Wetland Vegetation Monitoring Program for the Vasse-Wonnerup Wetland System.

Monitoring Design and Recommendations.

A technical report prepared by:

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March 1999

Contents

Background

As a Wetland of International Importance under the Ramsar Convention, the Vasse-Wonnerup wetland system is acknowledged as valuable habitat for waterbirds. Prior to 1988, the Vasse-Wonnerup was a predominantly fresh-brackish system due to the installation of floodgates in 1908 to prevent the entry of seawater. Since 1988, increasing volumes of seawater have been allowed back into the Vasse estuary by the Water Corporation during summer-autumn in attempts to prevent mass fish deaths. High levels of saline water retained in the system have been blamed for the death of fringing vegetation, damage to pastures and unknown impacts on the use of the estuary by waterbirds (Lane *et al.*, 1997).

A Technical Working Group established in March 1997 recommended that a formal monitoring program be established to properly assess recent changes and future trends in the health of fringing plant communities (Lane *et al.*, 1997). It was proposed that a contract be let to engage a consultant to:

- design an effective, low cost monitoring program to record trends in health of plant communities (principally melaleucas, eucalypts, sedges and samphires) fringing the Vasse estuary.
- include shallow monitoring bores and possibly other technologies in the design to monitor groundwater levels and salinities beneath plant communities.
- provide precise location and other details of proposed monitoring sites.
- provide a detailed estimate of the cost of implementation.

This report represents the outcomes of a short field investigation and a proposed design for the long-term monitoring program.

Monitoring Program Objectives

The general management objective for the fringing vegetation monitoring program, (J. A. K. Lane, pers comm) is as follows:

- To assess recent changes and future trends in the health of plant communities fringing the Vasse and Wonnerup estuaries.

To meet this objective in a quantitative way, specific monitoring objectives are required that focus on the variables to be assessed. Changes, or otherwise, in these variables should then be compared with physical and biological management criteria (requirements, benchmarks) to assess the vegetation status in light of management practices and/or objectives. The criteria should be identified before a monitoring program is implemented and monitoring design should allow the criteria to be addressed, ie. the design of the program and the variables monitored must permit assessment of the change/phenomenon of interest. Results should be analysed with the management criteria in mind, each time the monitoring is conducted.

The criteria can be based on biological, environmental, social or economic values. The scope of this report is to suggest criteria that address fringing vegetation survival, recruitment and interaction with key environmental parameters.

Specific Monitoring Objectives

With respect to the fringing vegetation, the key parameters to assess include changes in survival, recruitment, composition and distribution in response to (assumed) causal factors. With this in mind the following specific monitoring objectives are suggested:

- To assess change in fringing plant community distribution relative to estuary water regime and salinity.

- To assess change in the mortality of existing populations of structurally dominant and/or selected indicator species relative to estuary water regime and salinity.

- To identify occurrences of recruitment of structurally dominant and/or selected indicator species and assess establishment and survival relative to estuary water regime and salinity.

- To assess change in population size/age structure of structurally dominant and/or selected indicator species relative to estuary water regime and salinity.

- To assess change in fringing plant community composition relative to estuary water regime and salinity.

- To assess change in the waterbird habitat value of fringing plant community composition relative to estuary water regime and salinity.

Management Criteria

Management criteria are physical and biological requirements or states that have been identified as favourable with respect to long-term conservation of a natural resource. In this case, the criteria are 'benchmarks' that are believed to represent/facilitate the health of plant communities fringing the Vasse and Wonnerup estuaries.

Listed below are suggested criteria which address each specific objective. This list is by no means exhaustive and only includes criteria directly related to vegetation health.

- Fringing vegetation distribution should not alter in response to changes in water level or salinity. If a change does occur, it should not be due to the death of all individuals at an extreme of a species' distribution.

- Trend towards decline and mass death of individuals of an indicator species should not occur at any monitoring site.

- Where seedling recruitment of indicator species occurs, establishment should be successful, allowing for some mortality due to resource competition. Mortality should not be due to excessive inundation and salinity.

- Long-term assessment of indicator species population structure should not reveal a narrowing of the age distribution but include cohorts of different ages, reflecting periods of successful recruitment. Age distribution should not be strongly skewed towards older individuals.

- Change in fringing plant community composition, if occurring, should represent a rise in native species and not exotics.

- Structure and composition change that decreases the water bird habitat value should not occur.

Criteria that include specific surface water/groundwater levels (maxima, minima, durations) and water/soil salinities should also be stated once monitoring site conditions have been initially assessed.

Identification of Monitoring Sites

A 1 day assessment of suitable monitoring site locations was conducted in February 1999. The assessment did not involve identification of exact monitoring transect locations but areas where transect should be established. These areas were identified on the basis that they possessed one or more of the following attributes:

- Evidence of vegetation decline (suspected) due to waterlogging and salinity.
- Evidence of invasion by exotic plant species.
- Sufficient width of vegetation fringe to allow numerical assessment of species importance, vigour and distribution relative to gradient of shoreline.
- Large stand of (apparently) healthy vegetation.
- Representative of fringing plant community types present at estuary.

Status of ownership of the land on which the vegetation occurred was not an issue in site selection. Access to potential monitoring sites, other than from the estuary shoreline via boat/all terrain vehicle, was not determined. No monitoring sites were suggested for the Wonnerup Estuary because of the relative paucity of remnant fringing vegetation.

Each suggested monitoring area is marked on Figure 1a and b and characteristics are listed below, along with a photograph of the dominant communities present. Vegetation descriptions are taken from Tingay (1980) with modifications based on the author's field observations.

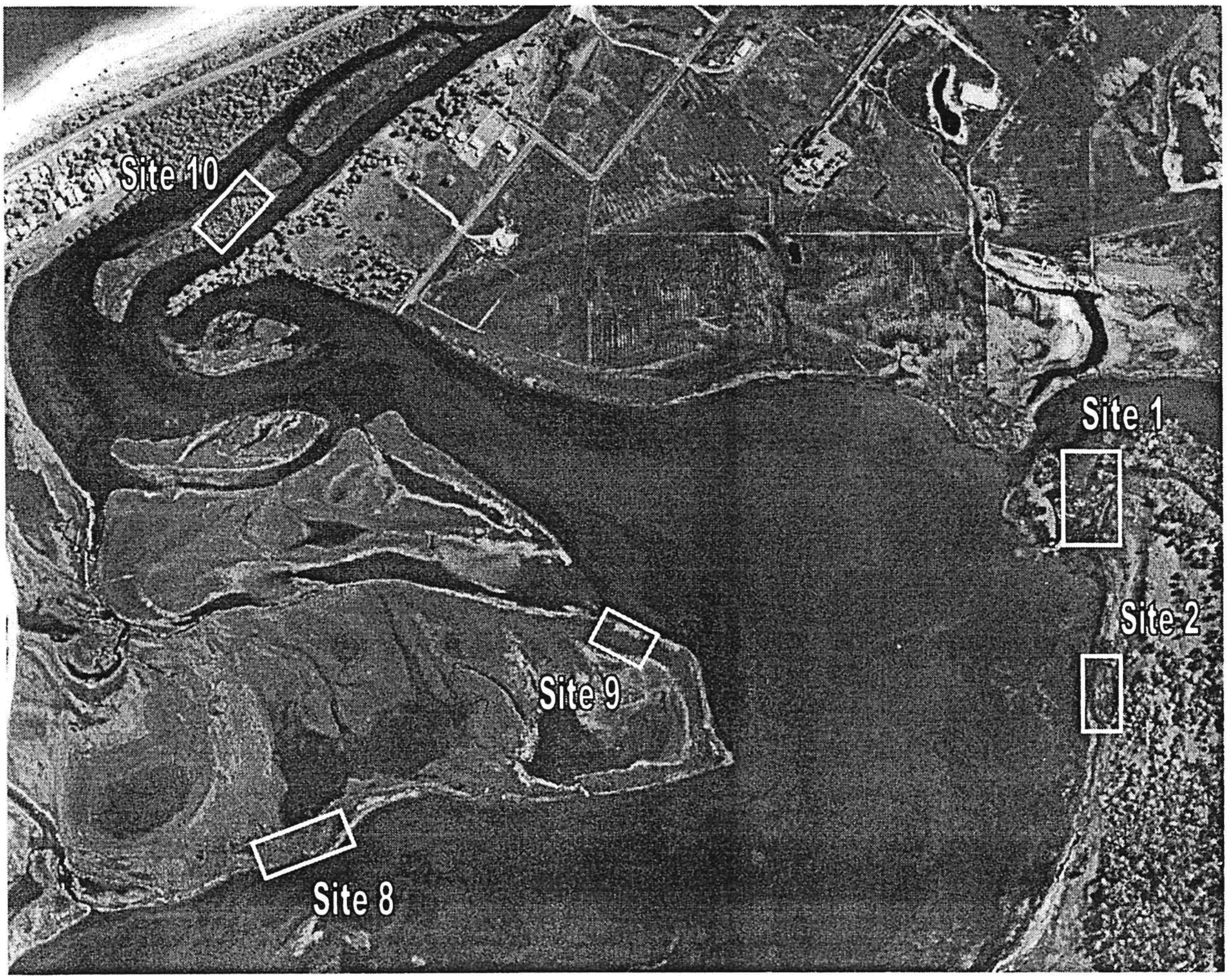


Figure 1a: Northern section of the Vasse Estuary (1996) showing suggested vegetation monitoring sites.

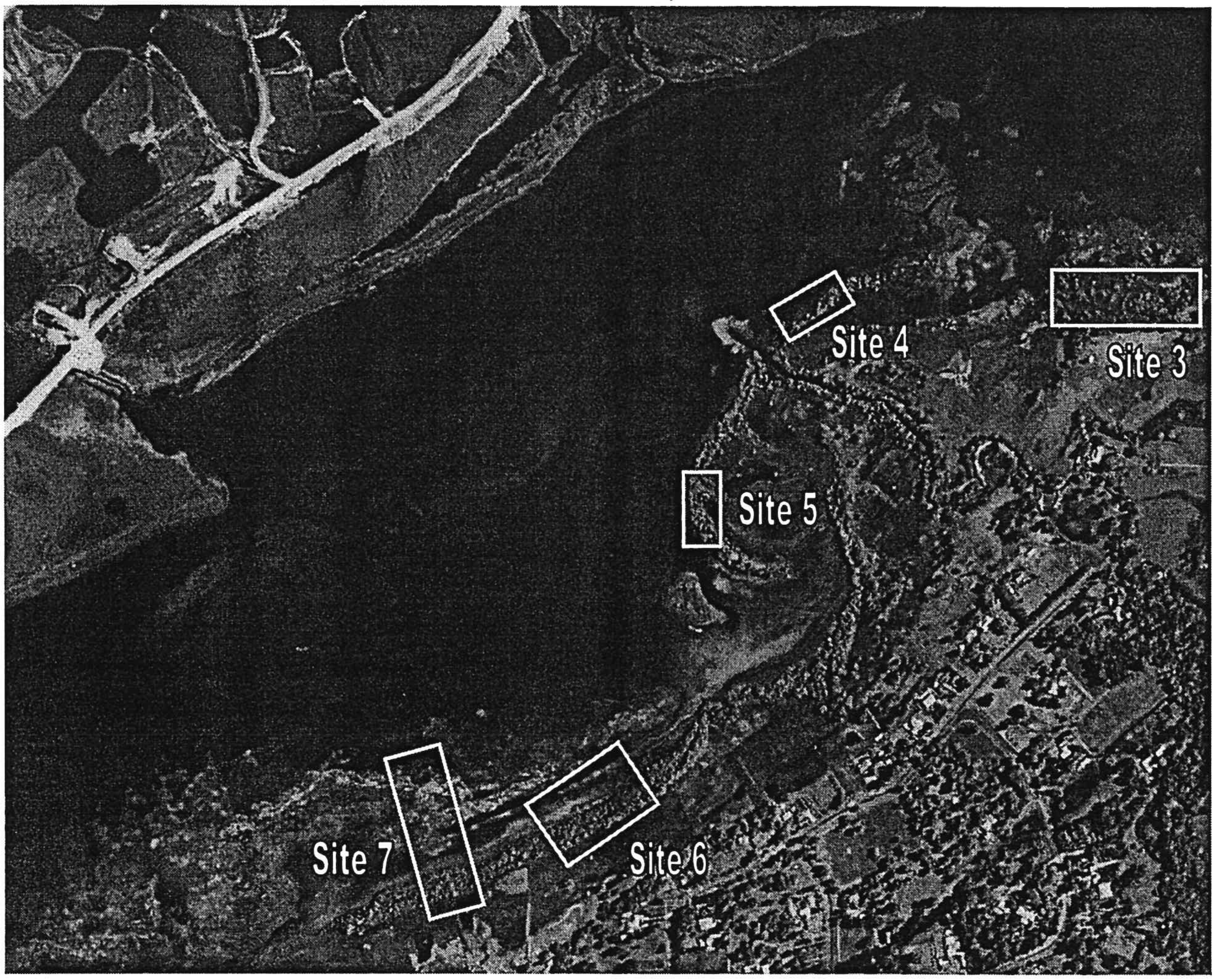


Figure 1b: Eastern fringe of the Vasse Estuary (1996) showing suggested vegetation monitoring sites.

Monitoring site locations are referred to in UTM 50 grid coordinates and were determined using a handheld GPS (not differential) that has a guaranteed accuracy of within 100m.

Site 1

Location: E353326 N6277422; Large area of remnant fringing vegetation at the north-eastern end of the Vasse Estuary near the mouth of the Abba River.

Vegetation: *Eucalyptus rudis* open woodland with understorey of *Juncus krausii.*

Recommendation: Represents a significant site where decline in the dominant overstorey species is very evident. Invasion by pasture species is also of concern, particularly in the suppression of tree seedling growth. It is an area large enough for 2 monitoring transects to be established.

Site 1

Site 1 (50-100m NE)

Site 2

Location: E353310 N6276917; Small area of remnant fringing vegetation at the north-eastern end of the Vasse Estuary south of the mouth of the Abba River.

Vegetation: *Melaleuca rhaphiophylla* woodland-low forest with shoreline vegetation of sedges, including *Juncus krausii.*

Recommendation: Represents a small patch of *M. rhaphiophylla* with some *E. rudis* at higher elevations. Excellent site to represent zonation along elevational gradient. Decline and death of individuals *of M. rhaphiophylla* is very evident. Invasion by pasture species is also of concern, particularly in the suppression of tree seedling growth. One transect should be established.

Site 2

Site 3
Location: E352448 N6276401; Large area of remnant fringing vegetation on the eastern edge of the Vasse Estuary.

Vegetation: *Melaleuca cuticularis/ M. hamulosa* low open woodland with shoreline vegetation of sedges, including *Juncus krausii.*

Recommendation: Represents a significant site where decline in the dominant overstorey species is evident. Invasion by pasture species is also of concern, particularly in the suppression of tree seedling growth. It is an area large enough for 2 monitoring transects to be established.

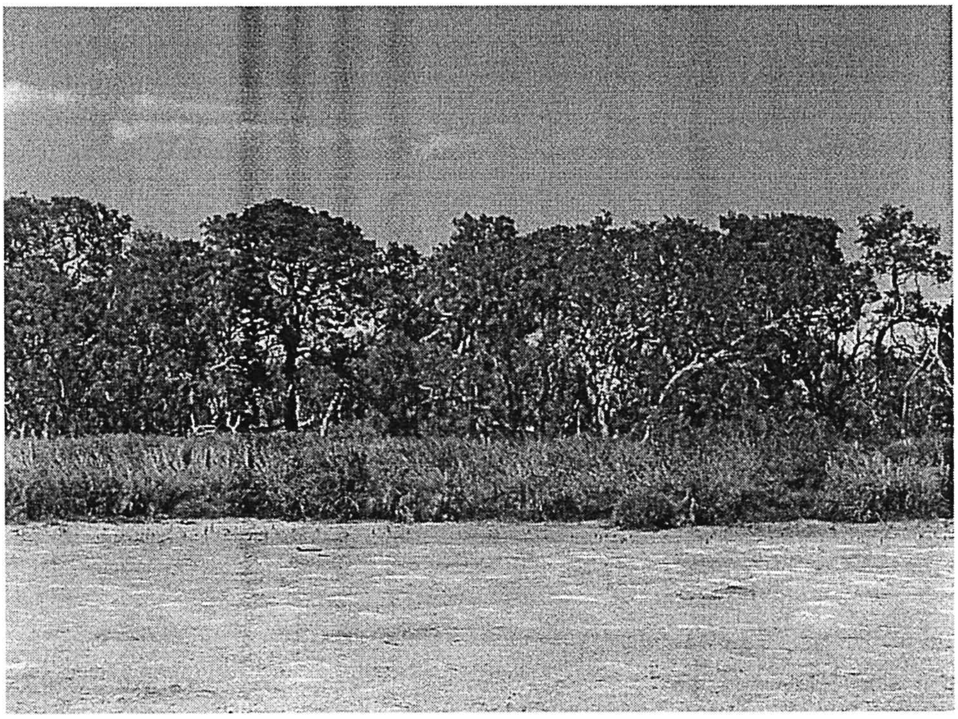
Site 3

Site 3 (50 m SW)

Site 4
Location: E351895 N6276299; Area of remnant fringing vegetation on the eastern edge of the Vasse Estuary near mouth of Sabina River.

Vegetation: *Melaleuca rhaphiophylla* low open forest with shoreline vegetation of sedges, including *Juncus krausii.*

Recommendation: Represents a small site where the dominant overstorey species is relatively healthy. Invasion by pasture species is of concern. Recommend one transect.



Site 4

Site 5
Location: E351589 N6276062; Small area of remnant fringing vegetation on the eastern edge of the Vasse Estuary, south of the mouth of the Sabina River.

Vegetation: *Melaleuca cuticularis/ M. rhaphiophylla* low open forest with shoreline vegetation of sedges, including *Juncus krausii.*

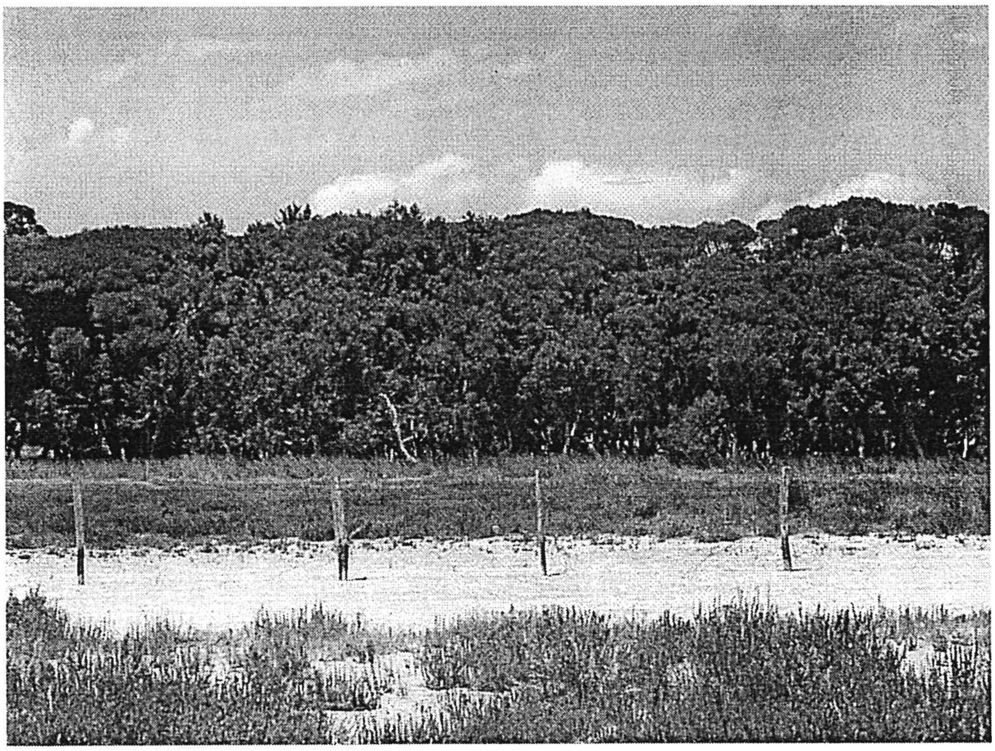
Recommendation: Dominant overstorey species in decline, some dead. Invasion by pasture species is also of concern. One transect recommended.


Site 5

Site 6
Location: E351441 N6275514; Area of remnant fringing vegetation on the eastern edge of the Vasse Estuary, south of the mouth of the Sabina River.

Vegetation: *Melaleuca hamulosa/ M. rhaphiophylla* low open forest with shoreline vegetation of samphires.

Recommendation: Dominant overstorey species relatively healthy. Invasion by pasture species less evident than other sites. Excellent location to assess healthy stand of Melaleucas.



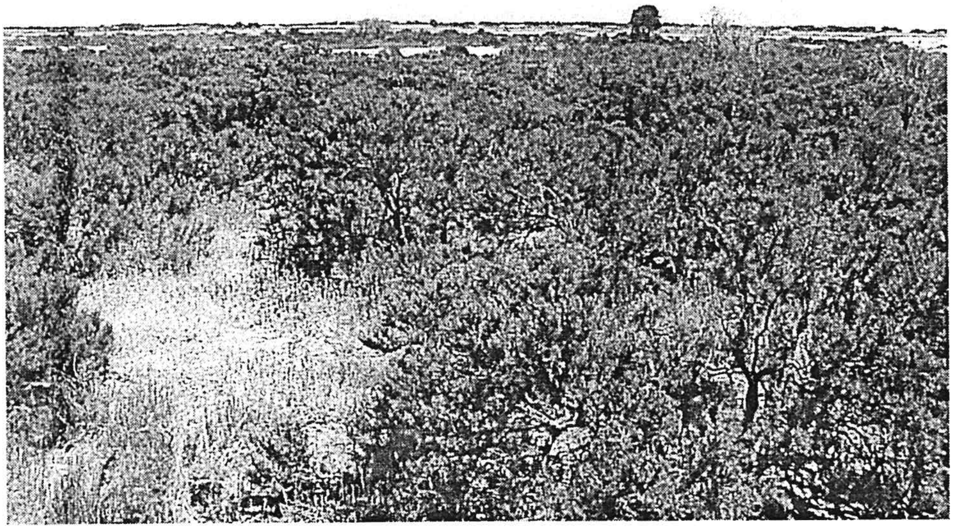
Site 6

Site 7
Location: E351161 N6275344; Small area of remnant fringing vegetation on the eastern edge of the Vasse Estuary.

Vegetation: *Melaleuca hamulosa/ M. rhaphiophylla* low open forest with shoreline vegetation of samphires, *Sarcocornia* sp.

Recommendation: Dominant overstorey species relatively healthy. Narrow band of trees but good condition. Shoreline vegetation of samphires (*Sarcocornia* sp), many old individuals. One long transect recommended to include old samphire stand.

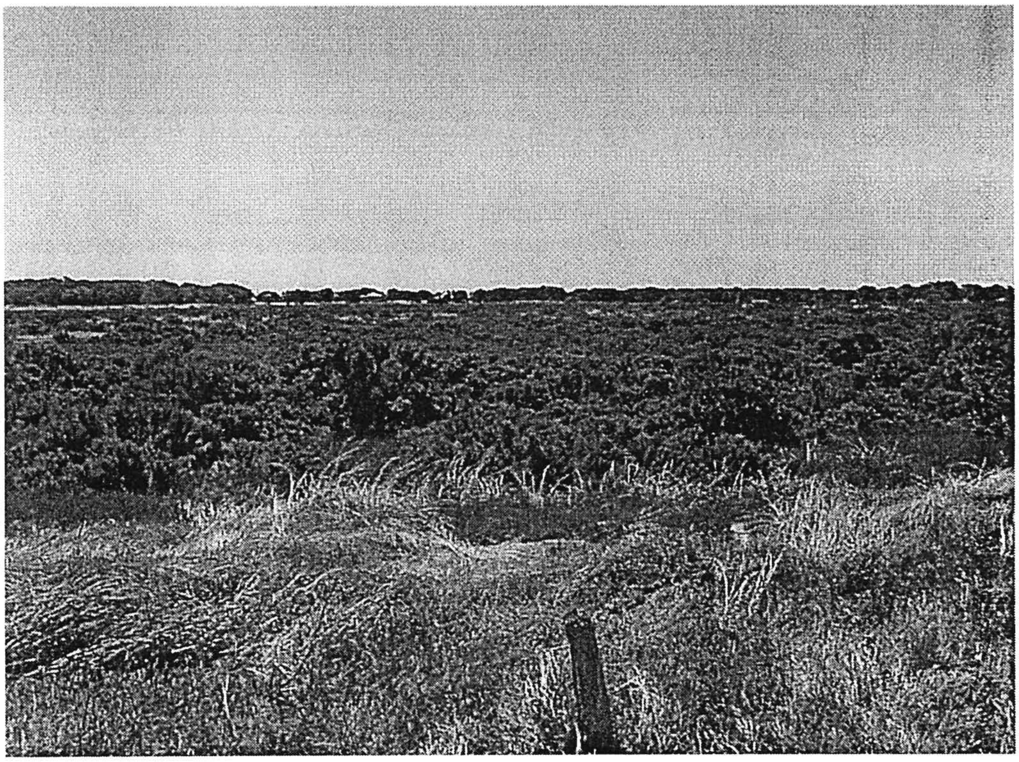

Site 7


Site 7 (facing west)

Site 8
Location: E351821 N6276691; Large area of remnant fringing vegetation on the western edge of the Vasse Estuary,

Vegetation: *Halosarcia* sp open - closed heath with invasive pasture species.

Recommendation: Dominant species is vigorous. Invasion by pasture species is of concern. One transect recommended.

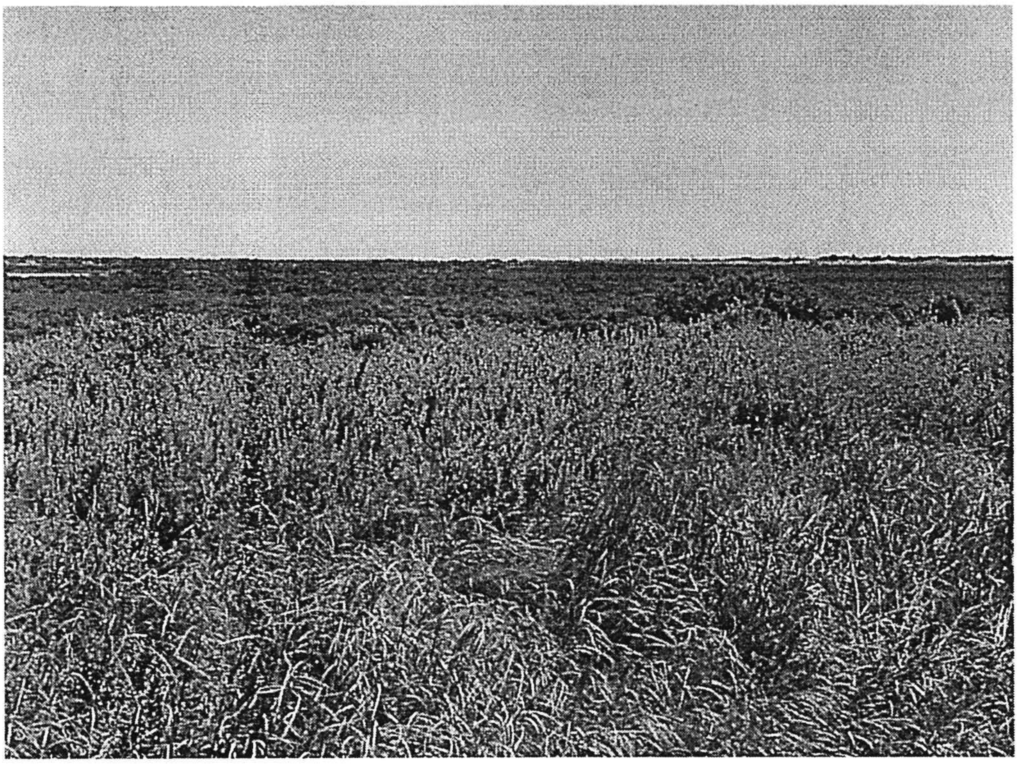


Site 8

Site 9
Location: E352597 N6277104; Large area of remnant fringing vegetation on the western edge of the Vasse Estuary,

Vegetation: *Halosarcia* sp open - closed heath with invasive pasture species.

Recommendation: Dominant species is vigorous. Invasion by pasture species is of concern. One transect recommended.



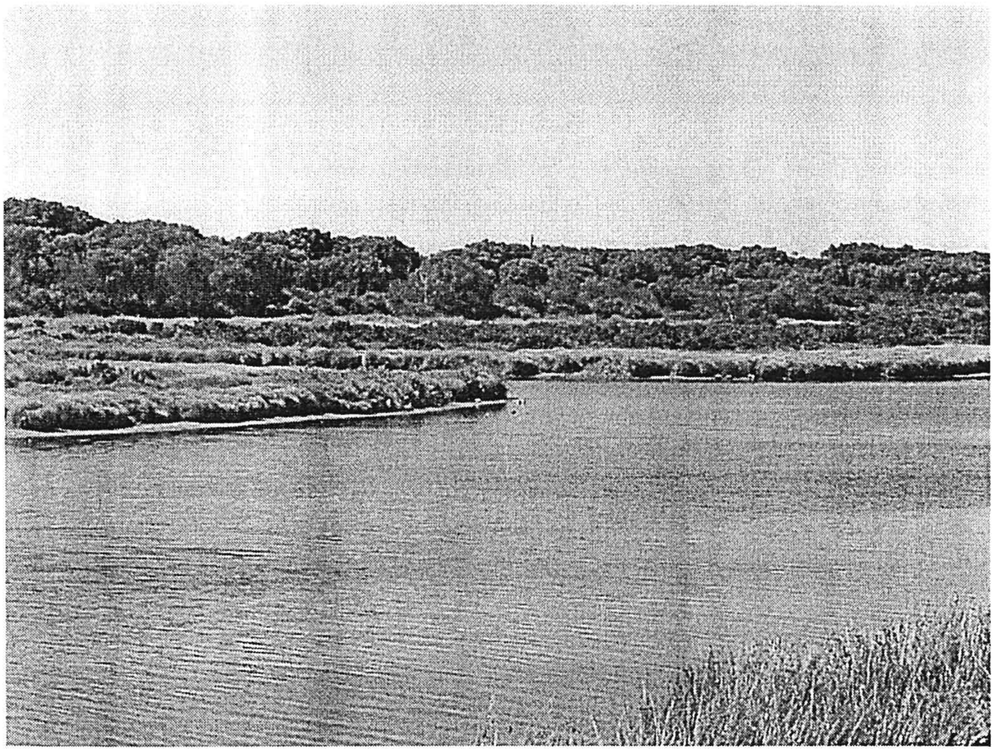
Site 9

Site 10
Location: E351865 N6277802; Remnant fringing vegetation on island at mouth of the Vasse Estuary,

Vegetation: *Melaleuca hamulosa* low closed forest and *Halosarcia* sp open - closed heath.

Recommendation: Dominant overstorey in decline. *Halosarcia* vigorous. Two transects recommended, one each island.

Site 10 (facing west)



Site 10 (facing NW)

Suggested Methodology

The methodology proposed has been specifically designed to address change in wetland vegetation floristics, physiognomy, individual plant vigour and population vigour and dynamics in response to long-term changes in hydrology and salinity. It is recommended the vegetation be assessed every 2 years. The rationale for this methodology is based on the Salinity Action Plan wetland vegetation monitoring program. A review of the literature addressing the monitoring of wetland vegetation is presented in Appendix 1.

Transect design

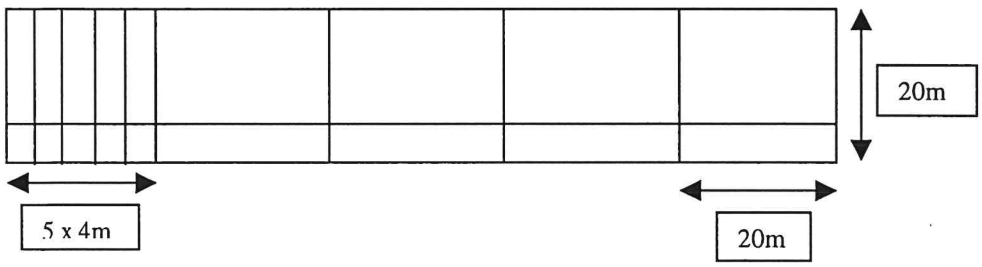
Either 1 or 2 permanently marked transects will be established at each of the identified monitoring sites.

The location of each transect should be determined using GPS and marked on maps for future reference. All location markers and tags used are to be of galvanised steel and aluminium respectively.

Transects should be made up of a number of contiguous 20 x 20 m quadrats and run perpendicular from the shoreline into upland vegetation. The lower extreme of each transect will include emergent macrophytes if present. Each of the 20 x 20 m quadrats is divided into five permanently marked 4 x 20 m quadrats, within which vegetation is described (see next section below) and individual trees tagged and assessed for vigour. Within 4 x 4 m subplots, all understorey plants (sedges and shrubs) are be described (see next section below). Floristic data on submerged vegetation can be collected from four to six 2 x 2 m permanent quadrats randomly located in the littoral zone adjacent to each transect.

Photographs of transect vegetation should be taken each monitoring year from two marked reference points, one at each end of the transect, facing in opposite directions.

Site data such as, topographic position, slope, aspect, surface soil characteristics, litter and water depth are to be recorded when initial vegetation assessment is made. Water depth, litter and surface soil characteristics should be assessed each time vegetation I monitored.



Floristic composition, species richness and diversity.

Within each 4 x 20 m subplot of each 20 x 20 m quadrat all overstorey species and large understorey species (>1.5 m) should be identified. All trees are to be tagged and given a unique reference number. Data for each overstorey subplot will be kept distinct to determine gradient transitions. Subplot data can be combined for each quadrat as required. Understorey 4 x 4 m subplots will focus on all understorey species (< 1.5 m). Species richness, diversity and similarity indices can be calculated for each overstorey and understorey subplot or combined for each quadrat.
Floristic data collected from the transects can be supplemented by surveys within 200 m either side of the transect. Any additional species found can be recorded but this information must be kept separate from the transect data.

The presence of seedlings of tree and large shrub species is to be recorded in the overstorey sub-plots.

Specimens of all species recorded are to be collected and their identification verified at the State Herbarium reference collection. A field herbarium should be compiled for future reference. Specimens should be mounted and lodged at the herbarium as required.

All field notes must be recorded on standardised forms and originals archived for future reference.

Density and foliage cover.

In addition to the qualitative vegetation data described above, quantitative information should also be collected. The density of overstorey and understorey species must be determined for each of the corresponding subplots. Percentage foliage cover for each understorey species is to be determined by direct measurement of (two foliage diameter measurements at right angles) each individual within each 4 x 4 m subplot. The foliage cover of understorey species that do not have distinct projected foliage area, such as sedges and rushes, can be estimated as a percentage of the subplot area.

Percentage canopy cover should be determined for each 20 x 20 m quadrat. This can be structured into overstorey and sub-overstorey if required. Tree and large shrub seedling density (each species) should be recorded in overstorey sub-plots.

Physiognomy.

Height ranges for each vegetation strata are to be measured at least within quadrats, or subplots if possible. Each overstorey and understorey species should be described using a growth form classification. Profile diagrams depicting vegetation structure and zonation should be constructed for each transect.

Tree and large shrub seedling height range (each species) should be measured in each overstorey subplot.

Tree vigour.

The vigour of each individual tree within each overstorey subplot can be categorised according to a subjective scale of 1 – 5 based on estimations of proportion of live canopy foliage. Evidence of water stress, chlorosis and pathogen activity should also be recorded.

Population dynamics.

The size class structure of key wetland tree species should be determined by measuring height and diameter at breast height (DBH) of each individual in each 20 x 20 m quadrat. Data from all Vasse estuary transects are to be combined and used to develop size class frequency plots and illustrate population structure. This information is valuable in identifying the frequency of seedling recruitment and senescent populations.

Seedling recruitment events should be recorded in the field when found. Mean seedling height, density and vigour should be measured and tracked between monitoring years as required. Interpretation of events/conditions which lead to mass seedling emergence and successful seedling establishment, is important in understanding vegetation change and response to salinisation or management actions.

Distribution of wetland plant communities, populations.

At the transect scale, the distribution of plant populations or community types, should be related to hydrology and salinity. The ground level at each end of each 4 x 20 m overstorey subplot should be measured using an auto level and staff. These levels can be tied-in to known benchmarks (mAHD). The elevational gradient along each transect can then be compared to wetland water levels and the water regime determined for different positions on the transect. To the extent that data are available historical wetland water levels can be related to vegetation distribution to identify past impacts and explain current distributions.

Once sufficient information has been collected, water regime requirements and salinity tolerances of key wetland plant species can be identified and used to predict impacts and identify restoration criteria.

Physico-chemical parameters.

Each transect is to have a groundwater monitoring bore adjacent to the top (highest elevation point) end of the transect. Information on groundwater level and salinity is vital for correct interpretation of vegetation change.

Records should be kept of the dates when fires occur irrespective of whether they cover the transects or not. Field assessments of transects should note any evidence of fire and plant deaths that may have resulted.

Surface soil salinities at each transect can be measured each monitoring year using an EM 38 and validated with limited soil sampling and direct measurement (EC of 1:5 soil:water extracts). Three EM 38 measurements should be taken within each overstorey subplot.

Other soil properties, such as horizon definition, particle size fractions, pH and % organic matter, can be determined along the transects to characterise the edaphic conditions. These measurements will not be repeated unless significant change is suspected.

Information on water salinity and nutrients may be available from other surveys and can be related to vegetation vigour and survival.

Care must be taken when monitoring not to trample vegetation, particularly in the established samphire communities.

Database

All data collected as part of the wetland vegetation monitoring must be databased in digital form and held by the Dept. CALM. Microsoft Excel can be used for this purpose. Original field record forms must be archived and referenced to the digital database.

Reporting

At the completion of each monitoring year's assessment, hardcopies and a digital copy of the report should be lodged with the Dept. CALM. Digital copies should be on CD-ROM and include the report text, all tables and figures, digitised plot photographs, digital versions of any maps and all raw and collated data.

Projected Costs

Two options are presented below for monitoring design and associated costs. Option 1 represents a less intensive design that can be implemented at a lower cost. Option 2 is more intensive, covers more sites, is replicated, and therefore has a higher implementation cost. **Neither option represents a quote from the author to conduct the specified work**. Each option represents an estimate using average consulting rates and expenses.

Option 1 – Low Cost

One transect each at sites 1, 2, 3, 5, 7, 8. This covers most of the dominant vegetation types but does not include replication. The design and measurement variables are the same as these suggested in the methodology (and as option 2). Measurement of soil variables can be omitted but is included in the costing, It is assumed that the consultant has all the necessary equipment and will not forward the cost of hire or purchase. The daily consulting rate used in the costings is $500 for field work and report preparation. This does not include travel which is estimated as 50c per kilometre. Vehicle hire and accommodation costs are not included.

Transect establishment and first assessment, 1 day per transect @ $500 per day		$3000
Travel, 1 round trip of approx. 500km @ 50c per km		$250
Report and data preparation costs, 5 days @ $500 per day		$2500
	Total	**$5750**

Option 2 – Higher Cost,

The following transect numbers are suggested:
Site 1: 2 transects
Site 2: 1 transect
Site 3: 2 transects
Site 4: 1 transect
Site 5: 1 transect
Site 6: 2 transects
Site 7: 1 transect
Site 8: 1 transect
Site 9: 1 transect
Site 10: 2 transects

This covers all of the dominant vegetation types and includes replication. The design and measurement variables are the same as those suggested in the methodology (and as option 1). Measurement of soil variables should be conducted and is included in the costing, It is assumed that the consultant has all the necessary equipment and will not forward the cost of hire or purchase. The daily consulting rate used in the costings is $500 for field work and report preparation. This does not include travel which is estimated as 50c per kilometre. Vehicle hire and accommodation are not included.

Transect establishment and first assessment, 1 day per transect @ $500 per day		$7000
Travel, 2 round trips of approx. 500km @ 50c per km		$500
Report and data preparation costs, 8 days @ $500 per day		$4000
	Total	**$11500**

On-going Monitoring

Once established, the cost of reassessing the transects will be significantly lower. Two transects can be assessed per day, therefore the cost of the transect assessment component of Options 1 and 2 is halved. Report and data preparation costs may be reduced, depending on whether the same consultant is used.

Appendix 1

MONITORING PROTOCOL FOR WETLAND VEGETATION ON THE SWAN COASTAL PLAIN

A SELECTED REVIEW OF SUBMERGENT, EMERGENT AND RIPARIAN VEGETATION.

Neil Pettit and Ray Froend

16 December 1996

Wetland vegetation monitoring techniques and protocols

In the majority of reports on wetlands on the Swan Coastal Plain (SCP) the vegetation is generally described in terms of the dominant species with perhaps some subjective indication of health and degree of weed invasion within the community (Arnold 1990; EPA 1990; Payne 1993) or a general description of the vegetation is given (Crook 1981; Bartle *et al.* 1986). In the United States an anecdotal but systematic technique for the evaluation of wetlands and wetland vegetation (Wetland Evaluation Technique) has been developed for wetland assessment and functional design (Adamus 1983; Marble 1990). There are very few quantitative studies of wetland vegetation on the SCP (e.g. McComb 1967; Brock & Pen 1984) which elucidate the ecological processes of these vegetation communities. This quantitative information is essential for the proper management of wetland vegetation. Therefore techniques for monitoring should reflect this so that protocols allow the collection of quantitative data that is repeatable both spatially and temporally.

The primary technique for monitoring vegetation in wetlands has been the use of ground surveys. Quantitative surveys can been done using various standard plant ecology techniques (Mueller-Dombois & Ellenberg 1974; Kent & Coker 1992) including the use of belt or line transects or various sized quadrats. Which method is to be used will depend on the objectives of the survey and the type and condition of the wetland vegetation. Plot size will depend on the type of vegetation to be monitored with smaller plots for the herbaceous layer and larger plots for shrubs and much larger plots for the overstorey. The size of a monitoring plot required for a particular vegetation type can be calculated using species area curves (Mueller-Dombois & Ellenberg 1974) and the number of plots or transects should accurately represent the vegetation of the wetland being studied. Transects or plots that are set up should, wherever possible, be permanently installed so that long term trends in vegetation health and change can be distinguished from year to year variations which may be dependent on climatic variability (Austin 1981). Permanent plots, where their position is well marked and precisely recorded, allow accurate re-assessment on subsequent visits. A methodology for the use of permanent nested quadrats has been developed for assessing change in conditions in natural areas in Western Australia (Hopkins, Brown & Goodsell 1987). Transects are most often useful for measuring changes in vegetation along a gradient such as changes in water regime or soil moisture content (e.g. Froend *et al.* 1993; Mattiske & Associates 1995).

The sorts of variables that can be measured in vegetation plots include number of species (i.e. richness), abundance and/or cover. Vegetation can be also be described in terms of structure (Muir 1977) and in many cases an indication of vegetation health can also be given (Trudgen 1991). This is usually recorded by a subjective scale ranging from poor through to good and can be based on a number of variables including density of the canopy, presence of dead branches and presence of epicormic sprouting (Froend 1987; Mattiske & Associates 1995; Ladd 1996). Phenology and productivity (growth) of particular species can be monitored along transects and this is usually done for species that are important within the wetland community such as the overstorey or emergent macrophytes (van der Valk 1987; Froend *et al.* 1993; Froend & McComb 1994; Stockey & Hunt 1994). These features of the vegetation are important in understanding the vegetation dynamics of the wetland community so that effects of changes to the wetland community can be predicted (van der Valk 1981). Other features of the vegetation that can be recorded include age structure and the presence of seedlings. These will give an indication whether the vegetation is senescent or regenerating. However, this may not be as important for species that rely mainly on vegetative reproduction, such as clonal growth from rhizomes, to sustain populations as is the case with many emergent macrophytes species, instead, measurement of ramet production can be carried out (Froend *et al.* 1993). A measurement of the occurrence and abundance of exotic species is also important. This gives an indication of the degree of disturbance of a wetland. High levels of weed invasion can have a negative effect on species diversity and the recruitment of native species (Pettit, Froend & Ladd 1995).

When monitoring vegetation it is also essential to measure environmental variables that will influence the vegetation communities. Which environmental variables should be measured will depend to some degree on the purpose of the study. These may include hydrology such as groundwater (Hagerthey & Kerfoot 1992) and fluctuating water regimes (Keddy 1985; Froend *et al.* 1993; van der Valk, Squires & Welling 1994); water quality including nutrients, salinity and industrial contaminants (White, Hendricks & Fortner 1992); soil type, such as peat or sand based wetlands and soil moisture and surface or groundwater levels (Hagerthey & Kerfoot 1992; White, Hendricks & Fortner 1992; Stromberg 1993). Information on climate, particularly rainfall can also be useful in determining the cause of changes to vegetation (Arrowsmith 1992). Record of past fires is also important as this can have a strong impact on the composition of the vegetation and can confound the effects of other environmental factors such as water regime on the vegetation (McComb 1987).

The other major technique that is useful for the monitoring of wetland vegetation is remote sensing by the use of satellite imagery and/or aerial photography. Aerial photography has been used extensively for the mapping and classification of wetlands (Hill *et al.* 1994) and can be used to map broad categories of vegetation communities. By the use of historical aerial photographs there is the potential to monitor the changes in area, type and health of vegetation in wetlands from the past to the present and for ongoing monitoring (Froend & McComb 1991; Hill *et al.* 1994). It is important that interpretation of aerial photography be verified with surveys on the ground. Aerial photography can also be combined with ground surveys to answer multiple questions on wetland vegetation monitoring such as general condition of wetland vegetation within a catchment and the specific effects of flooding or salinity on the vegetation (Froend & McComb 1991; Froend & van der Moezel 1991; van der Valk, Squires & Welling 1994). Other environmental information such as soils and topography can also be overlaid on the photographs to increase the amount of information that can be used.

Satellite imagery usually using Landsat thematic mapper (TM) data can be used at a broad scale to detect different vegetation communities and also the degradation of the vegetation caused, for example, by increased waterlogging (Kobryn, Strehlow & Froend 1992). In an evaluation of the usefulness of TM data for the remote sensing of wetlands, Johnston & Barson (1993) concluded that TM data may be useful for broad classification of wetlands but would not replace aerial photography for more detailed assessment. Remotely sensed data can also be used in combination with other environmental data and a Geographical Information System (GIS) to model and therefore predict changes in wetland vegetation communities (Wentworth, Johnson & Kologiski 1988; Remillard & Welch 1992; Poiani & Johnson 1993; Remillard & Welch 1993; Lehmann, Jaquet & Lachavanne 1994). This combination of technology can also be used to model successional processes in different vegetation communities using, for example, state and transition models (George, Brown & Clawson 1992; Hobbs 1994; Baker & Walford 1995) which could be applied to wetland vegetation.

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Indicator species and parameters

Wetland plants that would be useful as indicator species in monitoring wetland health usually include the dominant overstorey vegetation. However, this will depend on the parameters to be monitored in the wetland. Overstorey species are generally used to define vegetation communities and also tend to persist in highly disturbed plant communities when most other native species have disappeared. The overstorey also have many important ecological functions within the wetland community. On the SCP the major overstorey species in wetlands include *Eucalyptus rudis, Melaleuca rhaphiophylla, M. priessiana* and *Banksia littoralis* (Froend *et al.* 1993). Emergent macrophytes can also form a dominant community in wetlands and perform important ecological functions. Important species on the SCP include *Baumea articulata, B. juncea, Juncus pallidus, Schoenoplectus vallidus, Lepidosperma longitudinale* and *Typha orientalis* (Froend *et al.* 1993). Invasive exotic species can provide an indication of the level of disturbance within a wetland such as *Typha orientalis* and also many ruderal species such as the annual exotic grasses. The presence and abundance of fire ephemeral native legumes such as *Acacia saligna, A. pulchella* and *Jacksonia sternbergiana* can provide a indicator of the frequency of fire disturbance. Plant species can also provide an indication of water quality such as eutrophication (Congdon 1976) or salinity. In a survey of a large number of wetlands in the south west of Western Australia Halse, Pearson and Patrick (1993) provided evidence of species that may be used as indicators of saline or fresh conditions. For example, species that occurred only in saline conditions included *Frankenia* sp, *Halosarcia haloinenoidies* and *Melalueca thyoides*, while species which occurred only in freshwater include *Melalueca priessiana, Leptocarpus scariosus* and *Astartea* sp. Many plant species can be useful in determining wetland boundaries and for wetland classification. Davies and Lane (1995) provide a list of species useful in defining wetland boundaries while Seminiuk *et al.* (1990) give a list of indicator species for the classification of SCP wetlands. A statistical approach to defining wetland boundaries using plant community structure and proportion of hydrophytes has been used in the United States (Tiner 1991). This study also provides a definition of obligatory wetland species (i.e. hydrophytes).

Indicator parameters for wetland plants can include species diversity and evenness (e.g. Shannon-Wiener index (Kent & Coker 1992)) which can provide an indication of the level of disturbance and also vegetation community health. A weediness index can also be developed from wetland vegetation surveys based on the ratio of the number and cover of native species and exotic species recorded (Ladd 1996). General subjective indices of vegetation health can also be used as suggested for transect surveys. A regeneration index based on the number of seedlings recorded in surveys can also provide an indication of the wetland vegetation health (Ladd 1996).

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Indices of wetland vegetation condition/health

Many of the indices for monitoring wetland health and condition have already been mentioned in the previous sections. These include the use of multi-temporal satellite images in conjunction with ground surveys to develop an index of wetland condition based on vegetation vigour and spectral changes in reflectance (Morton 1986; Wallace & Wheaton 1990; Kobryn, Strehlow & Froend 1992). Other indices of wetland vegetation health include a subjective scale of plant vigour along monitoring transects which can then be translated into a vegetation health index for the whole wetland. Also the indices of weediness and regeneration already mentioned can be incorporated with a plant health index to a generate general indicator of wetland vegetation health (Ladd 1996).

An index of river foreshore condition has been developed for rivers in the south west of Western Australia (Pen 1994; APACE & Pen 1995). This system gives the river foreshore a rating based on the condition of the riparian vegetation and the degree of disturbance and erosion. There are 12 possible categories ranging from A1 (a pristine riparian zone) to D3 (freely eroding channel with little or no fringing vegetation). This system relies on some training of the observer but provides a useful indication of the health of the riparian zone to assist in planning for their management.

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Models of wetland vegetation change

Modeling wetland vegetation can provide insights to vegetation succession and allows predictions to be made on changes to vegetation structure resulting from changes to environmental conditions. A model on wetland succession uses 3 plant life history traits to predict vegetation community composition (van der Valk 1981). These traits include 1) life span (i.e. annual, perennial, vegetative perennial); 2) propagule longevity (presence of a seedbank); 3) propagule establishment requirements (i.e. flooding, shade tolerance, etc.). Another model looks at the growth dynamics of a single species and includes the use of the Richards equation to model the growth dynamics of *Typha glauca* through measurement of shoot growth in quadrats at various water depths (Waters & Shay 1991). The simulation model MEGAPLANT provides a framework for understanding the dynamics of submerged macrophytes (Scheffer, Bakema & Wortelboer 1993). The simulation produces growth curves for species based on data on growth, mortality, respiration and photosynthesis and also looks at the effects of stochastic environmental conditions. Several models take advantage of combining remotely sensed data and ground survey information with a GIS system that can make predictions of vegetation dynamics based on changed environmental conditions. Using multi-temporal aerial photography of aquatic vegetation distribution in a GIS

Remillard and Welch (1992); Remillard and Welch (1993) found that water depth and sedimentation accounted for 90% of vegetation distributions. Poiani and Johnson (1993) used GIS to model change in abundance, distribution and cover of emergent macrophytes based on seedbank composition, seedling recruitment and plant survivorship. A model using GIS estimates biomass and community structure of submerged macrophytes with GIS information layers draped over a digital elevation model (Lehmann, Jaquet & Lachavanne 1994).

More general plant ecology models that may have application in modelling wetland vegetation include the state and transition model developed to interpret vegetation dynamics in the highly disturbed rangeland environment (Westoby, Walker & Noy-Meir 1989). This state and transition model has also been applied to model changes in grazed grasslands using aerial photography (George, Brown & Clawson 1992) and may be further developed using a GIS system (Hobbs 1994).

A dynamic spatially explicit model has been developed to study the vegetation dynamics for wetlands in relation to hydrological regimes on the SCP (Nowell *et al.* 1996). This model examines the influence of vegetation community structure on resource availability and the response of the vegetation. Three common species of the SCP are examined including *Melaleuca priessiana, Baumea articulata* and *Typha orientalis.* A spatial model of wetland nutrient cycling has also been developed using bathymetry, substrate geology and macrophyte distribution and ecological information such as macrophyte productivity and nutrient uptake and release (Connell 1996). This model has been incorporated into a GIS system.

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Monitoring strategies used on the Swan Coastal Plain

There have been few long term monitoring programmes for wetland vegetation on the SCP. Many of the surveys of wetlands have been once off studies which give a brief description of the vegetation and are generally not easily repeated to give quantitative information on the long term changes in wetland vegetation. The use of historical aerial photography used for the mapping of wetlands has the potential to be used for long term monitoring (Hill *et al.* 1994). A long term monitoring programme using permanent vegetation transects has been established to assess the effect on the vegetation of groundwater drawdown on the Gnangara mound (Mattiske & Associates 1995). A similar study looking specifically at wetland vegetation commenced in 1995 (R.H. Froend pers comm.).

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Baseline vegetation data for the Swan Coastal Plain

Baseline data for vegetation in wetlands on the SCP tends to be scattered in many general reports on wetlands. These are not usually comprehensive descriptions of the vegetation but generally describe the vegetation community based on the dominant components e.g. (Aplin 1976; Congdon 1976; Tingay 1976; Majer 1979; Allender 1980; Backsall & Bridgewater 1981; Crook 1981; Bartle *et al.* 1986; WAWA 1986; Arnold 1990; Seminiuk *et al.* 1990; WAWA 1991; Godfrey, Jennings & Nichols 1992; DCE 1993; Halse, Pearson & Patrick 1993; Payne 1993; Hill *et al.* 1994). More detailed studies of the vegetation and floristics of wetland vegetation communities which can provide more useful information on past and present vegetation on SCP wetlands includes: Speck 1952; Smith & Marchant 1961; McComb 1967; Seddon 1972; Muir 1983; Cresswell & Bridgewater 1985; Keighery & Alford 1990; Keighery & Keighery 1991; Keighery & Trudgen 1992; Keighery & Keighery 1992; Mattiske & Associates 1995. A comprehensive floristic survey of the southern SCP identified 16 different plant community types that could be regarded as seasonal wetland/dampland communities (Gibson *et al.* 1994). This report identifies 2 community types that are considered endangered because of loss of these habitats and poor reservation. The present reservation and conservation status of each floristic community is also listed.

Baseline ecological information for vegetation is given for the vegetation community at Loch McNess (McComb 1967), for emergent macrophyte vegetation on various wetlands (Froend *et al.* 1993) and for samphire marshes in the Peel-Harvey area (McComb, Kobryn & Latchford 1995). Baseline data on riparian vegetation on several rivers on the SCP do not provide comprehensive species lists but give good general descriptions of the major species and their distribution, including weeds (Backsall & Bridgewater 1981; Pen 1987; Pen 1992; Pen 1993c; Pen 1993b; Pen 1993a).

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