SEASONAL AND YEAR-TO-YEAR CHANGES IN VEGETATION
OF FRESHWATER WETLANDS ON THE HAWKESBURY-NEPEAN FLOODPLAIN.

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ABSTRACT

Coastal floodplain wetlands in southeastern Australia are subject to irregular fluctuations in moisture in terms of magnitude, duration and frequency. These interact with geomorphology over seasonal and year-to-year time scales to produce different habitats at different times.

In freshwater wetlands on the Hawkesbury-Nepean River floodplain near Sydney in coastal New South Wales, major structural changes in vegetation following varying seasonal and weather conditions were observed over a period of seven years. The visible component of wetland plant species varied greatly within the yearly cycle of seasons, and from year to year in the same season depending on conditions. Examples from dominant species show that plant life cycle attributes, interacting with fluctuating biophysical conditions, provide the mechanisms for coping with habitat variation. Life cycle attributes that vary between species include longevity, propagule production and propagule availability. These respond to cues of flooding and drying out, and interact with temperature. Our observations highlight the importance of maintaining natural regimes of water level fluctuations, including periodic drying out, to retain species richness.

INTRODUCTION

To rehabilitate natural wetlands or attempt to recreate them, we must understand their dynamics and the mechanisms by which their biodiversity is maintained. In this paper, we present photographic evidence of temporal variation in vegetation structure and floristics in freshwater wetlands on the floodplain of the Hawkesbury-Nepean River near Sydney. We hope to highlight the implications of temporal variation for assessment, conservation, management, and rehabilitation of floodplain wetlands, in ways that will lead to a better understanding of this habitat by the general public and by land use decision makers. Better management of even a proportion of wetlands in the Sydney region described by Adam and Stricker (1989), for example, will have a beneficial effect on conservation of regional biodiversity.

Between 1991 and 1998 we made repeated inspections of five freshwater floodplain wetlands along the Hawkesbury-Nepean River near Sydney (Figure 1). The Hawkesbury-Nepean River flows alternately through rugged sandstone terrain with gorges, and floodplains formed of alluvium on shale-based landscapes (Figure 2). Our five wetland sites are between Agnes Banks and Cattai, on the extensive Richmond-Windsor floodplain. The average annual rainfall at Windsor (near our wetlands, 50km from the coast) is 760mm, mean maximum temperature is 29°C, mean minima 2-4°C, and average annual frost period may exceed 100 days.

Although all five wetlands are on the floodplain, they have differences in geomorphology and nutrient status. Two of the wetlands have water levels kept artificially high by damming, leaving only a narrow band at the wetland margin subject to fluctuating water levels. The other three wetlands are not dammed and have wide bands with fluctuating water levels (Table 1). Wetlands were inspected in late spring of 1991 and 1992, summer of 1992 and 1996, autumn of 1992, 1993,
Changes in wetland vegetation

1994, 1995, 1996 and 1998, and winter of 1993, 1994 and 1996. At each wetland we recorded responses to different seasonal and weather conditions photographically, and noted presence of native species in a broad band along approximately 150 metres of shoreline (Table 2). Plant species names follow Harden (1990-1993).

Figure 1: Hawkesbury-Nepean River, showing alternative sandstone and floodplain river segments, and locations of monitored wetland sites; ▲, clockwise from bottom left, The Driftway, Pughs Lagoon, Pitt Town Lagoon, Longneck Lagoon, Reedy Swamp.
Figure 2: Diagrammatic cross sections of Hawkesbury-Nepean floodplain showing wetlands as backswamps associated with broad and narrow floodplains.

Table 1. Characteristics of several freshwater wetlands of the Hawkesbury-Nepean floodplain, Sydney. (See also Figure 1 for locations.)

| Wetland (location) | Geomorphology | Major habitats/zones | Nutrient status | Number of native species recorded in monitored site |
|-------------------|---------------|----------------------|-----------------|---------------------------------------------------|
| Reedy Swamp (Cattai) | Small backswamp on alluvium, close to boundary with surrounding sandstone terrain | Wide band with fluctuating water level, standing water shallow, not permanent | Low-medium | 35 |
| Longneck Lagoon (Cattai – Pitt Town) | Large backswamp with low level weir that maintains high water level except in very dry periods | Mostly permanent open water, mostly narrow band with fluctuating water level | Medium-high | 17, + additional 6 when mudflats exposed |
| Pitt Town Lagoon (Pitt Town) | Large backswamp on alluvium, much simplified by past grazing | Wide band with fluctuating water level, high probability of standing water | High | 19 |
| Pughs Lagoon (Richmond) | Dammed backswamp on alluvium | Mostly permanent open water, very narrow band with fluctuating water level | High | 17 |
| The Driftway, UWS – Hawkesbury (Richmond) | Higher level swamp on older Tertiary alluvium, periodic grazing | Wide band with fluctuating water level, standing water shallow, not permanent | Low | 30 |
WETLANDS ARE NOT ALWAYS WET

At the three wetlands where water levels fluctuate naturally, we observed marked changes in level of standing water, and associated structural changes in vegetation, in response to varying seasonal and weather conditions between November 1991 and April 1998. Photographs 1-8, 10 and 11 show examples of the range of variation observed in these three wetlands, Reedy Swamp, Pitt Town Lagoon and The Driftway (at University of Western Sydney (UWS) Hawkesbury Campus). There is variation between years as well as between seasons, due to differences in weather conditions, for example at The Driftway in the autumns of 1992, 1993 and 1994 (photographs 6 –8).

COEXISTENCE AND CONTINUITY

The photographic record shows structural variation in wetland habitat associated with varying water levels and different seasons. In the three swamps with naturally fluctuating water levels, there was variation in the floristic composition recorded in the monitored sites depending on what was visible; under certain conditions and at some times of year some species were present only as seed or rootstock. For example, at the autumn 1992 visit, towards the end of a growing season, more species were added to the site lists first recorded at the end of a dry period during spring 1991. However, no species appeared to be lost over the longer term (seven years) despite variations in abundance over the shorter term (months). Table 2 is a composite species list for the monitored sites, and does not necessarily include all species for each named wetland. The dramatic changes in wetland appearance prompted investigation into the way species survive and coexist in these dynamic habitats.

Coexistence

To interpret the variation in wetland vegetation - both seasonal and year-to-year variation - we classified habitats by nutrient condition and water depth and compared prominent wetland species in relation to these. We considered 15 of the wetland species observed to be dominant or prominent at some stage in the zone of fluctuating wetness in these Sydney swamps. Based on our observations, and on ecological information collated as part of describing the river and floodplain system (Benson & Howell 1993, Howell et al. 1995), we placed each species in the classification where conditions seem to be optimum for best growth relative to the other species (Figure 3). Nutrient conditions ascribed to wetlands were based on their catchment geology. In each of the nine categories defined by the interaction of nutrient conditions and water depths, there is a slightly different combination of these two factors. After our classification, the 15 common wetland species were distributed across all nine categories. Further subdivision of the species groups is based on dry season coping mechanisms, separating seeders from resprouters. Thus, almost every species has a slightly different combination of factors for optimum growth relative to the other species. However, the conditions defining the categories are not discrete, but part of a continuum. There is considerable species’ tolerance of, and survival under, non-optimal conditions, each plant species will generally grow over a range.

Elsewhere in Australia, plant species in two shallow wetlands on the Northern Tablelands of NSW have been classified into functional groups based on germination, growth and reproduction responses (Brock & Casanova 1997).
Table 2. Native species present at sites monitored (1991 - 1998) in five freshwater wetlands of the Hawkesbury-Nepean floodplain, Sydney. (*See text for additional six species recorded when mudflats exposed.)

| Agrostis avenacea var. avenacea | Reedy Swamp | Longneck Lagoon* | Pitt Town Lagoon | Pughs Lagoon | The Driftway, UWS |
|----------------------------------|-------------|------------------|------------------|--------------|------------------|
| Alisma plantago-aquatica         | X           |                  |                  |              |                  |
| Alternanthera denticulata         | X           | X                |                  |              |                  |
| Atriplex australisica            | X           |                  |                  |              |                  |
| Azolla filiculoides var. rubra   | X           |                  |                  |              |                  |
| Azolla pinnata                   | X           |                  |                  |              |                  |
| Carex appressa                   | X           | X                | X                | X            |                  |
| Centella asiatica                | X           |                  |                  |              |                  |
| Centipeda minima var. minima     | X           | X                |                  |              |                  |
| Ceratophyllum demersum           | X           |                  |                  |              |                  |
| Cotula coronopifolia             | X           |                  |                  |              |                  |
| Cyperus australis                | X           |                  |                  |              |                  |
| Cyperus exaltatus                | X           | X                |                  |              |                  |
| Cyperus flaccidus                | X           |                  |                  |              |                  |
| Damasonium minus                 | X           |                  |                  |              |                  |
| Eclipta platyglossa              | X           |                  |                  |              |                  |
| Eladna hastata                   | X           |                  |                  |              |                  |
| Elatine gratioloides             | X           | X                |                  |              |                  |
| Eleocharis dietrichiana          | X           |                  |                  |              |                  |
| Eleocharis equisetina            | X           |                  |                  |              |                  |
| Eleocharis sphacelata            | X           |                  |                  |              |                  |
| Fimbristylis velata              | X           |                  |                  |              |                  |
| Glyceria australis               | X           |                  |                  |              |                  |
| Gnaphalium involucratum          | X           |                  |                  |              |                  |
| Hemarthria uncinata var. uncinata| X           | X                |                  |              |                  |
| Hydrocotyle peduncularis         | X           |                  |                  |              |                  |
| Hypalepis muelleri               | X           |                  |                  |              |                  |
| Isolepis fluitans                | X           |                  |                  |              |                  |
| Isolepis inundata                | X           |                  |                  |              |                  |
| Isolepis nodosa                  | X           |                  |                  |              |                  |
| Isotoma fluviatilis subsp. fluviatilis | X     |                  |                  |              |                  |
| Juncus prismatocarpus            | X           |                  |                  |              |                  |
| Juncus usitatus                  | X           | X                | X                | X            |                  |
| Lilaeopsis polyantha             | X           |                  |                  |              |                  |
| Ludwigia peploides subsp. montevidensis | X    | X                | X                | X            |                  |
| Lycopus australis                | X           |                  |                  |              |                  |
| Marsilea mutica                  | X           |                  |                  |              |                  |
| Melaleuca linariifolia           | X           | X                |                  |              |                  |
| Muehlenbeckia gracilicima        | X           |                  |                  |              |                  |
| Myriophyllum simulans            | X           |                  |                  |              |                  |
| Nymphoides geminata              | X           |                  |                  |              |                  |
| Panicum effusum                  | X           |                  |                  |              |                  |
| Panicum obtuseptum               | X           |                  |                  |              |                  |
| Pastpalum distichum              | X           | X                | X                | X            |                  |
| Persicaria decipiens             | X           |                  |                  |              |                  |
| Persicaria hydropiper            | X           | X                |                  |              |                  |
| Persicaria lapathifolia          | X           | X                |                  |              |                  |
| Persicaria orientalis            | X           |                  |                  |              |                  |
| Persicaria praetemissa           | X           |                  |                  |              |                  |
| Persicaria strigosa              | X           |                  |                  |              |                  |
| Persicaria subsessilis           | X           |                  |                  |              |                  |
| Philydrum lanuginosum            | X           |                  |                  |              |                  |
| Phragmites australis             | X           | X                |                  |              |                  |
| Polygonum plebeium               | X           |                  |                  |              |                  |
| Potamogeton tricarinatus         | X           |                  |                  |              |                  |
| Pseudoraphis paradoxa            | X           |                  |                  |              |                  |
| Pseudoraphis spinescens          | X           |                  |                  |              |                  |
| Ranunculus inunatus              | X           |                  |                  |              |                  |
| Schoenoplectus validus           | X           |                  |                  |              |                  |
| Spirodela sp. (Lemna sp.)        | X           |                  |                  |              |                  |
| Triglochin procerum              | X           | X                | X                | X            |                  |
| Typha orientalis                 | X           |                  |                  |              |                  |
| Utricularia australis            | X           |                  |                  |              |                  |
| Viola hederacea                  | X           |                  |                  |              |                  |
**Figure 3:** Simple classification of common freshwater wetland species using habitat conditions and life cycle attributes, showing how almost every species has a slightly different combination of factors for optimum growth.
European riverine wetland plant species have been categorised according to the trade-off in their attributes between competitive ability and stress tolerance (Hills et al. 1994). In Canada, for 25 species of the riverine zone, Shipley et al. (1989) characterised recruitment strategies as ‘fugitive’ or ‘stress-tolerant’. They found these varied independently from adult plant strategies of fugitiveness or competitiveness, giving four types of herbaceous strategies, compared with five functional groups based mostly on adult traits (proposed by Day et al. 1988).

**Life cycle variation in *Persicaria* species**

The interaction of life cycle events with geophysical factors produces variation in plant growth and cover between seasons and years, that allows for coexistence of the species. The mechanisms producing the variation in plant growth involve life cycle responses to fluctuating rainfall and water levels, temperature and soil nutrients. The result is that the same swamp will look different in different seasons, and different years. Also, under the same seasonal conditions, swamps with different nutrient status will have different patterns because of the influence of nutrients on the predominant species.

As an example, within the genus *Persicaria*, different species exhibit considerable variation in life cycles. We have recorded eight different species in our full suite of Hawkesbury-Nepean floodplain wetlands, all herbs of the zone of fluctuating wetness. Up to five species can co-exist at a single site. The five species we have found to be most abundant occupy four different levels in our classification (Figure 3), indicating slightly different combinations of characteristics favouring growth relative to the other species:

*Persicaria praetermissa* and *Persicaria strigosa* – perennials, grow better than the other species in wet ground with low nutrients.

*Persicaria hydropiper* – short-lived perennial, grows best in shallow water, medium nutrients.

*Persicaria decipiens* – short-lived perennial, grows best in wet ground, medium nutrients.

*Persicaria lapathifolia* – annual, grows best in shallow water, high nutrients.

Similar within-genus differences have been recorded elsewhere. Sultan et al. (1998) sampled natural populations of four species of *Persicaria* representing their habitat ranges in North America (called *Polygonum* there, *P. cespitosum*, *P. hydropiper*, *P. lapathifolium* and *P. persicaria*). They showed that these species differed in the relative breadth of their ranges for light, moisture, soil macronutrient status, soil structure and soil temperature. Parker and Leck (1985) found seeds of *Polygonum arifolium* were most abundant in infrequently-flooded sites, while those of *Polygonum punctatum* were more abundant in soils flooded more frequently and for longer periods, reflecting differences in distribution.

In ephemeral floodplain wetlands in South Africa, Brock and Rogers (1998) found within-genus variation in germination requirements in *Potamogeton* and *Nymphaea*. Experimentally, *Typha latifolia* and *Typha domingensis* in southeastern United States were found to respond differently to increasing water depth in terms of biomass allocation and resulting morphology, with *T. latifolia* allocating more biomass proportionally to leaves and *T. domingensis* increasing total ramet size (Grace 1989).

Regeneration niche, habitat niche and phenological niche were selected as factors of importance in co-existence of three amphibious plant species, *Marsilea mutica*, *Myriophyllum aquaticum* and *Ludwigia peploides* subsp. *montevidensis* at Bushells Lagoon, also on the Hawkesbury-Nepean floodplain, by Yen.
and Myerscough (1989). In reaches between weirs along the Murray River, Walker et al. (1994) found that 11 wetland species were favoured differently by different combinations of bank slope, water flow speed and saline seepage. In shallow coastal lagoons in South Australia, Rea and Ganf (1994a & b) found morphological responses to inundation by two rhizomatous perennials, *Baumea arthropylla* and *Triglochin procerum*, differed in both nature and time scale, highlighting the significant effect small changes in water regime can have on the structure and performance of wetland plants. In shallow coastal interdunal depression wetlands in Western Australia, Froend and McComb (1994) found that, although the emergent macrophytes *Baumea articulata* and *Typha orientalis* occupied similar overall ranges relative to mean water depth, between eight wetlands there was considerable difference in their distributions, likely to be due to site-specific variation in abiotic parameters and to interspecific interactions. For example, *Typha orientalis* showed a significantly greater growth response to increased nutrients than *Baumea articulata* and *T. orientalis* could germinate and establish while completely submerged, while *B. articulata* germinated only when sediment was waterlogged but exposed. In shallow wetlands on the Northern Tablelands of NSW, *Myriophyllum varifolium* was found to persist and maintain genetic diversity in the fluctuating wet and dry conditions by means of flexibility of growth and life cycle patterns (Brock 1991), similarly to *Ranunculus peltatus* in Europe (Volder et al. 1997).

Observations of others overseas, e.g. van der Valk and Davis (1978), Parker and Leck (1985), Wilson and Keddy (1985), Gopal (1986), confirm that distribution patterns of species in wetland habitats subject to periodic wetting and drying are the product of individual species’ responses to abiotic variables and interactions with other species. In Canada, Keddy et al. (1994) showed that the ability of 17 wetland species to tolerate presence of neighbours varied across environments that differed in soil fertility and soil moisture level. For shallow Canadian prairie marshes subject to fluctuating moisture regimes, Millar (1973) categorised four species as intolerant of, and five species as survivors of, two years of continuous inundation, another two species tolerated less than two years of flooding, and four species were indicators of recently exposed soil. In fen meadows of the Swiss plateau, *Phragmites australis* is spreading because of its ability to utilise stored reserves to grow more rapidly than neighbouring species in early summer (Güsewell 1998). The N:P ratios in wetland plants of European fens were found to vary strongly among species within sites, and among sites for a given species (Güsewell et al. 1998), giving rise to interspecific variation in responses to different wetland nutrient levels. Shipley et al. (1989) highlighted the fact that historical and stochastic factors mean that distribution of species may be related to environmental factors only locally, both in time and space.

**Continuity**

Wetland species have been classified as surviving dry times primarily by either seed or rootstock. Most of those that survive by seed do not re-establish in standing water but rather on wet mud or moist soil. Periodic drying out of wetland areas is therefore essential for germination of the seed and establishment of new generations of these plants (Photos 9, 12, 14, and see e.g. van der Valk & Davis, 1978 & 1979, Keddy & Reznicek 1982). For those that survive by rootstock, a flush of growth often occurs when water level is low and mud is exposed (Photo 13, and see, for example, Rea & Ganf 1994b).

The importance of naturally fluctuating water levels has long been recognised for species conservation in major areas of wetlands associated with Australian inland river systems (e.g. Briggs 1988, Bren...
In wetlands on the NSW Northern Tablelands, 58% of the 60 species germinating from soil seedbanks grew in the wet/dry ecotone subject to fluctuating water levels (Brock & Casanova 1997), and fewer seeds of *Myriophyllum varifolium* in particular were found in the soil under permanent or near-permanent water (Brock 1991). Poiani and Johnson (1989) found density of germinable seeds consistently lowest in mud in the centre of semipermanent north American prairie wetlands, inundated for longest periods, e.g. 8 and 16 years, compared with higher seed densities in mud exposed more frequently, reflecting more frequent opportunities for seed production. Artificial flooding of shallow South Australian lagoons stimulated seed production and dispersal of the clonal *Triglochin procerum*, but population increase occurred only in areas where the lagoons dried for suitable periods to allow germination and establishment of the short-lived seed (Rea and Ganf 1994c). Health of the clonal plant population, and ultimately the wetland, depended on periodic recruitment. Temporal and spatial variability in distribution was related to the variability of wetting and drying events in relation to the plant’s life cycle, as was also found for the wetland margin paperbark, *Melaleuca halmaturorum* (Denton & Ganf 1994). Other factors affecting germination of wetland seeds include soil particle size (Keddy & Constabel 1996), soil organic content (Moore & Keddy 1988), light (Garbisch 1998) litter (van der Valk 1986), and soil compaction by vehicles (Wisheu & Keddy 1991).

**Reduced water level fluctuations**

Two of our wetland sites, Pughs and Longneck Lagoons, have water levels kept artificially high and stable by damming, leaving only very narrow marginal bands with a fluctuating water level. The narrow zone is further reduced by the steepness of the bank. Pughs Lagoon, dammed by a road, showed relatively stable vegetation structure over the monitoring period, with the most noticeable variation being seasonal, in abundance of floating aquatics, related to effects of temperature on life cycles and to effects of spraying for the aquatic weed *Eichhornia crassipes*. Longneck Lagoon has had its water level kept artificially high since construction of a small dam wall associated with a road culvert in the 1970s. These two wetlands have the lowest species richness of our five sites (Table 2). In particular, continuous high level inundation had almost eliminated the resprouting emergent, *Eleocharis sphacelata*. Similarly, one year’s flooding killed the emergent sedge *Baumea arthrophylla* in South Australia (Rea & Ganf 1994b), four emergent species were eliminated by two or more years of continuous flooding in Canadian marshes (Millar 1973), and shrubs and trees of River Red Gum swamps in inland New South Wales are killed by more than four years’ continuous flooding (Briggs 1988).

In 1995 conditions changed at Longneck Lagoon. Two years of lower-than-average rainfall caused the lagoon’s water to drop below the level of the culvert dam wall, and part of the swamp normally covered by standing water dried out to a mudflat, where six species germinated that we had not recorded here before, *Mollugo verticillata, Fimbristylis velata, Cardamine paucijuga, Alternanthera denticulata, Persicaria lapathifolia* and *Persicaria orientalis*. There was also a huge increase in abundance of *Cyperus exaltatus* from germinated seed, forming herbland two metres tall (see Photos 12-14). One of the authors (DB) had not seen this part of the lagoon dry since 1972, despite periodic repeated inspections since then. Further research is needed (see for example Cellot *et al.* 1998) to determine whether seeds of the above plants remained viable in the mud since the last time they grew here, or whether seeds had arrived more recently at this site, having been transported, for example by floodwaters, from other locations.
The importance of seedbanks for wetland rehabilitation in Australia has been highlighted (Brock 1997). It has been recognised here and elsewhere that there is variability in seedbank density and composition between years and between wetland zones, and that vegetation present at any time is a function of the current water level and the seedbank (e.g. van der Valk & Davis 1976). Brock and Casanova (1997) cite experimental evidence that changing the water regime will change the plant community that develops. They highlight how wetland species’ survival in the face of water regime changes depends on the longevity of the seedbank. Although seedbank densities and species represented decline with time, apparent seed longevities of 15 years (Jensen, 1998), 40 years (Brown 1998), and 5-70 years (Wienhold & van der Valk 1989) have been reported. However, the last authors found nearly 60% of species were lost from prairie wetland seedbanks during twenty years of drainage. Brock and Rogers (1998) found soil seedbanks of species from South African floodplain wetlands persisted after two episodes stimulating germination, apparently due to staggered germination of propagules.

These biological factors underlie the importance of including sufficient areas subject to natural periodic wetting and drying, in order to conserve biodiversity in these inherently dynamic systems. A generous boundary zone to allow for future natural change is necessary when defining and mapping wetlands, despite the difficulties this may cause (Adam 1992).

CONCLUSIONS

Conservation, management, and rehabilitation of coastal floodplain wetlands requires understanding that healthy, functioning wetlands of this type show variation in plant structure and abundance over time, in response to varying weather between seasons and years. Consequently –

- surveying to document and record plant diversity as part of wetland assessment, conservation and management will often need multiple visits to include a range of weather and seasonal conditions;

- maintenance of natural water level fluctuations is necessary for retention of species richness, particularly to allow seedling recruitment on bare mud areas - observations suggest that wetlands with the least area subject to fluctuation are most susceptible to dominance by a few species; and

- it is very important to include and retain areas subject to periodic drying out as part of wetlands being conserved, to allow plant life cycles to function.

Our ability to manage coastal floodplain wetlands for species conservation needs to be enhanced by increased research in the following areas: quantitative monitoring of seasonal and year-to-year variations in abundance of dominant plant species; characterisation of life cycle attributes of species of lesser abundance; and longevity of seed in wetland seedbanks. In the mean time, we need to encourage land managers, decision-makers, and the general public, to understand that wetlands are not just duckponds. They are not always wet, and dried-out-looking mud flats can be essential to their health. Let floodplain wetlands dry out periodically – not by draining them, but by allowing their water levels to fluctuate naturally.

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