPI Salvinia Control Manual (DPI 2008)

4.6.4 Recreational use of Duralia Lake

The opening of Duralia Lake for recreational use increases the risk that noxious species of macrophytes and other aquatic fauna will be introduced into the lake. Species considered a threat to the lake include *S. molesta* and *E. crassipes*, which have been recorded elsewhere in the Penrith Lakes System but have not been recorded in Duralia Lake to date. Other species such as *Egeria densa* and *Elodea canadensis* are yet to be recorded in the Penrith Lakes System but have been found in the nearby Nepean River and could be introduced on boats, trailers or associated equipment. To reduce the likelihood of introduction of these unwanted species, a mandatory condition of use should be that all boats, trailers, wakeboards and other equipment are washed clean prior to entering the lakes (Beitzel 2007a).

Between 2006 and 2008, water level increases at Duralia Lake have led to a decline in submerged macrophytes, with the potential to adversely influence water quality. The Macrophyte Development Plan for this lake (Beitzel 2007b) therefore suggests that supplementary plantings of *V. gigantea* occur in priority areas such as outlet and inlet points, along with additional monitoring of *V. gigantea* populations and the management of boating (such as exclusion zones) to reduce the impact of wake disturbance on macrophyte beds. These measures are still recommended. However the results of this 2008 annual survey show that although submerged macrophytes have declined due to higher water levels, emergent macrophytes at the lake have expanded substantially. Emergent macrophytes can perform similar filtration functions to submerged macrophytes, so their development in appropriate locations will probably be beneficial to water quality.

4.6.5 Low Macrophyte Densities and Declines in coverage at Final Basin

Aquatic macrophyte cover, in particular of emergent macrophytes, has suffered declines over the three year monitoring period, most likely related to high turbidity levels. Of emergent macrophyte species, only a small patch of *B. articulata* remains. Like the other detention basins, however, the submerged macrophyte community has remained relatively stable since 2007. Consideration should be given to the suitability of replanting other emergent macrophyte species such as *Typha* sp. or *Phragmites australis* to improve the diversity of the community.

Final Basin has always maintained one of the lowest abundances of submerged macrophytes in the Penrith Lakes system, despite being one of the largest lakes in volume. Reasons for this have not been fully investigated, but planting regimes and the lake’s turbidity are undoubtedly key factors to consider.

During the most recent survey, high volumes of microalgae were observed in the Final Basin waters, particularly in the western part of the lake. Samples were not collected and field observations alone are not sufficient to identify whether the algae in question is green (Chlorophyceae) or blue-green (Cyanophyceae). Similar ‘blooms’ have also been observed previously in the lake (Josh St. Clair, Penrith Lakes pers. comm.). Algal blooms do not necessarily result in toxic or problematic conditions in a lake, but must still be adequately managed to ensure that no further problems develop. This is particularly true given that Final Basin is linked via sluice to the Regatta Lake, which has the most regular level of recreational use.

Algal blooms are the result of many different factors, but most commonly a high available nutrient load within a lake or a lack of mixing of different lake depths (Boulton & Brock 1999, DNR 2008). The simplest way to mitigate against the first condition (high nutrient levels) is to establish an extensive macrophyte population to effectively 'lock up' available nutrients into the macrophyte bed. This approach can limit the capacity for rapid algal growth even if other conditions are suitable. In Final Basin, this would best be achieved by the introduction of fast growing and durable species such as *Hydrilla verticulata* or *Potamogeton perfoliatus*. Added benefits of establishing these species would include a likely improvement in the lake's turbidity and increased fish habitat.

Both *H. verticulata* and *P. perfoliatus* would be readily sourced from the adjoining Regatta Lake, however this will need to be carefully considered as there are ongoing efforts to control their extensive populations. As previously mentioned, Final Basin and Regatta Lake are linked via sluice, so consideration will need to be given to the possibility of Final Basin becoming a potential source of invasive plants into Regatta Lake.

4.6.6 Survey Intensity at the larger lakes

Several lakes, particularly Northern Pond, Final Basin, Rowing and Warmup lakes, have exhibited very conservative community structures over the monitoring period to date, dominated by a small number of species. As such, they can be expected to maintain their conservative structures in the foreseeable future. These lakes have also been amongst the largest in the ongoing survey, which means that they have also been allocated the highest numbers of transects and shoreline units. The survey efforts can reasonably be reduced without losing any monitoring resolution for these lakes. Recommendations along these lines will be made for the 2009 survey period.

5 RECOMMENDATIONS

The following recommendations are suggested to improve the management of macrophytes:

- Continued monitoring of the lakes to provide further information on the growth, spread and compositional changes of macrophytes.

- Continued control of *Salvinia molesta* in all lakes, but with investigation of alternative control agents such as calcium dodecylbenzene sulfonate ("Agricrop Immerse Floating Herbicide") so as to reduce impacts to surrounding vegetation.

- Controlling *Eichhornia crassipes* and preventing its spread west of Castlereagh Road.

- Monitoring the expansions, contractions and colonisation by macrophytes particularly with increases in water height and changes of use.

- Developing a planting plan for submergent macrophytes based on the mapping and growth recorded in this study and previous studies.

- With the opening of Duralia Lake for wakeboarding, all boats, trailers, wakeboards and other equipment should be washed clean prior to entering the lakes, to prevent the spread of unwanted plants from other waterways. Monitoring of inlets and boat entry points for new species and other high risk species with potential to cause management problems such as *E. canadensis* or *E. densa* and developing of contingency plans for management of these species to combat any outbreak quickly.

- Changes to Survey Design to reduce the number of shoreline units in Northern Pond and Final Basin. It is recommended that shoreline units in Northern Pond be combined. Additionally, in Rowing and Warmup lake two transects per shoreline unit are sufficient to provide an adequate sample size for mapping. These alterations will provide time and cost savings for future surveys.

- Management (removal) of *H. verticulata* in Regatta Lake, both mechanically and through the maintenance of weed matting should occur to prevent hindrance to boating activities.

- Investigate the possibility of introducing fast growing macrophytes such as *H. verticulata* or *P. perfoliatus* into Final Basin in order to mitigate against potential algal blooms. Efforts to establish a viable macrophyte community in Final Basin are also likely to improve other aspects of water quality including turbidity.

- Expand annual monitoring to ensure that water level information and turbidity information are incorporated into the synthesis of aquatic macrophyte monitoring results. If these data are already collected, the data should be made accessible. If not, use of a sechi disk and establishment of a permanent water level monitoring gauge (stake) would be low-effort/cost, rapid solutions. These data can provide additional insight into the causes of community changes, and can be important to inform adaptive management.

APPENDICES

APPENDIX 1: SHORELINE UNITS

LAKE	SHORELINE UNIT	ZONE	Easting	Northing
DURALIA LAKE	BL01	56	286355	6268182
DURALIA LAKE	BL02	56	286368	6267895
DURALIA LAKE	BL03	56	286247	6267904
DURALIA LAKE	BL04	56	286179	6268155
ESCARPMENT LAGOON	CL01	56	286549	6267602
ESCARPMENT LAGOON	CL02	56	286652	6267665
ESCARPMENT LAGOON	CL03	56	286621	6267850
ESCARPMENT LAGOON	CL04	56	286541	6267775
FINAL BASIN	FB01	56	285919	6265641
FINAL BASIN	FB02	56	286116	6265619
FINAL BASIN	FB03	56	286362	6265694
FINAL BASIN	FB04	56	286277	6265778
FINAL BASIN	FB05	56	286090	6265759
FINAL BASIN	FB06	56	285881	6265760
MIDDLE BASIN	MB01	56	286308	6266482
MIDDLE BASIN	MB02	56	286338	6266067
MIDDLE BASIN	MB03	56	286445	6266233
MIDDLE BASIN	MB04	56	286499	6266547
MIDDLE BASIN	MB05	56	286353	6266804
NORTHERN POND	NP01	56	286335	6266859
NORTHERN POND	NP02	56	286439	6266879
NORTHERN POND	NP03	56	286353	6267057
NORTHERN POND	NP04	56	286221	6267250
NORTHERN POND	NP05	56	286119	6267185
NORTHERN POND	NP06	56	286160	6266977
NORTHERN POND	NP07	56	286280	6266933
NORTHERN POND	NP08	56	286262	6267053
REGATTA LAKE	RL01	56	283996	6266075
REGATTA LAKE	RL02	56	284477	6266064
REGATTA LAKE	RL03	56	284973	6266045
REGATTA LAKE	RL04	56	285394	6266022
REGATTA LAKE	RL05	56	285880	6266000
REGATTA LAKE	RL06	56	286226	6265908
REGATTA LAKE	RL07	56	285858	6265830
REGATTA LAKE	RL08	56	285352	6265853
REGATTA LAKE	RL09	56	284876	6265876
REGATTA LAKE	RL10	56	284410	6265900
WARM UP LAKE	WU01	56	284092	6266229
WARM UP LAKE	WU02	56	284490	6266151
WARM UP LAKE	WU03	56	284979	6266130
WARM UP LAKE	WU04	56	285450	6266160
WARM UP LAKE	WU05	56	285191	6266361
WARM UP LAKE	WU06	56	284726	6266352
WARM UP LAKE	WU07	56	284310	6266513
WARM UP LAKE	WU08	56	283993	6266600

APPENDIX 2: EXPLANATION OF USE OF LOGARITHMIC SCALE FOR COVER GRAPHS

A scale in which the logarithm of the physical variable is used instead of the raw value. This has the effect that equal steps along the scale represent equal ratios between the raw values . For example, using a $\log_{10}$ scale, the first interval covers the raw values zero to ten, the next one covers ten to 100, the next on 100 to 100 and so on. It is used as a method of displaying data (in powers of ten) to yield maximum range while keeping resolution at the low end of the scale.

The Charts below show the same data, plotted on a linear (Chart 27) and logarithmic ($\log_{10}$, Chart 28) scale. Note that using the linear scale, the lines representing species with low covers lie very close together, with little resolution to detect the differences between the species and the direction of change. Using the logarithmic scale, data at the low end of the scale are spread further apart, whilst data at the high end of the scale can remain in visible on the axis.

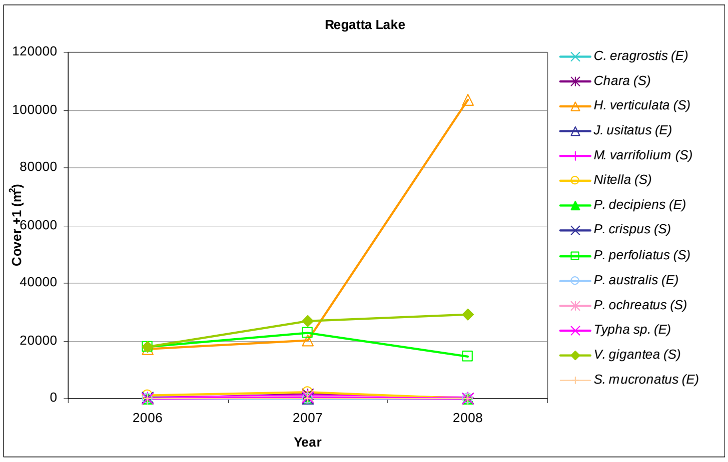

Chart 27: Data for Regatta Lake plotted on a linear scale.

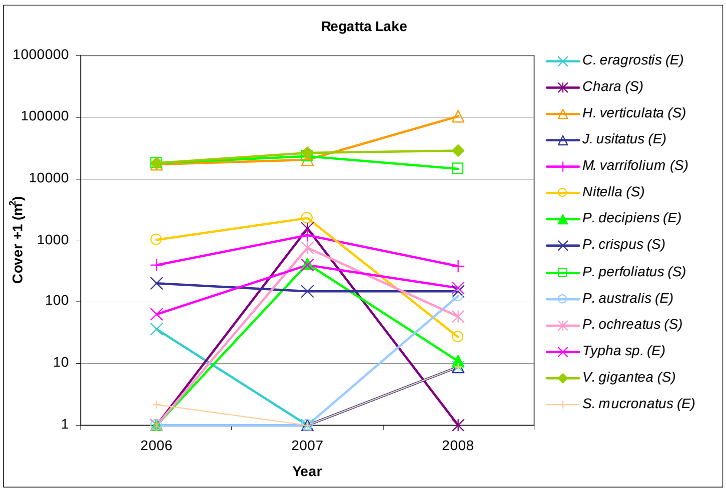

Chart 28: Data for Regatta Lake plotted on a logarithmic (log 10) scale.

Note that it is not possible to take the log of zero, and therefore raw cover values could not be plotted on the logarithmic scale where species recorded cover values of zero. To allow plotting of these values, data were transformed by adding 1 m^2 to the cover value of every species at the lake. This means that species that recorded zero cover were plotted as $\log_{10}(1)$, which is zero, and all other species had their cover values inflated by the same amount. This means that relative difference between values remains, although the values themselves are transformed.

However, it should be noted that rates of change cannot be easily inferred from the slopes of lines, on graphs using the logarithmic scale.

APPENDIX 3: SPECIES LIST

Species	Vegetation	DL06	CL06	FL06	MB06	NP06	RL06
Azola	Floating						
Baumea articulata	Emergent					X	
Bolboschoenus caldwellii	Emergent						
Carex sp.	Emergent		X			X	
Chara sp.	Submerged	X					
Cyperus sp.	Emergent						
Cyperus eragrostis	Emergent	X	X	X	X	X	X
Eichhornia crassipes	Floating						
Eleocharis acuta	Emergent						
Eleocharis cylindrostachys	Emergent		X			X	
Elatine gratioloides	Submerged						
Filamentous algae	Submerged						
Hydrilla verticillata	Submerged					X	X
Hydrocotyle bonariensis	Emergent						
Juncus cognatus	Emergent			X			
Juncus usitatus	Emergent	X	X	X	X	X	
Lemna sp.	Floating						
Ludwigia peploides ssp. *montevidensis*	Floating		X		X	X	
Marsilea mutica	Floating	X		X			
Myriophylum varifolium	Submerged	X					X
Najas marina	Submerged						
Nitella sp.	Submerged	X		X		X	X
Nymphaea alba	Floating						
Nymphoides geminata	Floating		X				
Ottelia ovaliflora ssp. *ovaliflora*	Floating						
Paspalum dilatatum	Emergent						
Persicaria decipiens	Emergent	X		X	X	X	
Phragmites australis	Emergent	X			X	X	
Phylydrum lanuginosum	Emergent						
Potamogeton crispus	Submerged					X	
Potamogeton ochreatus	Submerged	X					
Potamogeton pectinatus	Submerged	X					
Potamogeton perfoliatus	Submerged						X
Potomogeton tricarinatus	Submerged						
Salvinia molesta	Floating					X	
Schoenoplectus mucronatus	Emergent	X	X		X	X	X
Schoenoplectus validus	Emergent	X		X		X	
Typha sp.	Emergent	X	X		X	X	X
Triglochin microtuberosum	Emergent						
Unknown sedge A	Emergent					X	
Unknown submerged B	Submerged						
Unknown emergent sp.*1*	Emergent						
Unknown submerged sp.*2*	Submerged						
Vallisneria gigantea	Submerged	X	X	X	X	X	X

Species	**Vegetation**	**WL06**	**DL07**	**CP07**	**CL07**	**DP07**	**FB07**
Azola	Floating	X					
Baumea articulata	Emergent					X	X
Bolboschoenus caldwellii	Emergent						
Carex sp.	Emergent						
Chara sp.	Submerged	X					
Cyperus sp.	Emergent						
Cyperus eragrostis	Emergent	X			X	X	X
Eichhornia crassipes	Floating			X			
Eleocharis acuta	Emergent				X		
Eleocharis cylindrostachys	Emergent				X		
Elatine gratioloides	Submerged			X			
Filamentous algae	Submerged						
Hydrilla verticillata	Submerged	X					
Hydrocotyle bonariensis	Emergent						
Juncus cognatus	Emergent						
Juncus usitatus	Emergent	X			X	X	X
Lemna sp.	Floating			X			
Ludwigia peploides ssp. *montevidensis*	Floating	X			X	X	X
Marsilea mutica	Floating			X			X
Myriophylum varifolium	Submerged						
Najas marina	Submerged						
Nitella sp.	Submerged	X				X	
Nymphaea alba	Floating					X	
Nymphoides geminata	Floating				X		
Ottelia ovaliflora ssp. *ovaliflora*	Floating			X			
Paspalum dilatatum	Emergent						
Persicaria decipiens	Emergent	X	X		X	X	X
Phragmites australis	Emergent	X					
Phylydrum lanuginosum	Emergent						
Potamogeton crispus	Submerged	X					X
Potamogeton ochreatus	Submerged		X	X			
Potamogeton pectinatus	Submerged		X				
Potamogeton perfoliatus	Submerged	X					
Potomogeton tricarinatus	Submerged			X			
Salvinia molesta	Floating					X	
Schoenoplectus mucronatus	Emergent						X
Schoenoplectus validus	Emergent						X
Typha sp.	Emergent	X			X	X	
Triglochin microtuberosum	Emergent						
Unknown sedge A	Emergent						
Unknown submerged B	Submerged						
Unknown emergent sp.*1*	Emergent						
Unknown submerged sp.*2*	Submerged						
Vallisneria gigantea	Submerged	X	X	X	X	X	X

Species	Vegetation	MB07	NP07	WL07	RL07	QL07	WW07
Azola	Floating			X			
Baumea articulata	Emergent	X	X	X			X
Bolboschoenus caldwellii	Emergent	X	X				
Carex sp.	Emergent		X				X
Chara sp.	Submerged			X	X		
Cyperus sp.	Emergent	X					
Cyperus eragrostis	Emergent		X	X			X
Eichhornia crassipes	Floating						X
Eleocharis acuta	Emergent						X
Eleocharis cylindrostachys	Emergent						
Elatine gratioloides	Submerged						
Filamentous algae	Submerged						
Hydrilla verticillata	Submerged	X		X	X		
Hydrocotyle bonariensis	Emergent		X				
Juncus cognatus	Emergent						
Juncus usitatus	Emergent	X	X	X			X
Lemna sp.	Floating						X
Ludwigia peploides ssp. *montevidensis*	Floating	X	X	X			X
Marsilea mutica	Floating	X		X			
Myriophylum varifolium	Submerged	X		X	X	X	
Najas marina	Submerged					X	
Nitella sp.	Submerged		X	X	X	X	
Nymphaea alba	Floating						
Nymphoides geminata	Floating						
Ottelia ovaliflora ssp. *ovaliflora*	Floating						
Paspalum dilatatum	Emergent						
Persicaria decipiens	Emergent	X	X	X	X	X	X
Phragmites australis	Emergent	X	X	X			
Phylydrum lanuginosum	Emergent						
Potamogeton crispus	Submerged	X	X	X	X	X	
Potamogeton ochreatus	Submerged	X		X	X	X	
Potamogeton pectinatus	Submerged	X				X	
Potamogeton perfoliatus	Submerged			X	X	X	
Potomogeton tricarinatus	Submerged						
Salvinia molesta	Floating			X			
Schoenoplectus mucronatus	Emergent		X				
Schoenoplectus validus	Emergent		X				
Typha sp.	Emergent	X	X	X	X	X	X
Triglochin microtuberosum	Emergent						
Unknown sedge A	Emergent						
Unknown submerged B	Submerged				X		
Unknown emergent sp.*1*	Emergent						
Unknown submerged sp.*2*	Submerged						
Vallisneria gigantea	Submerged	X	X	X	X	X	

Species	**Vegetation**	**DL08**	**CP08**	**CL08**	**FL08**	**MB08**	**NP08**
Azola	Floating			X			
Baumea articulata	Emergent	X			X	X	X
Bolboschoenus caldwellii	Emergent	X				X	X
Carex sp.	Emergent	X	X	X		X	X
Chara sp.	Submerged	X					
Cyperus sp.	Emergent						
Cyperus eragrostis	Emergent	X	X	X		X	X
Eichhornia crassipes	Floating						
Eleocharis acuta	Emergent			X			X
Eleocharis cylindrostachys	Emergent	X	X	X			X
Elatine gratioloides	Submerged		X				
Filamentous algae	Submerged						
Hydrilla verticillata	Submerged					X	
Hydrocotyle bonariensis	Emergent						X
Juncus cognatus	Emergent						
Juncus usitatus	Emergent	X	X	X		X	X
Lemna sp.	Floating		X			X	
Ludwigia peploides ssp. *montevidensis*	Floating		X	X			X
Marsilea mutica	Floating			X	X		X
Myriophylum varifolium	Submerged	X				X	
Najas marina	Submerged						
Nitella sp.	Submerged	X					
Nymphaea alba	Floating						
Nymphoides geminata	Floating						
Ottelia ovaliflora ssp. *ovaliflora*	Floating		X				
Paspalum dilatatum	Emergent						
Persicaria decipiens	Emergent	X	X	X		X	X
Phragmites australis	Emergent	X				X	X
Phylydrum lanuginosum	Emergent						
Potamogeton crispus	Submerged				X		
Potamogeton ochreatus	Submerged	X				X	
Potamogeton pectinatus	Submerged						
Potamogeton perfoliatus	Submerged				X		
Potomogeton tricarinatus	Submerged						
Salvinia molesta	Floating						
Schoenoplectus mucronatus	Emergent		X	X			X
Schoenoplectus validus	Emergent						X
Typha sp.	Emergent	X	X			X	X
Triglochin microtuberosum	Emergent			X			
Unknown sedge A	Emergent						
Unknown submerged B	Submerged						
Unknown emergent sp.*1*	Emergent			X		X	X
Unknown submerged sp.*2*	Submerged		X				
Vallisneria gigantea	Submerged	X	X	X	X	X	X

Species	**Vegetation**	**WL08**	**WW08**	**RG08**
Azola	Floating	X	X	
Baumea articulata	Emergent	X		
Bolboschoenus caldwellii	Emergent	X		
Carex sp.	Emergent			X
Chara sp.	Submerged	X		
Cyperus sp.	Emergent			
Cyperus eragrostis	Emergent	X	X	X
Eichhornia crassipes	Floating			X
Eleocharis acuta	Emergent			X
Eleocharis cylindrostachys	Emergent			X
Elatine gratioloides	Submerged	X		
Filamentous algae	Submerged		X	
Hydrilla verticillata	Submerged	X		X
Hydrocotyle bonariensis	Emergent			
Juncus cognatus	Emergent			
Juncus usitatus	Emergent	X	X	X
Lemna sp.	Floating		X	
Ludwigia peploides ssp. *montevidensis*	Floating	X	X	
Marsilea mutica	Floating	X	X	
Myriophylum varifolium	Submerged		X	X
Najas marina	Submerged			
Nitella sp.	Submerged	X		X
Nymphaea alba	Floating			
Nymphoides geminata	Floating			
Ottelia ovaliflora ssp. *ovaliflora*	Floating		X	
Paspalum dilatatum	Emergent		X	
Persicaria decipiens	Emergent	X	X	X
Phragmites australis	Emergent	X	X	X
Phylydrum lanuginosum	Emergent		X	
Potamogeton crispus	Submerged	X		X
Potamogeton ochreatus	Submerged	X		X
Potamogeton pectinatus	Submerged		X	
Potamogeton perfoliatus	Submerged	X		X
Potomogeton tricarinatus	Submerged			
Salvinia molesta	Floating	X		
Schoenoplectus mucronatus	Emergent			X
Schoenoplectus validus	Emergent			
Typha sp.	Emergent	X	X	X
Triglochin microtuberosum	Emergent		X	
Unknown sedge A	Emergent			
Unknown submerged B	Submerged			
Unknown emergent sp.*1*	Emergent		X	
Unknown submerged sp.*2*	Submerged			
Vallisneria gigantea	Submerged	X		X

APPENDIX 4: MDS ANALYSES INCLUDING WEST WILCHARD WETLAND

West Wilchard Wetland had a very different aquatic macrophyte community than other lakes, particularly in 2007 (Chart 29). In that year, the wetland had no submerged macrophytes. The large difference caused all other sites to cluster closely together on the MDS plot, providing little resolution to determine differences in macrophyte communities between other sites. In the next MDS, West Wilchard Wetland 2007 data were excluded from the analysis (Chart 30).

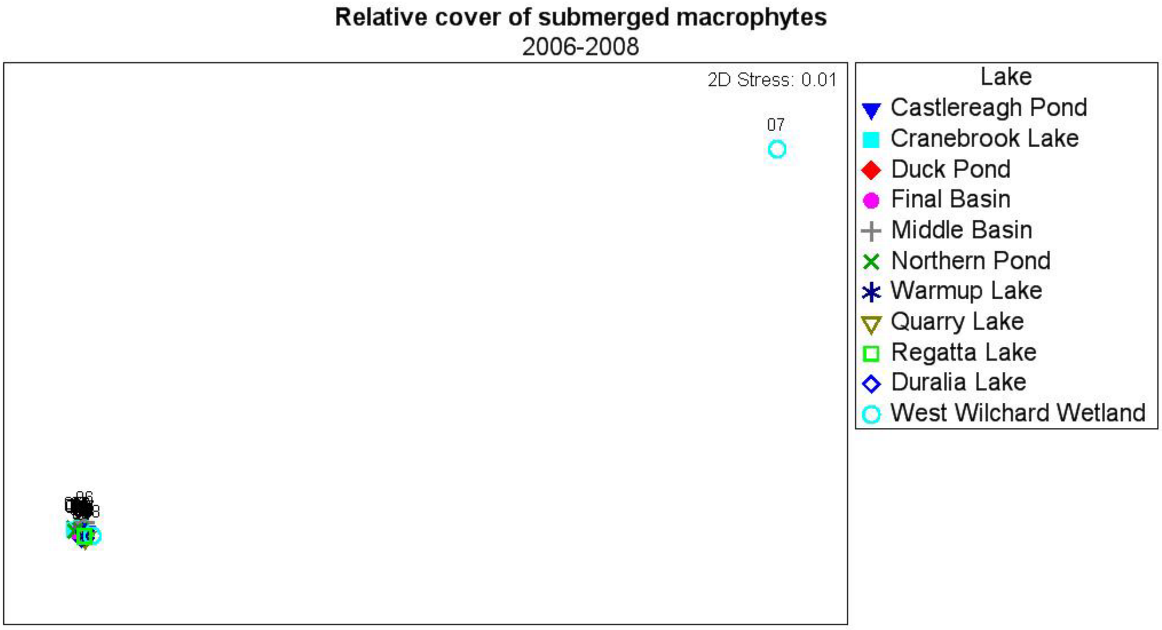

Chart 29: MDS plot of relative covers of submerged macrophytes 2006-2008, including all sites.

With West Wilchard 2007 data excluded from the MDS, the difference between macrophyte communities at West Wilchard Wetland in 2008 and all other sites/years became evident (Chart 30). Unlike all other sites, West Wilchard Wetland contained a filamentous alga, and no *V. gigantea*. Other sites were still clustered together on the MDS plot. Upon exclusion of West Wilchard Wetland 2007 and 2008 data (Chart 22) sites/years had a greater spatial spread, and could be interpreted more clearly.

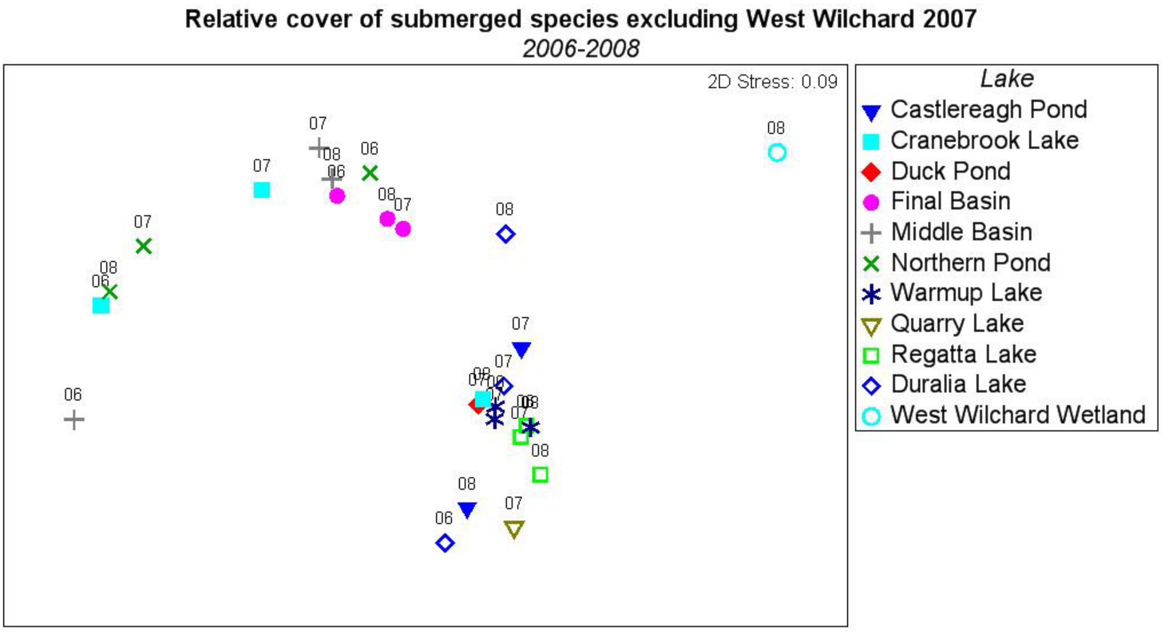

Chart 30: MDS plot of relative covers of submerged macrophytes 2006-2008, excluding West Wilchard Wetland 2007.

APPENDIX 5: MACROPHYTE COVER

Warmup Lake

Species	Area (m2)	Cover (m2)	Area/ Total macrophyte area in lake (%)	Area/ Total lake area (%)	Relative cover (Cover/Total lake area %)
Azola	762.00	38.10	0.50	0.19	0.01
Baumea articulata	469.00	46.90	0.31	0.12	0.01
Bolboschoenus caldwellii	140.00	14.00	0.09	0.04	0.00
Chara	5331.00	1018.40	3.48	1.35	0.26
Cyperus eragrostis	848.00	104.65	0.55	0.21	0.03
Elatine gratioloides	233.00	58.25	0.15	0.06	0.01
Hydrilla verticulata	110843.00	31243.75	72.42	28.06	7.91
Juncus usitatus	3082.00	165.75	2.01	0.78	0.04
Ludwigia peploides ssp. montevidensis	1943.00	139.30	1.27	0.49	0.04
Marsilea mutica	233.00	11.65	0.15	0.06	0.00
Nitella	11641.00	631.85	7.61	2.95	0.16
Persicaria decipiens	1707.00	85.35	1.12	0.43	0.02
Phragmites australis	1536.00	294.00	1.00	0.39	0.07
Potamogeton crispus	10120.00	506.00	6.61	2.56	0.13
Potomogeton ochreatus	1382.00	69.10	0.90	0.35	0.02
Potomogeton perfoliatus	87228.00	12385.50	56.99	22.08	3.14
Salvinia molesta	14432.00	1470.20	9.43	3.65	0.37
Typha sp	18233.00	9826.00	11.91	4.62	2.49
Vallisneria americana	86605.00	18569.40	56.58	21.93	4.70

Regatta Lake

Species	Area (m2)	Cover (m2)	Area/ Total macrophyte area in lake (%)	Area/ Total lake area (%)	Relative cover (Cover/Total lake area %)
Cyperus eragrostis	161.00	8.05	0.07	0.04	0.00
Hydrilla verticulata	207747.00	103581.10	96.62	53.83	26.84
Juncus usitatus	161.00	8.05	0.07	0.04	0.00
Myriophylum	7536.00	376.80	3.51	1.95	0.10
Nitella	1568.00	78.40	0.73	0.41	0.02
Persicaria decipiens	203.00	10.15	0.09	0.05	0.00
Phragmites australis	1242.00	124.20	0.58	0.32	0.03
Potamogeton crispus	2984.00	149.20	1.39	0.77	0.04
Potomogeton ochreatus	1129.00	56.45	0.53	0.29	0.01
Potomogeton perfoliatus	129100.00	14703.00	60.05	33.45	3.81
Schoenoplectus mucronatus	161.00	8.05	0.07		0.00
Typha sp	1654.00	165.40	0.77	0.43	0.04
Vallisneria americana	85693.00	29158.90	39.86	22.20	7.56

Final Basin

Species	Area (m2)	Cover (m2)	Area/ Total macrophyte area in lake (%)	Area /Total lake area (%)	Relative cover (Cover/Total lake area %)
Baumea articulata	241.00	19.50	4.00	0.28	0.02
Marsilea mutica	1218.00	393.70	20.22	1.39	0.45
Potamogeton crispus	343.00	17.15	5.70	0.39	0.02
Potomogeton perfoliatus	343.00	17.15	5.70	0.39	0.02
Vallisneria americana	4932.00	531.15	81.90	5.64	0.61

Middle Basin

Species	Area (m2)	Cover (m2)	Area/ Total macrophyte area in lake (%)	Area /Total lake area (%)	Relative cover (Cover/Total lake area %)
Baumea articulata	1309.00	314.45	19.01	0.93	0.22
Bolboschoenus caldwellii	485.00	67.85	7.04	0.34	0.05
Charex	62.00	3.10	0.90	0.04	0.00
Cyperus eragrostis	431.00	21.55	6.26	0.31	0.02
Hydrilla verticulata	807.00	40.35	11.72	0.57	0.03
Juncus usitatus	1980.00	223.85	28.75	1.40	0.16
Lemna sp	7.00	0.35	0.10	0.00	0.00
Myriophylum	263.00	13.15	3.82	0.19	0.01
Persicaria decipiens	492.00	24.60	7.14	0.35	0.02
Phragmites australis	1369.00	273.70	19.88	0.97	0.19
Potomogeton ochreatus	959.00	47.95	13.93	0.68	0.03
Typha sp	1339.00	114.20	19.45	0.95	0.08
Unknown1	305.00	16.75	4.43	0.22	0.01
Vallisneria americana	3308.00	328.30	48.04	2.34	0.23

Northern Pond

Species	Area (m2)	Cover (m2)	Area/ Total macrophyte area in lake (%)	Area/ Total lake area (%)	Relative cover (Cover/Total lake area %)
Baumea articulata	310.00	149.15	6.21	0.44	0.21
Bolboschoenus caldwellii	344.00	81.95	6.89	0.49	0.12
Charex	1090.00	99.50	21.84	1.56	0.14
Cyperus eragrostis	915.00	83.00	18.33	1.31	0.12
Eleocharis acuta	104.00	5.20	2.08	0.15	0.01
Eleocharis cylindrostachys	147.00	58.50	2.95	0.21	0.08
Hydrocotyle bonariensis	1229.00	85.40	24.62	1.76	0.12
Juncus usitatus	1301.00	69.20	26.07	1.86	0.10
Ludwigia peploides ssp. montevidensis	1008.00	63.00	20.20	1.44	0.09
Marsilea mutica	104.00	5.20	2.08	0.15	0.01
Persicaria decipiens	453.00	26.35	9.08	0.65	0.04
Phragmites australis	289.00	78.35	5.79	0.41	0.11
Schoenoplectus mucronatus	237.00	14.45	4.75	0.34	0.02
Schoenoplectus validus	324.00	44.15	6.49	0.46	0.06
Typha sp	4265.00	1208.55	85.45	6.10	1.73
Unknown1	225.00	11.25	4.51	0.32	0.02
Vallisneria americana	104.00	10.40	2.08	0.15	0.01

Escarpment Lagoon

Species	Area (m2)	Cover (m2)	Area/ Total macrophyte area in lake (%)	Area/ Total lake area (%)	Relative cover (Cover/Total lake area %)
Charex	2336.00	202.00	13.91	8.73	0.76
Cyperus eragrostis	3360.00	318.50	20.01	12.56	1.19
Eleocharis cylindrostachys	983.00	218.70	5.85	3.68	0.82
Elatine gratioloides	1691.00	84.55	10.07	6.32	0.32
Juncus usitatus	2084.00	176.60	12.41	7.79	0.66
Lemna sp	618.00	30.90	3.68	2.31	0.12
Ludwigia peploides ssp. montevidensis	175.00	8.75	1.04	0.65	0.03
Ottelia ovaliflora ssp. ovaliflora	2661.00	133.05	15.85	9.95	0.50
Persicaria decipiens	1567.00	78.35	9.33	5.86	0.29
Schoenoplectus mucronatus	590.00	29.50	3.51	2.21	0.11
Typha sp	1099.00	250.15	6.54	4.11	0.94
Vallisneria americana	13367.00	3763.95	79.60	49.98	14.07
Unknown 2	7241.00	3699.35	43.12	27.07	13.83

Cranebrook Lake

Species	Area (m2)	Cover (m2)	Area/ Total macrophyte area in lake (%)	Area/ Total lake area (%)	Relative cover (Cover/Total lake area %)
Azola	395.00	19.75	6.54	1.37	0.07
Cyperus eragrostis	203.00	10.15	3.36	0.71	0.04
Carex	417.00	20.85	6.90	1.45	0.07
Eleocharis acuta	59.00	2.95	0.98	0.21	0.01
Eleocharis cylindrostachys	1367.00	559.20	22.63	4.75	1.94
Juncus usitatus	1370.00	186.10	22.68	4.76	0.65
Ludwigia peploides ssp. montevidensis	1408.00	79.50	23.30	4.89	0.28
Marsilea mutica	155.00	7.75	2.57	0.54	0.03
Persicaria decipiens	59.00	2.95	0.98	0.21	0.01
Schoenoplectus mucronatus	167.00	8.35	2.76	0.58	0.03
Triglochin microtuberosum	179.00	8.95	2.96	0.62	0.03
Unknown1	302.00	15.10	5.00	1.05	0.05
Vallisneria americana	3894.00	1927.50	64.45	13.53	6.70

Duralia Lake

Species	Area (m2)	Cover (m2)	Area/ Total macrophtye area in lake (%)	Area/ Total lake area (%)	Relative cover (Cover/Total lake area %)
Baumea articulata	140.00	84.85	0.77	0.12	0.07
Bolboschoenus caldwellii	146.00	94.90	0.81	0.12	0.08
Chara	2559.00	127.95	14.15	2.11	0.11
Charex	123.00	6.15	0.68	0.10	0.01
Cyperus eragrostis	123.00	6.15	0.68	0.10	0.01
Eleocharis cylindrostachys	196.00	54.20	1.08	0.16	0.04
Juncus usitatus	991.00	49.55	5.48	0.82	0.04
Myriophylum	5028.00	420.05	27.79	4.14	0.35
Nitella	1745.00	87.25	9.65	1.44	0.07
Persicaria decipiens	390.00	19.50	2.16	0.32	0.02
Phragmites australis	122.00	12.20	0.67	0.10	0.01
Potomogeton ochreatus	9367.00	2952.25	51.78	7.72	2.43
Typha sp	222.00	11.10	1.23	0.18	0.01
Vallisneria americana	9353.00	1003.75	51.70	7.71	0.83

West Wilchard Wetland

Species	Area (m2)	Cover (m2)	Area/ Total macrophyte area in lake(%)	Area/ Total lake area (%)	Relative cover (Cover/Total lake area %)
Azola	2333.00	892.10	71.64	56.56	21.63
Charex	498.00	164.20	15.29	12.07	3.98
Cyperus eragrostis	164.00	8.20	5.04	3.98	0.20
Eichhornia crassipes	1404.00	118.05	43.11	34.04	2.86
Eleocharis acuta	59.00	2.95	1.81	1.43	0.07
Eleocharis cylindrostachys	873.00	151.80	26.81	21.17	3.68
Filamentous algae	48.00	2.40	1.47	1.16	0.06
Juncus usitatus	103.00	31.55	3.16	2.50	0.76
Lemna sp	2655.00	134.45	81.52	64.37	3.26
Ludwigia peploides ssp. montevidensis	1804.00	637.50	55.39	43.74	15.46
Marsilea mutica	271.00	13.55	8.32	6.57	0.33
Myriophylum	108.00	7.45	3.32	2.62	0.18
Ottelia ovaliflora ssp. ovaliflora	990.00	56.10	30.40	24.00	1.36
Paspalum dilatatum	16.00	4.00	0.49	0.39	0.10
Persicaria decipiens	128.00	43.00	3.93	3.10	1.04
Phragmites australis	80.00	4.00	2.46	1.94	0.10
Phylydrum lanugiriosum	54.00	2.70	1.66	1.31	0.07
Potamogeton pectinatus	383.00	77.05	11.76	9.29	1.87
Triglochin microtuberosum	1239.00	61.95	38.04	30.04	1.50
Typha sp	206.00	64.10	6.33	4.99	1.55
Unknown1	84.00	4.20	2.58	2.04	0.10

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