Freshwater aquatic plants of Darwin Harbour catchments

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ABSTRACT

This paper reviews published and other works relating, either directly or indirectly, to the aquatic plants and wetlands in the Darwin Harbour Catchments. Although some data are available, wetlands and aquatic plants of the area are yet to be systematically surveyed and the processes at work are frequently poorly understood. The area contains 65% of the aquatic plant species known from the northern part of the Northern Territory. Seasonally inundated wetlands and their flora are by far the most extensive, with lagoons and swamps on sandy substrates a major feature of the region. These lagoons and the lower Howard River floodplain are likely to be highly productive, though relatively species poor, based on research on similar wetlands in the Alligator Rivers Region. In contrast, the extensive very shallow wetlands on infertile sand are relatively high in NT endemic species and species of conservation significance. This environment is likely to be highly susceptible to raised nutrient levels and minor modification of drainage patterns and is threatened in the long term by surface mining and other development. There is a need to more clearly identify the values and vulnerability's of the different types of wetlands and associated flora to enable more effective planning, management and conservation of important areas.

INTRODUCTION

Aquatic plants can be a conspicuous feature of many of the Top End's wetlands and add significantly to the aesthetic and conservation values of these areas. They form the basis of the food chain in turn supporting dense aggregations of waterbirds and the region's freshwater fisheries.

The account presented here is based on first hand knowledge of wetlands in the Darwin Harbour Catchments, records from the NT Herbarium and a review of relevant parts of the published research. The published research available on aquatic plants relating specifically to the Darwin Harbour Catchments (those catchments whose estuaries are bounded by a line between Charles and Gunn Points) is limited. However, there is a more extensive body of published work relating to other parts of the Top End (that part of the Northern Territory north of 15ºS latitude), especially floodplains of the Alligator Rivers Region. The plants and biological processes at work in these wetlands are likely to be similar to some found in the Darwin Harbour Catchments.

<u>Definitions</u>

<u>Freshwater aquatic plant</u>. There is no universally accepted definition of an aquatic plant, and numerous differing examples can be found in the literature. Most have their limitations. For the purposes of this study an aquatic plant is defined as a plant thriving when growing partly or fully submerged in water, restricted to such habitats and apparently dependent on several months of inundation to complete its life cycle. Such species would normally have specific adaptations to the aquatic environment. Included are annual species present in shallowly inundated areas which have their foliage submerged for most of their life cycle, the flowering and fruiting phases being completed soon after water has receded. Specifically excluded here are rheophytic

species (those plants, often trees, which grow by streams and rivers and experience temporary inundation, in terms of the life cycle of the plant), species of rainforests on springs and mangroves which grow in inter tidal areas. However, in reality there are often not clear boundaries between freshwater aquatic plants, terrestrial species and plants of these other habitats.

Wetlands. The habitats occupied by aquatic plant species are collectively termed wetlands. Storrs and Finlayson (1997) in their review of conservation status of wetlands in the NT adopted the definition of Paijmans *et al.* (1985) as most appropriate and it is used here. This definition is "…land permanently or temporarily underwater or water logged. Temporary wetlands must have surface water or waterlogging of sufficient frequency and or duration to affect the biota. Thus the occurrence, at least sometimes, of hydrophytic vegetation or use by waterbirds are necessary attributes". As Finlayson and von Oertzen (1993) note this definition does not have a depth criterion. Although this definition includes tidal wetlands and coastal salt marshes, they have not been considered further in this paper. Although the classification of Paijmans *et al.* (*loc cit.*) is recognised as inadequate when applied to Top End wetlands, it is regarded as the best available and elements of it are used here (Finlayson and von Oertzen, 1993).

Systematic scope. Although the systematic scope of freshwater aquatic plants includes algae, bryophytes, ferns and flowering plants, algae are considered only briefly here. The algae are a heterogeneous group of organisms encompassing a greater diversity of lifeforms and metabolism than among the bryophytes or vascular plants.

Aquatic plants are collectively termed hydrophytes in the scientific literature (in Greek literally meaning 'water plant'), with larger (non-microscopic) species, both vascular and non-vascular, termed macrophytes. This paper deals mostly with the vascular species (ferns, fern allies and flowering plants). For the most part, authors of names of aquatic vascular plants follow Dunlop (1987).

ALGAE

In comparison to the macrophytes in the Top End, the algae are relatively poorly known. Surveys of macroalgae and diatoms in streams of Darwin Harbour Catchments have been carried out in April-May 2002 by Water Monitoring Section of DIPE with identifications by the National Herbarium of NSW (S. Townsend, pers. comm.). Fifty one taxa of macroalga were recorded from a total of 25 sites. In keeping with naturally soft water and a tropical climate, the macroalgae were reported as comprising a rich and healthy flora very similar to those reported for Arnhem Land, the Alligator Rivers Region and Magela Creek. *Scytonema archangelii*, *Schizochlamys gelatinosa* and *Spirogyra* sp. were the most frequently occurring species, although the majority of species occurred at only a few sites. Eighty three species of benthic diatoms were also recorded with *Achnanthidium minutissimum* the most common. Diatom assemblages correlated with water quality parameters, in particular conductivity, alkalinity, pH and nutrients. In comparison, Thomas (1983) recorded 160 taxa of diatom (representing 32 genera) from a variety of water bodies in the Alligator Rivers Region. In the Darwin Harbour Catchments, data from man-made water bodies (excluding Darwin River Reservoir (Townsend, 2001)), lagoons, drainage depressions and both lower and upstream floodplain types appear to be lacking. Also, if the work of Ling and Tyler (1986) in the Alligator Rivers Region is any indication, many more taxa are yet to be recorded from the Darwin Harbour Catchments. These authors recorded more than 530 taxa of non-diatom algae from the Alligator Rivers Region.

LIFE FORMS OF AQUATIC PLANTS

Two primary subdivisions in the lifeforms of aquatic macrophytes - attached and free-floating - are recognised by Sculthorpe (1967). Within the attached group three lifeforms are recognised: emergent-leaved attached macrophytes (e.g. most aquatic Cyperaceae, most aquatic Poaceae, *Typha*); floating-leaved attached macrophytes (e.g. *Nymphaea, Nymphoides, Potamogeton*) and submerged-leaved, attached macrophytes (e.g. *Eriocaulon, Hydrilla, Maidenia, Vallisneria*). Among the free floating macrophytes, Sculthorpe (*loc. id.*) recognised a number of variations including submerged-leaved (e.g. *Utricularia aurea, Ceratophyllum*), floating-leaved (e.g. *Azolla*, *Lemna aequinoctialis*, *Spirodella polyrhiza*) and emergent-leaved (e.g. *Pistia, Salvinia*).

The groups differ in their ability to utilise wetlands of different water depths (Sculthorpe, *loc. id.*). Emergent attached species are usually in water less than 1.5 m deep, and floating leaved, attached species in less than 3.5 m of water. Submerged attached species occur in water depths to approximately 11 m. Free floating species can be in any water depth but are restricted to still or slow flowing water bodies. Apart from the obvious structural differences, there are some important differences in how these groups obtain their nutrients. The free floating plants obtain nutrients from the water column, while many of those rooted in sediment obtain nutrients from that source, although some can use both pathways.

PHYTOGEOGRAPHY OF VASCULAR AQUATIC PLANTS

As in other regions, the aquatic plant flora of the Top End consists largely of widely distributed taxa and is relatively low in genera and species endemic to Australia. A similar situation also exists in the mangrove flora and the lowland monsoon forest flora (Taylor and Dunlop, 1985). Cowie *et al*., (2000) found that at the generic level, only three (*Hygrochloa*, *Omegandra* and *Maidenia*) of the 130 genera of strictly floodplain plants are endemic to Australia. One of these (*Omegandra)* is not aquatic but grows during the dry phase. Similarly, the closeness of the aquatic flora of an African floodplain to those of the Top End has been noted by Howard (1985). The number of endemic genera of aquatic plants is in contrast to some other habitats in the Top End, notably the sandstone flora (Taylor and Dunlop, 1985).

Endemism. Of the aquatic species recorded in the Top End by Cowie *et al.* (2000) or in the NT Herbarium, 38% (108) are endemic to Australia with only a small proportion (6%) restricted to Australasia. Some 43% (125) of species are found in the Old World, and 14% (39) are pantropical. Terrestrial or mud flat species present during the dry phase were excluded. Of the Australian endemics, relatively few aquatic species are restricted to the Northern Territory (*Bambusa arnhemica*, *Hygrochloa aquatica*, *Nymphoides planosperma, N. spongiosa, N. subacuta*, three *Eriocaulon* spp. and ten *Utricularia* spp). Although none are restricted to the Darwin Harbour Catchments, the ranges of *Nymphoides subacuta, Utricularia holtzei* and *U. hamiltonii* are centred on the Darwin Rural area.

FRESHWATER WETLANDS TYPES IN THE DARWIN HARBOUR CATCHMENTS

Permanent and near permanent wetlands

Channel billabongs. Channel billabongs are residual permanent water bodies found in the main stream channel of creeks and rivers during the dry season. They have steep, tree lined banks with a small littoral zone, are relatively deep, have relatively coarse sediments, moderate to fast wet season flows and support few aquatic plants. Such billabongs can be found on the Howard River, below the Gunn Point Road. From research in the Alligator Rivers Region, the dry season water quality in this type of billabong remains close to that of wet season stream water with phosphorous levels, conductivity and levels of salts remaining low throughout the dry season (Walker & Tyler, 1984). In the dry season, they can remain relatively clear.

Springs. Howard Springs and Berry Springs are probably the two best known examples in the Darwin Harbour Catchments. The water in these springs is relatively hard and flow conditions are low to medium. Howard Springs contains the only known population of *Ottelia alismoides* in the Darwin Harbour Catchments and also supports *Ceratophyllum demersum*. Berry Springs appears to be a faster flow environment and supports few aquatic plants. The plants in these systems have not been studied in the Top End.

Man-made lakes. These wetlands are variable in depth and size. Waterbodies in urban areas like Fairway Waters and Marlow's Lagoon have low water flow, relatively steep edges and consequently a small littoral zone and are relatively shallow. At times during the dry season they can be 'topped up' by input of town water, with water levels remaining relatively constant and thus providing habitat for species like *Typha*. They often receive urban runoff, with a likely input of nutrients through leaching of garden fertilisers (and potentially other pollutants).

The other extreme is Darwin River Dam. This environment has low water flow, is quite deep by local standards, but receives drainage that is low in nutrients (Townsend, 2000) from an undisturbed, natural catchment. In places the banks can be quite steep, with small littoral areas. *Vallisneria* dominate shallow areas of the reservoir (S. Townsend pers. comm).

Seasonal wetlands. As is the case elsewhere in the Top End, seasonally inundated wetlands are by far the most extensive type in the Darwin Harbour Catchments with a pronounced cycle of inundation and drying. This cycle results from the subdued local topography and the monsoonal climatic regime of a short but intense wet season followed by a long dry season with high evaporation (McDonald and McAlpine, 1991).

Lagoons. Lagoons are one of the most important wetland types in the Darwin Harbour Catchments and are especially well represented in the Howard River Catchment. Examples include Knuckey, McMinn's, Fischer, Lyon's, Girraween, Dutchies and London Lagoons. They are enclosed, relatively shallow, seasonally flooded depressions perhaps at most 2–3 metres deep during the wet season. They have a wide seasonally inundated (littoral) zone, low flow rates and gently sloping banks, often drying out completely over the course of the dry season. They are scattered through the landscape away from the major drainage lines. In terms of their morphology and floristics (but not hydrology or origins) they appear to be similar to the backflow billabongs (more correctly known as lateral lakes (Bayly and Williams, 1973) elsewhere in the Top End. The limnology and biology of backflow billabongs in the Alligator Rivers Region has been comparatively well documented (Finlayson *et al*. 1990). In these water bodies, sodium chloride levels in the water increase as the dry season progresses with phosphorous and turbidity levels higher than in the wet season and the pH lower (4.0–6.0) (Walker and Tyler, 1984). They are probably highly productive.

Communities supported on lagoons in the Darwin Harbour Catchments include those dominated by *Scleria poaeformis*, *Pseudoraphis spinescens*, *Nymphaea* spp, and *Melaleuca viridiflora*.

Drainage depressions and upstream floodplains. The lagoons form part of an environmental and floristic continuum with drainage depressions and upstream floodplains. At one extreme, lagoons can be permanently or almost permanently wet but at the other extreme grade into swampy drainage depressions or upstream floodplains that hold water perhaps only a few cm deep during the wet season. There is a corresponding change in the dominant vegetation along this gradient, with the shallowest habitats supporting communities such as *Eriachne burkittii* grassland, *Melaleuca nervosa* woodland, *Melaleuca viridiflora* low woodland and *Banksia dentata* shrubland. Some (although perhaps not all) of the species in them are clearly aquatic. (Although existing in water only a few cm deep, they have submerged foliage and emergent inflorescences, are dependant on wet season flooding, and complete their life cycle rapidly once surface water recedes.) In the Darwin Harbour Catchments, many of these depressions are on sandy substrates and they support far more aquatic species of conservation significance than other wetland habitats in the region. They are generally poorly studied.

Coastal floodplains. The lower Howard River floodplain (mostly that part in the Howard Springs Hunting Reserve) is the prime example of this wetland type in the Darwin Harbour Catchments. Although it is relatively small, it has features in common with the larger floodplains in other parts of the Top End. It probably has low water flow, is shallow with an extensive seasonally flooded (littoral) zone, and is probably highly productive. There is probably a pronounced salinity gradient as it merges with the adjacent coastal plain with their mangrove and saltmarsh vegetation. Unlike most of the larger floodplains, it appears to be relatively sandy. Although a small floodplain by the standards of many Top End rivers, the lower Howard has examples of some of the plant communities found on this type of floodplain. Important communities include those dominated by *Schoenoplectus litoralis*, *Leersia hexandra*, *Oryza rufipogon,* and *Melaleuca* spp.

Swamps of coastal plains. Coastal plains appear to have formed around Shoal Bay by deposition of marine sediments and resulting prograding of the coastline. Although consisting of extensive areas of mangroves, mud flat and chenier ridges (low ridges of shelly sand laid down over muddy inshore sediments), shallow swamps have formed adjacent to uplands and in old river and creek channels. Some of these swamps may experience regular, though infrequent, seawater intrusion as a result of king tides. They are probably a low flow environment, with low to high productivity depending on salinity. They are poorly studied in the Top End.

Other land subject to seasonal inundation

River and creek banks. These support some aquatic species, although most species in this habitat are rheophytes. They are often characterised by high flow.

Channels (various substrates). – There are many examples of creek and river channels in the area. They tend to be poor environments for aquatic plants and most are probably of low productivity. They dry out seasonally and are often relatively fast flow environments with coarse infertile substrates.

GENERAL VEGETATION PATTERNS IN TOP END WETLANDS

Wetland plant communities

A broad scale, systematic survey of larger Northern Territory floodplains and wetlands on associated coastal plains towards the end of the 1989–1990 wet season gives an overview of the wetland plant communities occurring in the northern NT (Wilson *et al* 1991). Major floodplains and coastal plains from the Moyle River near Port Keats to the Arafura Swamp in central Arnhem Land were included. Unfortunately, wetlands like the lagoons of the Darwin Harbour Catchments and the lower Howard River floodplain were too small to be included in this survey. Similarly, the shallowest wetlands like drainage depressions and upstream floodplains were also beyond its scope. However, from this study we can gain an insight into and perspective on many of the wetland plant communities present in the Darwin Harbour Catchments and their environmental relationships.

Wilson *et al*. (1991) recognised 24 floristic groups based on herbaceous vegetation, with most groups associated with distinct salinity and water depth regimes. Three broad groupings were recognised, namely saline/semi-saline, ‘dry’ freshwater and ‘wet’ freshwater respectively.

Saline/semi-saline communities generally occur on the coastal plains near the mouths of the major rivers and on prograding coastlines. In these areas they can be found on the landward side of tidal creeks or tidally inundated saltflats in shallow water 20 cm deep or less. They are underlain with saline muds and may experience irregular tidal inundation on king tides. These communities generally consist of grasslands, or in deeper areas, brackish swamps and are characterised by species (in order of increasing conductivity levels of sites occupied) such as *Leptochloa fusca (*syn. *Diplachne parviflora)/Eleocharis spiralis, Paspalum distichum/Eleocharis, Sporobolus virginicus, Eleocharis dulcis/Monochoria, Schoenoplectus litoralis* and *Xerochloa imberbis* (Fig.1). Similar communities are to be found on coastal plains around Shoal Bay. These communities are generally devoid of paperbark forest or woodland. However, relictual *Melaleuca* forests exist where saltwater intrusion has occurred. Relict beach ridges and chenier ridges (low ridges of shelly sand laid down over muddy inshore sediments) containing terrestrial communities such as monsoon vine-forest, grasslands or *Pandanus* shrublands are also associated with this group. Also, mangrove communities backed by samphire communities occur along the seaward edge of the floodplains or along tidal channels.

The 'dry' freshwater communities mostly occupy extensive areas of more elevated floodplains which are inundated only at the peak of the wet season and are the first regions to dry out in the Dry season. They are often contiguous with the middle and upper reaches of the tidal sections of main river channels but may also occur in the lower (more seaward regions) of the floodplains on levees surrounding the old river channels (palaeochannels). These communities occurred in water around 20 cm deep at the time of the study. In order of low but increasing conductivity they are characterised by: *Cyperus scariosus/Imperata, Malachra fasciata/C. scariosus, Eleocharis spiralis/C. scariosus* and *Ischaemum australe/Ludwigia* (Fig.1). They are generally fringed on the landward sides by forests and woodlands of *Melaleuca* spp., *Eucalyptus* spp. or monsoon vine-forest species. Communities of herbs, excluding grasses or grasslands can also occur on the edge of the seasonal wetlands.

The 'wet' freshwater communities occur in low lying parts of floodplains, including in flood basins, depressions, billabongs, and backswamps and water that has low conductivity. It should be noted that local use of the term billabong is at variance with accepted use elsewhere in Australia. In the Top End, the term is applied to remnant water bodies in stream channels, in paleochannels on floodplains or for lateral lakes. Elsewhere in Australia the term is used for oxbow lakes (Bayley and Williams, 1973). These areas represent the wettest parts of the floodplains with surface water persisting for at least a few months into each dry season or in billabongs, all year. The communities are characterised by: *Echinochloa polystachion/Leersia, Oryza/Eleocharis, Phragmites vallatoria*, *Pseudoraphis/Eleocharis, Scleria poaeformis* and *Urochloa mutica*, (in similar water depths). In deeper water *Melaleuca leucadendra/Lepironia articulata/Eleocharis sphacelata, Hymenachne/Leersia/Oryza, and Oryza/Pseudoraphis* communities occur (Fig.1). In progressively deeper water again *Hymenachne acutigluma, Leersia/Actinoscirpus* and *Pistia/Nelumbo* communities are found. The relatively drier groups (those that dry out first after the wet season) are often characterised by the grasses *Oryza rufipogon sens. lat.* and *Pseudoraphis spinescens*, and sedges such as *Eleocharis dulcis* and *Eleocharis* (Beatrice Hill entity). Although often not present, most communities can support *Melaleuca* spp. forests. Billabongs may be fringed by *Pandanus spiralis, Barringtonia acutangula* and locally *Bambusa arnhemica* and support floating mat communities. The exotic floating aquatic fern, *Salvinia molesta* has invaded some communities, especially in billabongs.

Melaleuca communities. The occurrence of *Melaleuca* trees (paperbarks) varies greatly between wetlands. All floodplains and other wetland systems studied by Wilson *et al*. (1991) have at least a partial fringe around the margin. However, some support extensive forests (e.g. Arafura Swamp, the Liverpool/Tomkinson floodplains, seasonal wetlands south west of Milingimbi and the Mary River/Swim Creek floodplains). The canopy cover of paperbark communities can be highly variable, from dense closed-forests to isolated patches or scattered individual trees. *Melaleuca* trees can occur in association with most of the herbaceous communities but are not always present, a finding also noted by others such as Finlayson *et al*. (1989). Factors such as fire and establishment conditions during the early wet season may be involved and require further investigation. However, on any particular floodplain the occurrence of individual species of *Melaleuca* appears to reflect a distinct pattern of flooding and salinity tolerance (Wilson *et al*. 1991). Of the three major species, *Melaleuca viridiflora* apparently tolerates the driest conditions (shortest period of inundation) and *M. leucadendra* the wettest conditions (longest period of inundation). *M. cajaputi* apparently tolerates the most saline conditions of the three but also appears more tolerant of flooding than *M. viridiflora*.

Relative extent of wetland communities. In the study by Wilson *et al.* (1991), the most common community type, are grasslands dominated by Wild Rice (*Oryza* spp.), with or without a paperbark forest overstorey. These grasslands are also more abundant on seasonal wetlands south-west of Darwin. The next most common community is the *Cyperus scariosus* sedgelands, which appear more dominant on seasonal wetlands to the east of the Mary River. Although many of the communities recognised by Wilson *et al.* (1991) are widespread, some are associated strongly with particular floodplains (e.g. those dominated by *Phragmites vallatoria, Actinoscirpus grossus* or *Ischaemum australe*). This may be explained in part by differences in geomorphology between the different river systems. Floodplains such as those of the Finniss, Reynolds, Glyde/Goyder (Arafura Swamp), and Mary Rivers and Magela Creek are dominated by flood basins or palaeo-estuarine plains and tend to have larger areas covered by ‘wet’ communities. In contrast, floodplains such as the Adelaide, South Alligator, East Alligator and West Alligator Rivers with large deltaic-estuarine plains (i.e. adjacent to tidal sections of the river) and relatively small flood basins have more extensive areas of dry communities. Also, the distribution of some species may be affected by past activities of feral animals. *Phragmites vallatoria* and *Echinochloa polystachion* are least abundant in areas that have, until the mid 1980’s, supported large numbers of feral buffalo.

Comparative species richness

Regional level. Within the Darwin Harbour Catchments approximately 187 macrophytes have been recorded (NT Herbarium records). This represents 65 % of the macrophytes found in the Top End. Notably absent are species characteristic of deeper, permanent billabongs and swamps such as *Nelumbo nucifera*, *Nymphaea macrosperma*, *Pistia stratiotes* and *Actinoscirpus grossus*. Also absent are those restricted to sandstone pools and creeks (e.g. *Myriophyllum callitrichoides*, *Nymphoides planosperma*, *N. furculifolia*), some restricted endemic species (e.g. *Vallisneria triptera*) and species more characteristic of southern parts of the Top End.

Community level. Plant communities of the floodplains are species poor compared to local woodland and open forest communities dominated by *Eucalyptus* spp. (Taylor and Dunlop, 1985). This is also probably true of other wetlands in the Top End, including Darwin Harbour Catchments. Among the floodplain communities, species richness is lowest at wet and saline sites and highest at the drier sites. For example, the more deeply flooded *Oryza* and *Eleocharis* dominated communities have significantly fewer species than the 'drier' *Fimbristylis* sedgeland.

Zonation with depth

A number of generalised, common zones in the vegetation occurring around billabongs on the Magela Creek system have been described (Finlayson *et al*., (1994). Similar patterns of zonation can be found around other seasonal wetlands elsewhere in the Top End.

On backflow billabongs the zones recognised were:

(i) a fringe of *Melaleuca* spp. in seasonally flooded areas around the edges;
(ii) a mixture of grasses and sedges in seasonally inundated areas shaded by tree canopies;
(iii) a band of *Eleocharis* spp. (mostly *E. dulcis*) in water that is usually less than 1.5 m deep during the wet season;
(vi) patches of water lilies (mostly *Nymphaea violacea* and *Nymphoides indica*) and submerged species (e.g. *Najas, Ceratophyllum* and *Hydrilla*) along the deep water edges of the *Eleocharis*; and
(iv) a small area of open water in the centre, usually between 1.5–2.0 m deep during the wet season.

On lagoons and some backflow billabongs elsewhere in the Top End the *Eleocharis* zone can be replaced by a band dominated by *Pseudoraphis spinescens,* and *Nymphaea violacea* or *Nymphaea hastifolia.* Also, on some lagoons the fringing zone of *Melaleuca* spp. may be absent.

PLANT COMMUNITIES IN DARWIN HARBOUR CATCHMENTS WETLANDS

Within the Darwin Harbour Catchments, remnant vegetation including wetland plant communities have been mapped into broad groups for the Rapid Creek Catchment (Clark and Brocklehurst, 1991), Casuarina Coastal Reserve (Brocklehurst, 1991), Darwin Municipality (incorporating the earlier mapping) (Brock, 1995) and Litchfield Shire (Conservation and Natural Resources Group, 2002). The methodologies for these studies varied. In some cases vegetation units recognised by Brock (1995) are descriptions of polygons, without an underlying classification or ordination of the vegetation data. The other maps are based on the traditional classification of representative vegetation plots and description of map units based on the vegetation types recognised in the classification (P. Brocklehurst, pers. comm.). Map units frequently represent the lowest division of vegetation information that can be practically mapped at the scale selected. They may include a number of different plant communities.

The map units that can include aquatic plants are listed below. They include many of the vegetation types recognised by Wilson *et al*. (1991), but also include the smaller and shallower wetlands not included in that study. Map units common (or closely allied) in both the Conservation and Natural Resources Group (2002) and Brock (1995) studies were:

- *Lophostemon lactifluus* mixed species open forest with *Acacia auriculiformis* and *Melaleuca leucadendra*. A transition community.
- *Pandanus spiralis* low woodland to very low open woodland, with *Lophostemon lactifluus* and *Grevillea pteridifolia*. Ground layer dominated by mixed species grasses and sedges. On drainage floors.
- *Murdannia vaginata*, *Bothriochloa bladhii* closed herbland/grassland. Seasonal blacksoil swamp, with mixed species grasses, sedges and herbs.
- *Bothriochloa bladhii*, *Pseudoraphis spinescens* closed grassland, with *Eleocharis sundaica, E.dulcis, Chrysopogon elongatus* (syn. *Vetiveria pauciflora), Sorghum stipoideum, Ectrosia agrostoides* and *Eriachne burkittii*. Seasonal inundated fringes of freshwater lagoons.

- *Closed* grassland/sedgeland on coastal plains. *Sporobolus virginicus* and *Xerochloa imberbis* are common on saline areas. *Fimbristyli*s spp. and *Eleocharis* spp. are found in brackish to freshwater sites, while *Ischaemum australe*, *Imperata cylindrica* and *Eriachne burkittii* occur on the landward margins. A complex of species, where presence and density of species are determined by depth and duration of flooding and degree of salinity. This was mapped as two separate units, *Ischaemum australe* closed grassland and closed grassland/sedgeland, by Brock (1995).
- *Melaleuca cajuputi* closed forest swamp.
- *Melaleuca leucadendra*, *M.cajaputi*, *M.viridiflora* open forest to closed forest freshwater swamp occasionally with *Acacia auriculiformis.*

The wetland units mapped only for Litchfield Shire were:

- Mixed species association lining freshwater streams. *Pandanus spiralis* is common, sometimes in pure stands. Other species are allied to monsoon rainforest, including *Acacia auriculiformis*, *Syzygium armstrongii*, *Carallia brachiata* and *Melaleuca leucadendra.*

- *Dapsilanthus spathaceus* (syn. *Leptocarpus spathaceus*), *Sorghum intrans*, *S. stipoideum* closed grassland/sedgeland with *Xyris complanata* and *Eriachne burkittii*, and scattered low emergents including *Grevillea pteridifolia* and *Banksia dentata*. Seasonally inundated freshwater swamps.

- *Melaleuca viridiflora* low open forest to low woodland swamp, with *Pandanus spiralis, Lophostemon lactifluus* and occasional *Melaleuca cajuputi.*

- *Melaleuca nervosa, Grevillea pteridifolia, Lophostemon lactifluus* mixed species low woodland to low open woodland. Dense to mid dense sedgeland/grassland includes *Dapsilanthus spathaceus (*syn. *Leptocarpus spathaceus), Eriachne burkittii, E. triseta* and *Pseudopogonatherum* spp.
- Degraded areas affected by mining activities, including sand, gravel, rock and topsoil extraction. Excavation has resulted in numerous shallow to deep waterholes, the shallower ones creating seasonal swamps which support localised populations of *Melaleuca* and *Grevillea* species. On some cleared areas some shrub and small tree regeneration occurs, and includes various *Acacia* species and *Calytrix exstipulata*. Infestations of weeds are common in these degraded areas, with substantial eroded and run-off areas left unrehabilitated.

Map units recognised exclusively by Brock (1995) and probably including aquatic plant species include:

- *Melaleuca leucadendra* stunted very low open woodland.

- Regeneration of *Melaleuca viridiflora* low woodland to low open woodland with *Pandanus spiralis* and *Lophostemon lactifluus*. Commonly includes areas of seasonal swamp.

ABIOTIC DETERMINANTS OF SPECIES DISTRIBUTION

<u>Water depth and period of inundation</u>

These factors are treated together here because period of inundation is often highly correlated with water depth in wetlands in the Top End. Although deep water areas are usually permanently inundated and shallow areas seasonally inundated, exceptions may include parts of spring-fed wetland systems which are shallow but remain permanently wet. In permanent water, depth acts on plants principally through its effect on light penetration. Light availability decreases with depth in the water column, the light being absorbed by turbidity, plankton and colouration of the water (for example caused by dissolved organic compounds such as tannins). The general depth limit of submerged attached macrophytes in still water is circa 11 m (Sculthorpe, 1967), while in the Top End rooted floating-leaved species are absent in water > 3-4 m deep.

The period of inundation determines the time available for an aquatic plant species to complete its life cycle, and thus also affects what species are able to utilise an area. Water depth and period of inundation (or microtopography) have been found to be primary determinants of the distribution of macrophyte communities elsewhere in the Top End (Bowman and Wilson, 1986; Finlayson *et al.* 1989; Morley, 1981; Wilson *et al*. 1991). The arrangement of plant communities known from the Darwin Harbour Catchments in relation to water depth data derived from Wilson *et al*. (1991) can be seen on Fig.1.

Water chemistry

Hardness. Most wetlands in the Region contain relatively soft water; the exception being some springs fed by ground water. The only known occurrence of *Ottelia alismoides* in the Darwin Harbour Catchments, at Howard Springs, may well be explained by the relative water hardness. The species is also well known from the Roper River area but is rare on the coastal floodplains and lagoons in the Top End.

Salinity. Salinity can also be a determinant of the distribution of aquatic plant communities in the Top End (Bowman & Wilson, 1986; Wilson *et al*. 1991; Cowie *et al.* 2000). Salinity is a complex factor as variations in salinity correspond to differences in conductivity, pH, density, osmotic pressure, and proportions of various ions in addition to Na and Cl. On the coastal plains around Shoal Bay, brackish wetlands inundated by seawater on the largest tides, but with a strong freshwater input during the wet season may occur. The arrangement of plant communities known from the Darwin Harbour Catchments in relation to salinity data derived from Wilson *et al*. (1991) can be seen on Fig.1.

Nutrients. Changes in nutrients may act to change the competitive relationships between vascular plant species (for example promoting the growth of free floating species such as Salvinia over attached species) or between algae and vascular plant species. Nutrient levels in many of the region's water bodies are thought to be low except towards the end of the dry season in some waterbodies (Walker and Tyler, 1984). In shallow wetlands on sand, it is likely that nutrient levels are very low, although these have yet to be investigated.

Water flow

May act through mechanical damage to plants and in its effect on substrate (at higher velocities, the substrate becoming less stable, and the particle size coarser). In the NT, flow rates can also influence plant species distribution in some situations (Morley, 1981). Locally, running water tends to favour species with long narrow or deeply segmented leaves.

Substrate

Substrate conditions are often related to water flow, with particle size proportional to stream flow. However, it is apparent that a number of species prefer sandy or organic substrates, others a clay substrate.

Fire

Fire may be a significant factor influencing woody species in seasonally inundated wetlands. For example, anecdotal evidence suggests that a flush of germination and establishment of some leguminous shrubs and trees such as *Mimosa*, *Sesbania* and *Melaleuca* can occur during the wet season after a fire. Also, fire regimes may influence the post establishment survival of woody plants. However, preliminary studies of fire in *Pseudoraphis* grassland indicated that dry season fire had little affect on composition of herbaceaous species the following wet season (B. Bailey unpubl. data).

Light

Although not seen as a primary determinant of vegetation patterning in macrophyte communities in the Top End, the dense shade cast by *Melaleuca* trees may influence both the species composition and cover of vegetation beneath them (Sanderson *et al*. 1983). Walker and Tyler (1984) recorded a massive increase in turbidity during the dry season in most of the billabongs they sampled. This was sufficient to limit primary productivity at a time of nutrient abundance. As discussed above light availability is also inversely proportional to water depth, with the distribution of aquatic plants in deeper water restricted by light.

Other factors

Wave action can also influence distribution of macrophytes (Sculthorpe, 1967), but it has not been reported in the Top End, probably because there are few local waterbodies large enough for significant wave development to occur. While temperature may affect the distribution of plants at a larger scale (Sculthorpe, 1967), it is probably not important at the local scale in this area.

In addition, there are a number of biotic factors that can influence the distribution of plant species, including competition, grazing, etc

DYNAMICS OF WETLAND PLANT COMMUNITIES

Many wetland plant communities are inherently dynamic, both on a seasonal basis and year to year.

Seasonal changes

A notable feature of wetlands in the Darwin Harbour Catchments (as elsewhere in the Top End) is the high proportion of seasonally inundated wetlands. This type of wetland can undergo large changes in composition and foliage cover between wet and dry seasons (Finlayson *et al.* 1989). In the cases studied, the flora is composed of distinct wet phase and dry phase (terrestrial) floras with some species present in both phases. The success of the majority of species depends on mechanisms that enable them to survive the climatic extremes of dry season desiccation and wet season inundation. Many aquatic species persist through the dry phase purely as seed, while a lesser proportion persist with the aid of perennial under ground storage organs (tubers or rhizomes). Some persist as a reduced, xeromorpic dry land phase (e.g. *Pseudoraphis spinescens, Ludwigia adscendens*).

Year to year changes in vegetation

Apart from the distinct seasonal changes in the vegetation, year to year changes in the species composition and abundance can be significant. Many of the communities occurring on seasonal wetlands in the Top End have a high proportion of annual plant species and those of the Darwin Harbour Catchments are likely to be similar. For example, on seasonally inundated parts of the Magela Creek floodplain, 72% of species were annual, while for herbaceous floodplain communities in the Alligator Rivers Region 64–80% were annual (Finlayson *et al*. 1990; Taylor and Dunlop, 1985). The floristic composition of plant communities dominated by annuals is especially vulnerable to year to year changes in composition (Grubb *et al.* 1982). Differences between wet seasons in the timing, duration and intensity of rainfall are thought to interact with the germination and establishment requirements of the different species to bring about changes in the vegetation. These interactions may help explain observed year to year variations in species dominance (Finlayson *et al*. 1990).

PRODUCTIVITY

Most of the information on productivity of freshwater wetlands in the Top End comes from the Alligator Rivers Region. There, seasonal changes in standing crop of three aquatic grasses (*Hymenachne acutigluma, Pseudoraphis spinescens* & *Oryza meridionalis) were* measured over an 18 month period. To estimate productivity of *Melaleuca* dominated communities, litter fall was measured over a 32 month period. Productivity of *Nymphaea* has also been estimated. Grasslands dominated by *Pseudoraphis*, *Nymphaea* communities and *Melaleuca* woodlands are common in wetlands of the Darwin Harbour Catchments. The *Melaleuca* and grassland communities in particular can be regarded as highly productive.

Grasslands

Productivity in the grasslands is strongly seasonal and is tied to the annual cycle of flooding and drying. Annual productivities of 0.51 kg m $^{-2}$ dry weight have been recorded for *Oryza meridionalis*, 1.91 kg m $^{-2}$ for *Pseudoraphis spinescens* and 2.09 kg m $^{-2}$ for *Hymenachne acutigluma* (Finlayson 1991; Finlayson *et al*. 1993). *Pseudoraphis spinescens* communities in particular appear to relatively common on lagoons in the Darwin Harbour Catchments. Although the figures for *Pseudoraphis* and *Hymenachne* are high compared to native savanna grasses in the NT and many other wetlands, they are not as high as for some large emergent aquatic plants elsewhere in the world (Finlayson and Woodroffe, 1996). *Hymenachne acutigluma* (although occurring little in the Darwin Harbour Catchments) is highly nutritious by any standard and with > 2% N and an average of 0.2% P, is especially so for an unfertilised grass (Calder, 1982). The Darwin Harbour Catchments have wetlands dominated by other large emergent macrophytes, like *Scleria poaeformis*. The productivity of these are yet to be measured but could well exceed those for *Pseudoraphis spinescens* and *Hymenachne acutigluma*.

Nymphaea communities

Williams (1983) has estimated the productivity of *Nymphaea* sp. in a backflow billabong in the Alligator Rivers Region at 0.056 to 0.225 kg m $^{-2}$ y $^{-1}$ dry weight. Although using a different methodology to that used for grasses, in comparison with them and some other macrophytes, this level of productivity is relatively low.

Melaleuca forests and woodlands

In tree dominated communities productivity can be measured indirectly through the production of leaf and other litter material produced by a forest. In the *Melaleuca* dominated forests and woodlands that are a prominent feature of the floodplain fringes, litter fall has been measured at 0.7 to 1.5 kg m $^{-2}$ y $^{-1}$ reflecting different densities of trees (Finlayson *et al*. 1993). This level of productivity is equivalent to or higher than in many forests elsewhere in Australia.

AQUATIC PLANTS OF CONSERVATION SIGNIFICANCE IN DARWIN HARBOUR CATCHMENTS

Swampy depressions and upstream floodplains with 16 species are by far the most important habitat in term of numbers of aquatic plants species of conservation significance (Appendix 1). The species represented include 9 species of *Utricularia*. In comparison lagoons have three species (*Eleocharis* A63452 Coonjimba Billabong, *Nymphoides subacuta* and *Websteria confervoides)*. Just one aquatic species of conservation significance (*Peplidium maritimum*) is known from the swamps on coastal plains. Some species occur in more than one habitat. Also, some habitats are inextricably connected in a number of ways and cannot be conserved in isolation. Although no aquatic species are restricted to the Darwin Harbour Catchments, the ranges of *Nymphoides subacuta, Utricularia holtzei* and *U.hamiltonii* are centred on the Darwin Rural area.

The genus Utricularia and Darwin Harbour catchments wetlands

Aquatic plants of the genus *Utricularia* are a common component of the seasonally inundated swampy depressions and upstream floodplains. The Top End with 36 species is a world centre of diversity for the genus (Taylor, 1989). Most of those in the Top End are submerged aquatics growing attached to the substrate in very shallow water for most of their life cycle. In addition, six species are free-floating aquatics. As Taylor (*loc. id.*) notes, the majority of attached species occur in open vegetation in the seasonally wet tropics favouring areas of near flat, poorly drained, acid, infertile sand over a less permeable substrate so that the soil is wet or inundated for at least part of the year. In the Top End, this diversity of species is nowhere better developed than on the extensive sandsheets of the so-called Koolpinyah land surface in the Darwin rural area. Here, up to 14 species can be found on an area of just 0.1 ha, inhabiting the drainage depressions and upstream floodplains. Twenty six species can be found within a few km. Seven species in the Darwin Harbour Catchments are endemic to the NT, with the occurrence of two (*Utricularia holtzei* and *U. hamiltonii*) almost confined to the Darwin Rural area.

THREATS TO WETLANDS

Drainage, clearing and other disturbance

Drainage, clearing and other forms of disturbance can have detrimental impacts on native plant communities. Drainage works have been constructed in many rural residential subdivisions around in the Darwin rural area and these may have the effect of lowering of the water table in nearby wetlands. Some wetland areas in the rural area have been cleared and in some cases shallow wetlands used for horticulture. Siltation resulting from erosion of nearby earthworks could also be a factor in some instances.

Introduced plants

Riparian and wetland plant communities are the most susceptible to weed invasion both world wide and in Australia (Holzner, 1982; Humphries *et al.* 1991). Introduced aquatic plants can have serious consequences for the wetlands they invade, with the effects in Australia documented by Mitchell (1978) and the Top End by Storrs and Finlayson (1997). In the Top End, there are a number of introduced plant species known to invade wetlands including*: Cabomba caroliniana, Echinochloa polystachya, Hymenachne amplexicaule, Mimosa pigra, Salvinia molesta* and *Urochloa mutica*. One of the primary impacts of all of these species is the complete or partial displacement of native flora and fauna on wetlands.

Saltwater intrusion

Intrusion by tidal creeks into freshwater wetlands has been documented on a number of floodplain systems in the western Top End (Woodroffe *et al.* 1985; Woodroffe and Mulrennan, 1993). Although no such intrusion has been documented for wetlands of the Darwin Harbour Catchments, those around Shoal bay, especially the Howard River and King Creek may be vulnerable.

Nutrient enrichment and pollutants

Nutrient load on local wetlands may be increased by agricultural activities through discharges from heavily settled areas. Horticulture especially is a developing industry in the Darwin Rural area, utilising large areas of land and quantities of fertilisers and pesticides. Intensive animal husbandry enterprises such as poultry farms and cattle feed lots produce discharges with very high nutrient concentrations. Light industrial activities can also result in increased inputs of nutrients and pollutants into wetland systems. There is no information available on effects of nutrient, pesticide or other pollutants in local wetlands. However, it is expected that increased nutrient inputs would be highly detrimental to the shallow wetlands on infertile sands that support *Utricularia* spp.

Natural surface run-off water elsewhere in the Top End is neutral to acidic, very soft with low buffering capacity and low ionic concentrations (e.g. Walker and Tyler 1984; Hart *et al.*, 1987; Townsend and Douglas, 2000). However, although the water quality of billabongs during the wet season reflects that of the stream systems, during the dry season the waters of many billabongs are concentrated considerably (up to 1200%) by evaporation (Walker and

Tyler, 1983). A similar process of concentration is likely to occur in lagoons in the Darwin Harbour Catchments and could lead to concentration of pollutants in these water bodies.

Mining

The shallow deposits of almost pure sand found in some drainage depressions and on the margins of upstream floodplains are a prime, cheaply utilised source of clean sand for the local building industry. These deposits are underlain by more impervious clayey or laterite layers and are frequently excavated to a depth of only 0.5-1.5 metres. Extensive areas of land in the Howard River catchment have already been affected by sand extraction. The ongoing utilisation of this resource is a long term threat to the continued existence of the diverse communities of *Utricularia* species and other specialised flora associated with this habitat. Although mining of this sand sheet and other habitats can create shallow wetlands, which favour a number of aquatic species, these areas are rarely suitable for the more specialised species found in very shallow water on almost pure sand areas.

STATE OF KNOWLEDGE

Inventory of aquatic species. With a few exceptions, inventory of aquatic plant species in the Darwin Harbour Catchments has been largely incidental to other activities. However, a substantial list of species has been accumulated for the area as a whole, with a few wetlands in Darwin Harbour Catchments well surveyed. Algae have been surveyed in streams in Darwin Harbour Catchments. However, if the work of Ling and Tyler (1986) in the Alligator Rivers Region is any indication, many more taxa are yet to be recorded from other wetland types.

Inventory of wetlands. A brief overview of plant communities associated with wetlands has been completed and vegetation units mapped as part of projects to map the remnant vegetation of Darwin and Litchfield Shire. However, this could be usefully refined further. To place wetlands in the Darwin Harbour Catchments into their appropriate ecological and conservation context, a good overview of the wetlands in the Top End is necessary. For wetlands associated with the larger floodplains and coastal plains this regional context is available (Wilson *et al.*, 1991) but is lacking for lagoons and shallow wetland types. The shallow wetlands especially are high in endemic plant species and species of conservation significance.

Ecological processes. Ecological processes on the larger floodplains in the Top End are well studied, but this knowledge may not translate directly to some wetland types in the Darwin Harbour Catchments. Information is needed for wetlands on coastal plains, lagoons and shallow wetland types. Also, specific information on the relatively sandy lower Howard River floodplain is also lacking.

Understanding of impacts. The climate and consequently the wetland systems are different from temperate regions and other parts of Australia. Information from these areas may not translate to the Top End of the NT. Information specific to the area is needed.

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APPENDIX 1

Aquatic Species of conservation significance in Darwin Harbour Catchments

SCROPHULARIACEAE
Peplidium maritimum (L.f.) Asch.
IUCN CATEGORY: Near Threatened
Habitat: Swamps on coastal plains

MENYANTHACEAE
Nymphoides subacuta Aston
NT endemic
IUCN Category: Near Threatened
Habitat: swampy depressions and lagoon margins, usually on sandy substrates

CYPERACEAE
Eleocharis A63452 Coonjimba Billabong
IUCN Category: Near Threatened
Habitat: margins of lagoons

Websteria confervoides (Poir.) S.S.Hooper
IUCN Category: Data Deficient
Habitat: lagoons

BYBLIDACEAE
Byblis aquatica Lowrie & Conran
NT endemic
IUCN Category: Near Threatened
Habitat: swampy depressions and upstream floodplains on sandy substrates

ERIOCAULACEAE
Eriocaulon carpentariae G.J.Leach
IUCN Category: Data Deficient
Habitat: swampy depressions and upstream floodplains on sandy substrates

Eriocaulon inapertum G.J.Leach
NT endemic
IUCN Category: Near Threatened
Habitat: swampy depressions and upstream floodplains on sandy substrates

Eriocaulon odontospermum G.J.Leach
IUCN Category: Data Deficient
Habitat: swampy depressions and upstream floodplains on sandy substrates

Eriocaulon tricornum G.J.Leach
NT endemic
IUCN Category: Data Deficient
Habitat: swampy depressions and upstream floodplains on sandy substrates

GOODENIACEAE
Goodenia D73968 elaiosoma
NT endemic
IUCN Category: Data Deficient
Habitat: swampy depressions and upstream floodplains on sandy substrates

LENTIBULARIACEAE
Utricularia D127178 rubra
NT endemic
IUCN Category: Data Deficient
Habitat: swampy depressions on sandy substrates. Known from one locality only.

Utricularia dunstaniae F.E.Lloyd
IUCN Category: Endangered
Habitat: swampy depressions and upstream floodplains on sandy substrates

Utricularia hamiltonii F.E.Lloyd
NT endemic
IUCN Category: Near Threatened
Habitat: swampy depressions and upstream floodplains on sandy substrates

Utricularia holtzei F.Muell.
NT endemic
IUCN Category: Near Threatened
Habitat: swampy depressions and upstream floodplains on sandy substrates

Utricularia involvens Ridl.
IUCN Category: Near Threatened
Habitat: swampy depressions and upstream floodplains on sandy substrates

Utricularia quinquedentata F.Muell. ex P.Taylor
IUCN Category: Near Threatened
Habitat: swampy depressions and upstream floodplains on sandy substrates

Utricularia singeriana F.Muell.
IUCN Category: Vulnerable
Habitat: swampy depressions and upstream floodplains on sandy substrates

Utricularia subulata L.
IUCN Category: Endangered
Habitat: swampy depressions and upstream floodplains on sandy substrates

Utricularia triflora P.Taylor
NT endemic
IUCN Category: Near Threatened
Habitat: swampy depressions and upstream floodplains on sandy substrates

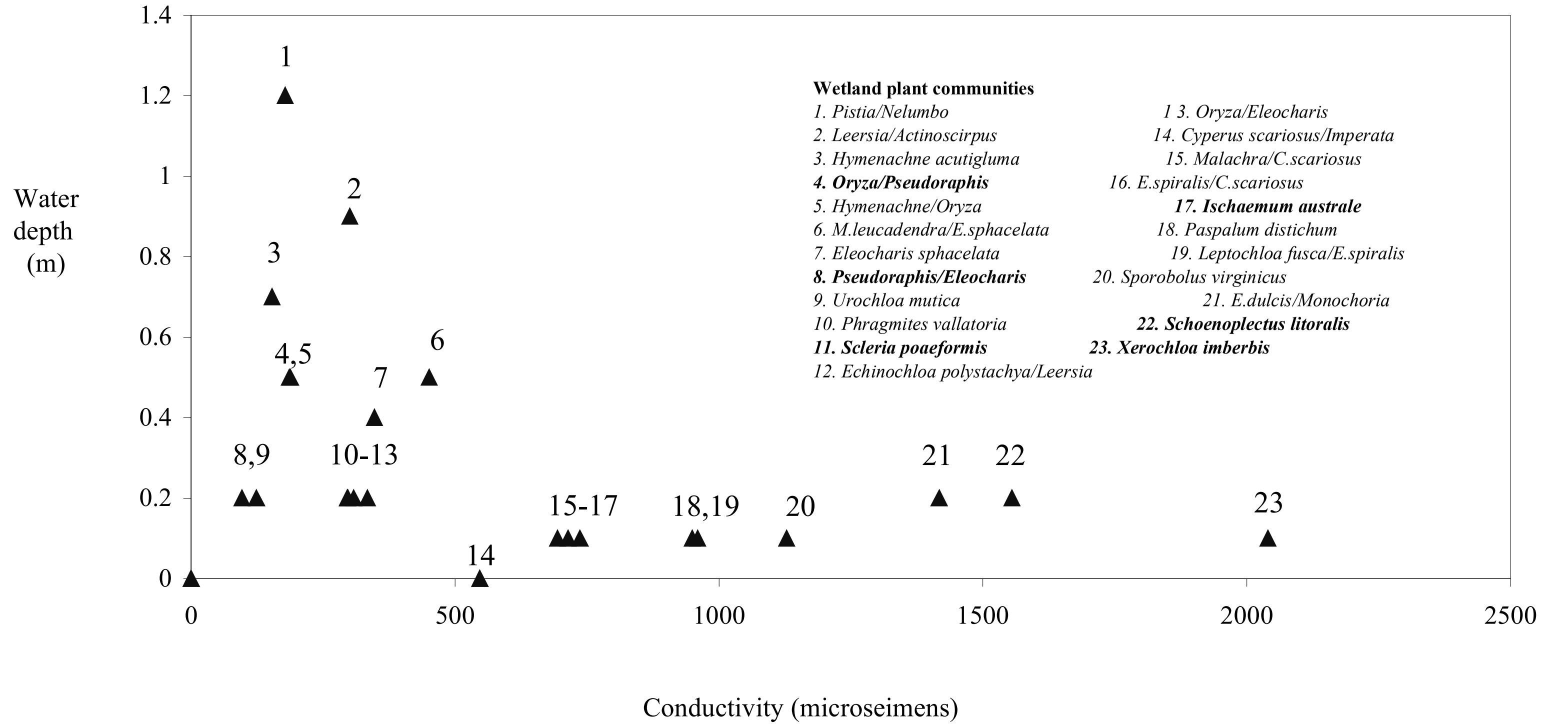

Figure 1. Wetland plant communities in relation to late wet season water depth (m) and salinity (conductivity in microseimens). Those known from Darwin Harbour Catchments are shown in bold. (after Cowie *et al* ., 2000; data from Wilson *et al* ., 1991)