Department of
Sustainability and
Environment

Index of Wetland Condition

Review of wetland assessment methods

A Victorian Government initiative

Victoria
The Place To Be

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The Index of Wetland Condition

Review of wetland assessment methods

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1 Introduction

This literature review was undertaken as part of the project: 'Core indicators for biodiversity – wetland ecosystem extent and distribution and wetland ecosystem condition'. The project was undertaken by the Department of Sustainability and Environment (DSE) with funding assistance from the National Action Plan for Salinity and Water Quality (NAP) and the Natural Heritage Trust (NHT).

The principal project output is a method to assess the condition and extent of wetlands in Victoria. The wetland condition assessment method has been termed the Index of Wetland Condition (IWC). The document 'Index of Wetland Condition - Conceptual Framework and Selection of Measures' (Department of Sustainability and Environment 2005a) sets out the rationale and requirements for development of the method, its form and the condition measures that make up the method.

This review summarises wetland assessment methods reported in the literature from Australia and overseas and highlights examples of how aspects of wetland assessment and monitoring have been undertaken that have most relevance to Victoria. Information on recent wetland assessment programs in Victoria and overseas is also encompassed. Some information is drawn from a literature review undertaken for the State Water Quality Monitoring and Assessment Committee in December 2002 (Butcher unpublished). The review describes wetland assessment concepts and definitions, existing assessment and monitoring programs and examines indicators for assessing wetland condition.

1.1 Wetlands – an introduction

Significance of wetlands

Wetlands play an important role in maintaining biological diversity and perform such ecological functions as biochemical transformation and storage, production of living plants and animals and decomposition of organic materials. Wetlands also provide critical habitats for plants, invertebrates, fish, birds, and mammals, including rare and threatened species, and improve water quality, control floods, regulate global carbon levels and have significant cultural and recreational values (Richardson 1994, United States Environmental Protection Agency 2002a, Clarkson *et al.* 2003).

Uses of wetlands include recreational activities such as bird watching, canoeing, boating, fishing and bush walking. Scientific research is often undertaken in wetland areas, contributing to the general understanding of wetlands and how they interact with other ecosystems. Many wetlands are also of high cultural significance and are a focal point for various communities (State Wetland Action Group 2002). Wetlands are however, amongst the most threatened ecosystems worldwide due largely to destructive practices such as draining, infilling, drainage, development, alteration of wetting/drying cycles and high exposure to pollutants and litter (State Wetland Action Group 2002, Environment Australia 2001).

In Victoria, there are approximately 16,700 non-flowing wetlands covering 540,900 hectares, of which 12,800 (covering 432,800 hectares) are natural and the remaining 3,900 wetlands are artificial (Figure 1) (Department of Sustainability and Environment 2005b). Eleven wetland systems are Ramsar sites of international importance and 159 are wetlands of national importance (Environment Australia 2001).

Wetland loss and degradation

There has been a significant loss of wetlands globally, through infilling, drainage and mining, urban growth, agricultural production and resource extraction. A review by Spiers (1999) documented wetland loss since 1900 globally at 50%, 90% in New Zealand and approximately 50% in the United States. It has been estimated that a similar degree of loss has occurred in Australia, 26.8% in Victoria, and close to 90% in south-eastern South Australia and the Swan Coastal Plain region of south-west Western Australia (Spiers 1999).

In Victoria, almost 4,000 natural wetlands (191,000 hectares) have been lost since European settlement, attributed primarily to drainage for agricultural purposes (Department of Conservation and Environment and Office of the Environment 1992). This assessment is based on comparison of two geospatial coverages for Victoria (Department of Sustainability and Environment 2005b)[1]

A range of external pressures can lead to the degradation of remaining wetlands. For example, changes in hydrology, water pollution, nutrient enrichment, invasion by weeds and pests and unsustainable or over-exploitation of wetland products can lead to biodiversity loss and impaired wetland functioning (Moser *et al.* 1996, Clarkson *et al.* 2003). Degradation of wetlands can occur at two levels: the direct loss and degradation that occurs to the wetland itself; and the indirect loss and degradation, which occur as a result of changes in the wetland's catchment (Moser *et al.* 1996).

1.2 Existing literature reviews of wetland assessment programs

A number of reviews of wetland assessment programs have been undertaken. Most recently Butcher (unpublished) and Harding (2002) provided a review of wetland assessment and monitoring programs in Australia with some reference to overseas programs. Additional programs are summarised in section 3.4 of this document. Table 3.1 in Appendix 3 summarises these and other programs from overseas and in Australia that were not included in those reviews.

Bartoldus (1999) prepared a manual describing and evaluating 40 wetland assessment procedures developed in the United States of America over the last thirty years. The methods reviewed were designed for a variety of purposes including assessing habitat quality and quantity, impact assessment, assessment of wetland function, wetland evaluation for community planning, education and inventory and assessment of watershed and wetland integrity. The manual is aimed at assisting managers in selecting, reviewing or designing wetland assessment procedures. Each procedure is reviewed in a standard format providing information on such aspects as the primary purpose of the method, expertise needed, wetland types to which it is applicable, time required for assessment and extent of field-testing. References are provided as well as a detailed outline setting out specific information about steps in the procedure and details of analysis and reporting. The manual provides a useful guide about the range of procedures in use and the potential applicability of methods in designing a wetland monitoring and assessment program for Victoria.

The United States Environmental Protection Agency reviewed rapid assessment methods described by Barltoldus (1999) and compared them against criteria such as whether the method (i) was rapid, (ii) a measure of condition, (iii) could be verified and (iv) was an on-site assessment. Sixteen of the approaches are discussed in more detail in Fennessy *et al.* (2004).

2 Terms and definitions

Classification, inventory, assessment and monitoring terminology is often used interchangeably in the literature reviewed. Each activity can be considered an integral part of an inter-connected process that together describe the ecological character of wetlands, identify the threats and values of wetlands and changes to ecological character, and provide information regarding the extent of change (Finlayson *et al.* 2001, Butcher unpublished).

2.1 Wetland classification

Classifications are generally simple representations of spatial and temporal complexity (Kingsford *et al.* 2004). Classifications of wetlands should be quantitative and based on the objectives of the classification (Pressey and Adam 1995; Rempel *et al.* 1997, Kingsford *et al.* 2004).

Hierarchical classification approaches developed in the United States (Cowardin *et al.* 1979) are commonplace globally and are based mainly on vegetation characteristics. In Australia, a

[1] Assessment based on air-photo interpretation and ground survey. One coverage estimates wetland extent at the time of European settlement and the second wetland extent in the period 1975-1994. The coverages do not include wetlands less than one hectare in area as it was not possible to adequately determine the original extent of small wetlands because of the lack of large scale air photos and subsequent clearing and drainage of wetlands leading to poor shoreline definition. (A. Corrick pers. comm.)

classification system based on water regimes, salinity and vegetation is used in the Directory of Important Wetlands (Appendix 1, Environment Australia 2001). The Directory identifies 40 different wetland types in three categories: marine and coastal zone wetlands, inland wetlands, and human-made wetlands. The system is based on that used by the Ramsar Convention in describing Wetlands of International Importance, but was modified slightly to suit the Australian situation in describing wetlands of national importance. Notable alterations to the Ramsar classification system included the addition of non-tidal freshwater-forested wetlands and rock pools. Inland karst systems were also added, although the Ramsar classification system now includes karst systems under all categories (Environment Australia 2001).

In Victoria, classification schemes have been based on water regimes, salinity and vegetation types (Harding 2002). The most widely used classification system is that developed by Corrick and Norman (1980). In this system, there are nine categories based on water depth, water permanency and salinity (Appendix 2). Victoria's wetlands have been mapped and classified using the Corrick and Norman system and two spatial GIS layers have been developed by DSE for pre-European settlement (WETLAND_1788) and wetlands mapped from 1975-1994 (WETLAND_1994) (Department of Sustainability and Environment 2005b).

2.2 Wetland inventory

Wetland inventory has been undertaken for a number of purposes that include providing a list of a particular type or even all wetlands in an area, identifying wetlands of national or international importance based on agreed criteria, describing the occurrence and distribution of various taxa, identifying or describing natural resources; identifying the functions and values of each wetland and providing a base for assessing wetland loss or degradation (Finlayson *et al.* 2001). Other functions of a wetland inventory may be to establish a baseline for measuring change in a wetland and a tool for wetland planning and management (Costa *et al.* 1996).

Finlayson *et al.* (2001) notes that the purpose or objective for wetland inventory is inseparable from the spatial scale of the assessment. Wetland inventory has been carried out at a number of spatial scales, with specific objectives at each scale (Phinn *et al.* 1999). Butcher (unpublished) has adapted the following spatial scales from Finlayson *et al.* (2001):

- Site: single site within a single wetland (m^2). Looks at variability within a wetland.
- Local: wetland scale, individual wetlands can vary considerably in size (1 ha to 100s of ha).
- Regional: area determined by boundaries between either geological or biological regions, scale of predominance of specific wetland types.
- State/National: distributions of regions within continents or islands dominated by wetlands.
- Global: usually only presence/absence data in specific continents and islands.

Finlayson (1999) chose three scales for wetland inventory within a hierarchical approach for an Australia-wide inventory as follows:

- wetland regions within a continent with maps at a scale of 1:5 000 000;
- wetland aggregations within each region with maps at a scale of 1:250 000; and
- wetland sites within each aggregation with maps at a scale of 1:50 000 or 1:25 000 (Finlayson *et al.* 2001).

Butcher (unpublished) describes the adaptation of the four-level Asian Wetland Inventory to the Australian situation as follows: "In Victoria, the level of detail is related to the scale of the maps, with Victorian wetlands one hectare and greater in size being mapped and classified according to hydrology, salinity and plant associations (Level 1). Information on climate and geology exist as GIS layers that should be able to be interfaced with the Wetlands Mapping Database. Level 2 requires wetland regions to be identified within broader geological regions or river basins. Whilst river basins are available as GIS layers, wetland regions have not been delineated. Level 3 analyses require the grouping of wetland complexes within each region using a higher level of detail, and level 4 analyses comprise information on individual wetland habitats. This level of detail is considered to be the core data level required and is partially available for Ramsar sites and perhaps a few other well-studied systems."

2.3 Wetland assessment

Wetland assessment is the identification of the status of wetland services and values and threats to them as a basis for the collection of more specific information through monitoring activities. Wetland functions (=services) and values are often determined as part of wetland assessment (Thiesing 2001). The definition of wetland functions varies between authors. Thiesing (2001) defines wetland functions as the physical, chemical, or biological processes occurring within wetland systems (Thiesing 2001). The Ramsar definition defines function as activities or actions, which occur naturally in wetlands as a product of the interactions between the ecosystem structure and processes. Functions include flood water control; nutrient, sediment and contaminant retention; food web support; shoreline stabilization and erosion controls; storm protection; and stabilization of local climatic conditions, particularly rainfall and temperature (Ramsar Convention 2002a).

2.4 Wetland monitoring

A popular definition of monitoring used by Finlayson *et al.* (1999) and in the Ramsar Convention (Ramsar Convention 2002b) is the collection of specific information for management purposes in response to hypotheses derived from assessment and the use of the monitoring results for implementing management. These authors suggest that the collection of time series information that is not hypothesis driven should be termed surveillance rather than monitoring.

The approach and the scope of activity for inventory, assessment and monitoring as separate components of the management process differ substantially but these are not always well distinguished in implementation projects. Importantly, wetland inventory and wetland monitoring require differing types of information and, whilst wetland inventory provides the basis for guiding the development of appropriate assessment and monitoring, wetland inventories repeated at given time intervals do not constitute 'monitoring' (Butcher unpublished).

Monitoring the success of management activities may be defined as regular collecting of information on the site using characteristics of the site or its catchment, for which any change may produce a negative impact on the site. Monitoring is important for detecting these negative changes so remedial action can be taken (Clarkson *et al.* 2003).

2.5 Wetland condition

Although the term 'condition' is widely used with respect to wetlands, it is less often defined. In some wetland studies, condition has been used synonymously with 'ecosystem health' and 'ecosystem integrity'. Spencer *et al.* (1998) use ecosystem health as the basis for their definition of condition, which includes the stability and sustainability of the ecosystem to withstand environmental stress (Rapport 1995) and the capacity of the ecosystem to support a diverse community of organisms and perform functions compared to that of a local unimpaired site (Karr and Dudley 1981). Ortega *et al.* (2004) developed an ecological integrity index for littoral wetlands in semi-arid Mediterranean regions and considered 'ecological integrity' to encompass wetland condition.

The former Ramsar Convention definition of ecological character provides a useful basis for defining condition, it reads: "Ecological character is the sum of the biological, physical, and chemical components of the wetland ecosystem, and their interactions, which maintain the wetland and its products, functions, and attributes. Change in ecological character is the impairment or imbalance in any biological, physical or chemical components of the wetland ecosystem, or in their interactions, which maintain the wetland and its products, functions and attributes." (Ramsar Convention 2002). Ortega *et al.* (2004) use a similar definition for ecological integrity. The ecological character definition was revised recently (Ramsar Convention 2005).

Wetland condition can be interpreted as the 'state' of the wetland, that is the '*biological, physical, and chemical components of the wetland ecosystem, and their interactions*'. The wetland is in a natural (ideal or reference) state in a natural landscape and can support a full range of services characteristic of that wetland type. In a landscape changed by anthropogenic activities, the wetland is subject to threats and risks, which lead to an impaired or imbalanced condition and a diminished level of services being supported. The former Ramsar Convention definition has been adopted by recent wetland condition studies (Butcher unpublished, Wimmera Catchment Management Authority unpublished, Department of Sustainability and Environment 2005).

2.6 Wetland condition indicators

An indicator can be defined as an expression of the environment that estimates the condition of ecological resources, magnitude of stress, exposure of a biological component to stress, or the amount of change in a condition (Breckenridge *et al.* 1995). Indicators may be of two broad types, they may be based on wetland characteristics whereby the deviation from reference forms the measure, or wetland threats (also known as 'stressors') where the impact of the threat on a wetland characteristic is the actual measure. It has been suggested that indicators should possess most of the following attributes (Kent *et al.* 1992, Spencer *et al.* 1998):

- show natural and temporal variation;
- be highly responsive to condition change;
- be repeatable in their measure;
- not be ambiguous in their interpretation;
- be cost effective and simple to apply;
- have regional applicability;
- be biologically relevant;
- be a simple or commonly measured parameter;
- be non-destructive on the ecosystem; and,
- be able to have results summarised so as to be understood by non-experts.

3 Wetland condition methods

3.1 Approaches to assessing wetland condition

There are a number of different approaches to wetland condition assessment that vary according to the specific objectives of the associated programs. The approaches used must consider the individual requirements of the project (e.g., the project scope, resources available, availability of data and knowledge). Approaches may involve an assessment of the whole wetland or specific biotic groups. Types of assessments include the following:

- condition of wetland: techniques primarily based on characteristics and components that define wetlands (e.g. Roth *et al.* 1996, Spencer *et al.* 1998, Ladson *et al.* 1999, Bolton 2003, Washington State Department of Ecology unpublished);
- condition of wetland: techniques based on impacts or threats known to damage wetlands (e.g. Brooks *et al.* 2002, Clarkson *et al.* 2003);
- condition of wetland: techniques that measure biotic groups as a surrogate for wetland condition (e.g. Davis *et al.* 1999, Chessman *et al.* 2002); and
- condition of biotic groups: techniques based on indices that measure the state of wetland biotic groups (such as fish or amphibians) or combinations of groups rather than wetland condition (e.g. United States Environmental Protection Agency 2002a, Mack 2001, Mack 2004).

The characteristics and components that define wetland: the hydrologic cycle, unique soil conditions (hydric soils) and vegetation adapted to wet conditions (hydrophytes) (Mitch and Gosselink 2000), could form a sound framework for the development of a wetland condition assessment method.

3.2 Reference condition

Reference condition describes the characteristics of a wetland least impacted by anthropogenic activities, which can be based on data from sites that represent the least impacted condition for a particular wetland type in a landscape, ecoregion, catchment or state (Butcher unpublished). It is necessary to characterise the ecological character of reference sites to have a clear benchmark against which assessments and monitoring of change in wetland condition can be made (Kent *et al.* 1992, Butcher unpublished). With regard to development of guidelines for nutrients and other water quality variables, consideration of historical data, where available, predictive models and expert judgment should be used as adjuncts to the information collected in the process of characterising reference sites. By using a reference condition approach it is also possible to account for some degree of variability typical of wetland parameters such as water quality, which can be affected by local climate, hydrological and soil characteristics.

Using a hierarchical approach to the selection of reference sites that incorporates different scales of assessment, should allow for a reduction in variability to some degree. For example, at the regional level it would be possible to select sub-groups of wetlands on similar features such as size, physical and geographic features, which should make the wetlands more comparable with less variability.

The care with which reference sites are selected, the development of reference condition variables, and the selection of assessment techniques will have a strong influence on effectiveness of any condition assessment. As a minimum, reference conditions should be established for each of the wetland category types used to classify wetlands at the state level. In addition, reference condition needs to be established according to the classification

Various approaches have been used to characterise reference condition (United States Environmental Protection Agency 1998). These are not mutually exclusive and the best results will perhaps be achieved by using a combination of approaches to characterising wetland reference condition. Each approach has advantages and disadvantages (Table 1).

Table 1. Strengths and weaknesses of various methods for determining reference condition (adapted from Butcher unpublished).

Method	Strengths	Weaknesses
Expert Consensus	• Guides and reviews other procedures. • May be used alone. • Relatively inexpensive. • Common sense and experience can be incorporated.	• Qualitative descriptions of "ideal" community structure. • Might be unrealistic and not representative of a best attainable potential. • Experts might have strong biases.
Biological Survey	• Details obtainable best current condition. • Any community structure deemed important can be used. • Two methods: selected reference sites, and best of ambient conditions.	• Even best sites subject to human impacts. • Degraded sites might lower subsequent biocriteria.
Paleolimnology	• Yields historical time series for community structure of diatoms, chrysophytes, and to a lesser extent, some crustaceans and some insects. • Can infer water quality.	• Preservation of fish, invertebrates, macrophytes, and non-diatom algae is poor. • Studies may require complex data analysis and interpretation by experts. • Adequate sediment record may not exist in reservoirs.
Historical Data	• Yields actual historical information on status. • Inexpensive to obtain.	• Data might be limited. • Studies likely were designed for different purposes, data might be inappropriate. • Human impacts present in historical times were sometimes severe.
Predictive Models	• Useful when data are insufficient. • Work well for water quality.	• Extrapolation beyond known data and relationships is risky. • Can be expensive.

3.3 Indicators used in wetland condition methods

Indicators or measures of condition used in wetland condition assessment methods can be classified according to the types of assessments outlined in Section 3.1. That is, indicators are based on wetland characteristics and components (such as soils, vegetation and water properties), impacts and/or threats (such as presence or absence of grazing) and biotic groups (such as fish, macroinvertebrates and amphibians). Table 3.1 in Appendix 3 outlines indicators used for wetland condition assessment methods.

In a review of 16 rapid assessment methods, Fennesy *et al.* (2004) summarised the most commonly used indicators used in rapid condition assessment programs that reflect these ecological factors (reproduced in Table 2).

Table 2. Major categories of indicators used in the 16 rapid assessment methods reviewed by Fennesy *et al.* (2004). Numbers in brackets are the tally for the times the indicator is used in a rapid assessment procedure (of the 16 reviewed).

Hydrology	**Soils/substrate**	**Vegetation**	**Landscape setting**
Hydrologic alterations (14)	Soil type (4)	Number of vegetation classes (12)	Surrounding land use cover (14)
Hydroperiod (9)	Substrate disturbance (2)	Degree of interspersion (8)	Connectivity to other wetlands or corridors (8)
Type of outlet restriction (8)	Presence of mottles (1)	Extent of invasive species (8)	Extent of and/or vegetation type in buffer zone (7)
Water quality (8)	Depth of A horizon (1)	Vegetation alterations (6)	Extent of human land use in buffer (5)
Surface water connectivity (7)	Munsell color (1)	Habitat value to wildlife (5)	Wetland size (5)
Flood storage potential (7)	Microtopography (1)	Endangered/threatened species, their habitat or communities (4)	Ratio of wetland to watershed size or watershed size (3)
Groundwater recharge and/or discharge (4)	Sediment composition (1)	Coarse woody debris (3)	Land use in watershed (3)
Water source(s) (3)		Dominant vegetation (2)	Wetland morphology (2)
Degree of water level fluctuation (3)		Plant species diversity (2)	Position of wetland in watershed (1)
Maximum water depth (1)		Area of open water (1)	

3.4 Examples of wetland condition methods

See Appendix 3 for a more comprehensive list of wetland condition assessment methods.

National methods

Recently, the National Natural Resource Management Monitoring and Evaluation Framework (Natural Resource Management Standing Committee unpublished a) and the National NRM Standards and Targets Framework (Natural Resource Management Standing Committee unpublished b) have established national outcomes and 'resource condition matters for targets' to guide investment through national natural resource management programs, particularly under NAP and NHT). Resource condition indicators have been developed to measure the performance of investments made under natural resource management programs such as the National Action Plan and the Natural Heritage Trust. Under this framework the integrity of inland aquatic ecosystems (rivers and other wetlands) has been defined as one of the key targets for assessment and *wetland ecosystem condition* is a key indicator for this target. The recommended sub-indicators are:

- colour;
- dissolved oxygen and temperature;
- extent of inundation;
- macroinvertebrate diversity and community composition;
- macroinvertebrate index;
- macroinvertebrate indicator species;
- nutrients (phosphorus and nitrogen);
- transparency;
- vegetation; and,
- phytoplankton.

These indicators are under review pending findings from other projects.

Australian states and regions

Spencer *et al.* (1998) developed indicators of wetland function for a rapid appraisal wetland condition index for the Murray Darling basin floodplain wetlands based on the wetland attributes of soils, fringing vegetation, aquatic vegetation and water quality. Thirteen indicators related to wetland condition were developed for these four wetland attributes (Table 3).

Table 3: Indicators used in the development of a rapid appraisal wetland condition index (from Spencer *et al.* 1998).

Attribute	Function(s)	Indicators
Soil	Interception of overland flows; nutrient storage; supports growth of vegetation; habitat for fauna	• Bank stability • Pugging by livestock • Soil organic content
Fringing vegetation	Interception of overland flows; nutrient storage habitat for fauna; carbon source for aquatic food webs	• Width • Continuity • Height diversity
Aquatic vegetation	Habitat for fauna; carbon source for aquatic food webs; damping wind-driven mixing.	• Cover • Spatial heterogeneity • Attached algae
Water	Habitat for biota medium for biogeochemical processes	• Turbidity • Conductivity • Colour • Algal bloom frequency

Each indicator is scored from 0 to 4, whereby the highest scores reflect the best condition and the lowest scores reflect the most degraded condition. Each sub-index score is normalised to produce a score out of 10. A final score of 10 = excellent condition and 0 = extremely poor condition. Spencer *et al.* (1998) indicated that referenced wetlands would be required in each major bioregion to ensure the scoring reflected regional variation.

In New South Wales (NSW), the former Department of Infrastructure, Planning and Natural Resources (DIPNR) in New South Wales (now Department of Natural Resources) developed methods for the assessment of the effectiveness of the Integrated Monitoring of Environmental Flows (IMEF) program that includes river reaches and wetlands. The present method includes indicators for wetted area, plants, macroinvertebrates, amphibians and birds (Department of Land and Water Conservation 2003).

Prior to the development of these methods, the rapid assessment approach of Spencer *et al.* (1998) was used to assess the health of floodplain wetlands (Appendix 3, Table 3.1). Twenty-four wetlands were assessed over a four-week period every summer and winter over three years (2001-2003). This method, however, was found to be flawed for the purpose of ranking the wetlands, as it overestimated the ecological value of wetlands used for permanent water storage and underestimated the value of ephemeral wetlands if the surveys were conducted when the wetlands were dry (Ecos Consulting unpublished).

The NSW Department of Natural Resources (DNR) has also commenced an assessment on the application of the rapid assessment method (Spencer *et al.* 1998) to other regions in NSW (James Maguire, DNR, pers. comm.).

WetlandCare Australia has synthesised and augmented existing condition assessment methods for north coast wetlands in NSW. Methods were originally developed by Boulton (unpublished a, b, c, d) between 2001 and 2003 for freshwater wetlands and paperbark wetlands. A method for estuarine wetlands was added, and the revised method termed the 'WetlandCare Australia Wetland Assessment Technique' (WetlandCare Australia unpublished). The revised method comprises five high-level sub-indices: connectivity, human disturbance, acid-sulfate soils, vegetation and habitat. The different wetland types have additional specific sub-indices and there are a number of measures within each sub-index for each wetland type (Table 4).

Table 4: Sub indices and measures used in the WetlandCare Australia method (WetlandCare Australia unpublished).

Wetland type	Sub index	Measures
Paperbark	Paperbark condition	• Vine growth • Galls • Standing dead and dying trees • Clusters of fallen trees • Necrotic spots
	Wetland establishment	• Girth circumference • Depth of peat layer
Open freshwater	Fringing vegetation	• Width • Diversity • Species number • Weeds
	Bank condition	• Erosion • Pugging • Bank gradient
	Water quality	• pH • Turbidity • Electrical conductivity • Nitrate • Ammonium • Phosphate
Estuarine	Mangrove condition	• Foliage cover • Foliage health • Community structure
	Saltmarsh condition	• Ground cover • Crab burrows • Snail density • Necrosis • Mangrove & terrestrial, freshwater weed encroachment
	Tidal restrictions and hydrology	• Mapped changes • Presence of • structures affecting tide • Vegetation indicators

In Victoria, an index of wetland condition has been developed for the Gippsland Lakes. The Victorian Wetland Classification System was recommended to form the basis for the development of the index (Ecos Consulting unpublished). Wetland vegetation and birds were determined to be useful indicators based on the objectives of the project and an assessment of the key values and threatening processes within Gippsland Lakes and a United State Environment Protection Agency review (United States Environmental Protection Agency 2002f). A full list of indicators that show promise for flora and birds are shown in tables 5 and 6.A sub-set of these indicators will be used for the index after the initial reference data set is collected.

Table 5: Characteristics of wetland vegetation that are likely to be useful in developing an Index of Wetland Condition for the Gippsland Lakes, and how they are likely to respond to human disturbance. Reference wetlands are those that are least affected by human disturbances. Wetland characteristics and the suggested scoring system are likely to need modifying once the reference data set has been collected (Ecos Consulting unpublished).

Characteristic	**Relationship to environmental degradation**	**Scoring**
Wetland-zonation	Shift	Score shift as: Large (score = 1) Moderate (score = 2) Small (score = 3) Will require prior information of wetland zones
Species richness	Decrease	Score relative to expected "high" species richness of reference wetlands e.g. poor (< 10 species) (score = 1) fair (10 – 50 species) (score = 2) moderate (50 – 100 species) (score = 3) excellent (> 100 species) (score = 4)
Number of Victorian Flora and Fauna Guarantee Act 1988 species, rare or threatened species (see Table 5)	Decrease	Score relative to expected "high" number as determined from reference wetlands (i.e. as for species richness).
Health of overstorey (if present)	Decrease	Score as: poor (score = 1) fair (score = 2) moderate (score = 3) excellent (score = 4)
Number and dominance of invasive species (*Phragmites australis*, *Typha* sp.)	Increase	Score as: poor (2 or more invasive species covering > 20 % of wetland) (score = 1) fair (2 or more invasive species covering < 20 % of wetland) (score = 2) moderate (< 2 invasive species covering < 20 % of wetland) (score = 3) excellent (no invasive species) (score = 4).
Vegetation that is dominated by one species	Increase	Score relative to expected dominant species mix and coverage as determined from reference wetlands.
Density of vegetation	Shift to either extremely high (weed invasion) or extremely low (permanent inundation)	Score relative to expected density of vegetation as determined from reference wetlands.

Table 6: Characteristic of wetland birds that are likely to be effective in developing an Index of Wetland Condition for the Gippsland Lakes, and how they are likely to respond to human disturbance. Reference wetlands are those that are least affected by human disturbances (Ecos Consulting unpublished).

Characteristic	**Relationship to environmental degradation**	**Scoring**
Diversity of feeding groups (piscivores, grazers, seed-eaters, omnivores, aerial insectivores, waders, birds of prey)	Decrease	Score relative to expected "high" number of feeding groups as determined from reference wetlands e.g.: poor (< 2 feeding groups) (score = 1) fair (2-3 feeding groups) (score = 2) moderate (4-5 feeding groups) (score = 3) excellent (6+ feeding groups) (score = 4)
Species diversity within species-rich feeding groups (i.e. number of different piscivores, grazers, seed-eaters, omnivores, aerial insectivores, waders – exclude birds of prey)	Decrease	Score relative to expected "high" species diversity within a feeding groups (FG) as determined from reference wetlands e.g.: poor (< 2 species in each FG) (score = 1) fair (2-3 species in each FG) (score = 2) moderate (4-5 species in each FG) (score = 3) excellent (6+ species in each FG) (score = 4)
Percent of species that are (or potentially) long-distance migrants (Japan-Australia Migratory Bird Agreement or China-Australia Migratory Bird Agreement species)	Decrease	Score relative to expected "high" species richness of reference wetlands e.g.: poor (< 0-5%) (score = 1) fair (5-10 %) (score = 2) moderate (10-20 %) (score = 3) excellent (20 % +) (score = 4)
Cumulative frequency of occurrence of Victorian Flora and Fauna Guarantee Act 1988, rare or threatened species	Decrease	Score relative to expected "high" frequency of reference wetlands
Percent of the expected species based on geographic range, wetland type, vegetated area and other variables	Decrease	Score as: poor (< 0-5%) (score = 1) fair (5-25%) (score = 2) moderate (25-50%) (score = 3) excellent (50 % +) (score = 4)
Proportional abundance (%) of introduced species (e.g. blackbirds and starlings)	Increase	Score as: poor (> 25 % +) (score = 1) fair (10 - 25%) (score = 2) moderate (10% <) (score = 3) excellent (0 %) (score = 4)

In the Gippsland region of Victoria, ecological indicators are being developed in order to assess ecological condition of the Dowd Morass Wetland in Gippsland. To date, indicators based on vegetation (fringing and submerged) and physico-chemical parameters and ecosystem processes have been developed (Wetland Ecology Group 2003).

In the Wimmera region of Victoria, a rapid assessment method was developed in 2005 to provide a broad rating of wetland condition (i.e. 'good', 'moderate' and 'poor') for wetlands in the Millicent Coast Basin and Douglas Depression regions of the Wimmera Catchment Management Authority (CMA) region. Threats and risks were also considered in the method (Wimmera CMA unpublished). Many indicators trialed in pilot study - the following indicators were short-listed and tested in the final trial:

- Hydrological integrity
- Geomorphological integrity
- Water quality
- Riparian and wetland vegetation
- Surrounding land use

New Zealand

Indicators have recently been developed following the trend of using soil and vegetation characteristics as the most important indicators of wetland condition (Cowardin *et al.* 1979, Faulkner *et al.* 1989, Tiner 1991, 1999 cited in Clarkson *et al.* 2003). This is because they: (i) cover most or all the area of estuarine and palustrine wetlands, and hence can be sampled in most or all locations within these wetlands; (ii) are not mobile and therefore are permanent features of the landscape and (iii) integrate environmental stress factors over long time periods.

Five semi-independent indicators of current state (condition) evolved during trials in different wetland types throughout New Zealand. They are based on major threats and stress factors known to damage wetlands. Each indicator comprises a number of components, scored using a semi-quantitative technique that enables assessment of the degree of modification that has occurred. Indicator component scores are averaged to produce a sub-index indicator score, which is totaled to provide an overall index that represents condition of the wetland (Clarkson *et al.* 2003).

The wetland condition indicators are as follows:

Change in hydrological integrity

- Impact of manmade structures
- Water table depth
- Dryland plant invasion

Change in physico-chemical parameters

- Fire damage
- Degree of sedimentation/erosion
- Nutrient levels
- von Post index

Change in Ecosystem intactness

- Loss in area of original wetland
- Connectivity barriers

Change in browsing, predation and harvesting regimes

- Damage by domestic or feral animals
- Introduced predator impacts on wildlife
- Harvesting levels

Change in dominance of native plants

- Introduced plant canopy cover
- Introduced plant understorey cover

Each indicator component is scored on a scale from 0 to 5, with 5 representing the unmodified condition and 0 representing the most degraded condition. A 'Specify and Comment' column provides information on the reason a particular score has been given so it can be recalled at a later date. This is essential if the scoring system is to be used to monitor change in condition over time, which is its main function. The scores are based on observations made and data collected during site visits and from knowledge/data about the site already available (Clarkson *et al.* 2003).

United States

The United States Environmental Protection Agency (USEPA) has developed (and continues to develop) bioassessment methods for evaluating wetland condition based on a multi-metrics approach. This approach develops multiple measures (or indicators) for each assemblage, which are combined to form one index for that group, collectively termed an Index of Biotic Integrity (IBI). Biotic indicators have been developed for invertebrates (United States Environmental Protection Agency 2002b) and guidelines have been prepared for the development of IBIs for other biotic groups including vegetation (United States Environmental

Protection Agency 2002c), algae (United States Environmental Protection Agency 2002d), amphibians (United States Environmental Protection Agency 2002e) and birds (United States Environmental Protection Agency 2002f). This work commenced in 1999, with the purpose of these reports being to help States and Tribes develop methods to evaluate (1) the overall ecological condition of wetlands using biological assessments and (2) nutrient enrichment of wetlands (United States Environmental Protection Agency 2002a).

Advantages and disadvantages of each of the biotic assemblages are as follows (United States Environmental Protection Agency 2002f):

- Convenience, money, and time are often key factors in selecting a biological assemblage. The selected assemblage must be cost-effective to sample and identify. However, a number of other factors affect an assemblage's practical usefulness and ability to reflect real changes in wetland condition.
- Vegetation is a convenient assemblage because it occurs in most wetland types and there are well-established sampling protocols; however, identifying metrics can be challenging (United States Environmental Protection Agency 2002b).
- Macroinvertebrates have been widely used in stream bioassessments and show a lot of promise for wetlands, but current sampling methods focus on wetlands with standing water (United States Environmental Protection Agency 2002c).
- Algae have been used to a limited degree but offer an inexpensive and effective alternative for some wetland types (United States Environmental Protection Agency 2002d).
- Amphibians offer many advantages but have insufficient taxonomic diversity in some regions for traditional bioassessment methods (United States Environmental Protection Agency 2002e).
- The mobility of birds makes them well suited for landscape-level assessments (United States Environmental Protection Agency 2002f).
- Fish have many advantages that have been demonstrated in other waterbodies, but the fish assemblage is limited to a few wetland types, such as emergent wetlands on the fringes of lakes and estuaries.

Sixteen methods for assessing the condition of wetlands in individual states of the USA are reviewed in Fennessy *et al.* (2004). Additional methods are reviewed in Bartoldus (1999).

Lists of wetland assessment projects that utilize indicators for wetland condition are presented in Appendix 3. Butcher (unpublished) provides a list of advantages and disadvantages of various taxa as tools for monitoring wetland condition.

4 Conclusion

The review highlighted that terminology is used interchangeably in the wetland condition assessment literature, for example, definitions for wetland monitoring, assessment and inventory vary amongst wetland practitioners. Clear definitions are needed at the commencement of a project to avoid confusion. Also, at this stage, setting clear objectives is required to assist with the identification of the appropriate activity suitable for that task, i.e. inventory, monitoring or assessment.

There are a number of different approaches to wetland condition assessment, which vary according to the specific objectives and requirements of the associated programs. Approaches vary in their scale, from the assessment of individual wetlands to regionally-based assessments. Methods and their indicators can be classified according to the nature of the attributes that are measured. For example, they may be based on biotic groups, stressors or threats and wetland characteristics and components or combinations of some or all of these. The practical aspects of the methods also vary considerably. For example, some methods take a number of days to complete, whilst other methods can be completed in less than two hours. Skill levels required for the methods range from experienced wetland practitioners through to people with little experience in wetland systems.

There are significant differences and variability between methods and their objectives and no one method can be easily adapted as a Victorian statewide method. The review has highlighted the important aspects of these methods that must be considered in the development of a wetland condition assessment method, including the framework for the development of indicators or measures and the practical requirements. It is important that these aspects are canvassed during the development of the Victorian wetland condition assessment method.

5 References

Butcher, R unpublished, *Options for the assessment and monitoring of wetland condition in Victoria*, Report to the State Water Quality Monitoring and Assessment Committee (SWQMAC), Victoria. http://www.vcmc.vic.gov.au/Web/vcmc-public.html

Baldwin, D S, Nielsen, D L, Bowen T and Williams, J 2005, *Recommended Methods for Monitoring Floodplains and Wetlands*, MDBC Publication No. 72/04, Murray-Darling Basin Commission and Murray Darling Freshwater Research Centre.

Bartoldus, C C 1999, *A Comprehensive Review of Wetland Assessment Procedures A Guide for Wetland Practitioners*, Environmental Concern inc. Maryland, USA.

Bolton, K G E unpublished a, *North Coast Wetland Assessment Guide Manual. Paperbark Wetlands*. Department of Land and Water Conservation and Southern Cross University.

Bolton, K G E unpublished b, *North Coast Wetland Assessment Guide Manual. Freshwater Wetlands*. Department of Land and Water Conservation and Southern Cross University.

Bolton, K G E unpublished c, *North Coast Wetland Assessment Field Manual. Paperbark Wetlands*. Department of Land and Water Conservation and Southern Cross University.

Bolton, K G E unpublished d, *North Coast Wetland Assessment Field Manual. Freshwater Wetlands*. Department of Land and Water Conservation and Southern Cross University.

Breckenridge, R P, Kepner, W G, Mouat, D A 1995 'A process for selecting indictors for monitoring conditions of rangeland heath', *Environmental Monitoring and Assessment*. **36**:45-60.

Brooks, R P, Wardrop, D H, and Bishop, J A 2002, *Watershed–Based Protection for Wetlands in Pennsylvania: Levels 1 & 2 – Synoptic Maps and Rapid Field Assessments*, Final Report. Report No. 2002-1 of the Penn State Cooperative Wetlands Centre, University Park, PA. 16802.

Chessman, B C, Trayler, K M and Davis, A J 2002, 'Family and species level biotic indices for invertebrates in the wetlands of the Swan Coastal Plain, Western Australia', *Marine and Freshwater Research*. **53**:919-930.

Clarkson, B R, Sorrell, B K, Reeves, P N, Champion, P D, Partridge, T R and Clarkson, B D 2003, *Handbook for Monitoring Wetland Condition. Coordinated Monitoring of New Zealand Wetlands*, A Ministry for the Environment Sustainable Management Fund Project.

Corrick, A H and Norman, F I 1980 'Wetlands of Victoria I Wetlands and waterbirds of the Snowy River and Gippsland Lakes catchment'. *Proceedings of the Royal Society of Victoria*. **91**:1-15

Corrick, A H 1982, 'Wetlands of Victoria III Wetlands and waterbirds between Port Phillip Bay and Mount Emu Creek'. *Proceedings of the Royal Society of Victoria*. **94(2)**:69-87

Costa L T, Farinha, J C, Hecker, N and Tomàs, V P 1996, *Mediterranean Wetland Inventory: A reference manual,* MedWet, ICN, Wetlands International, Greek Biotope, EKBY Publication, Lisboa.

Cowardin, L M, Carter, V, Golet, F C and La Roe, E T 1979, *Classification of wetland and deepwater habitats of the United States*, U.S. Fish and Wildlife Service. Biological Services Program: FBS/OBS - 79/31,US Government Printing Office, Washington DC.

Davis, J, Norris, R and Chessman, B 1999, *Monitoring Wetland Health: Are National River Health Programs Applicable?* National Wetlands Research and Development Program, Department of Environment and Heritage, Australia.

Department of Conservation and Environment and Office of the Environment 1992, *An Assessment of Victoria's wetlands*, Department of Conservation and Environment, East Melbourne.

Department of Environment and Heritage. State of the Environment Report Australia 2001. http://www.deh.gov.au/soe/2001/inland/index.html

Department of Environment and Heritage. National Land and Water Resources Audit. http://audit.ea.gov.au/ANRA/docs/fast_facts/fast_facts_34.html

Department of Land and Water Conservation 2003, *Integrated Monitoring of Environmental flow – an Overview.*

Department of Sustainability and Environment 2005a, *Index of Wetland Condition. Conceptual framework and selection of measures*, Department of Sustainability and Environment, East Melbourne, Victoria.

Department of Sustainability and Environment 2005b, Corporate Geospatial Data Library.

Department of Sustainability and Environment 2005c, *Framework for describing the ecological character of Ramsar wetlands, including a description of the ecological character of the Barmah Forest Ramsar Site*, Department of Sustainability and Environment, East Melbourne, Victoria.

Ecos Consulting unpublished, *Developing a method to determine an Index of Wetland Condition relevant to the Gippsland Lakes and surrounding wetlands*, Report to the Department of Sustainability and Environment.

Environment Australia 2001, *A Directory of Important Wetlands in Australia. Third Edition*, Environment Australia, Canberra, viewed 18 November 2005, < http://www.deh.gov.au/water/wetlands/database/directory/>.

Faulkner, S P, Patrick, Jr. W H and Gambrell, R P 1989, 'Field techniques for measuring wetland soil parameters', *Soil Science Society of America Journal* **53***:* 883-890.

Fennessy, M S, Jacobs, A D, Kentula, M E, 2004, *Review of Rapid Methods for Assessing Wetland Condition*, EPA/620/R-04/009, U.S. Environmental Protection Agency, Washington, D.C.

Finlayson, C M 1999, *Protocols for an Australian national wetland inventory.* In Techniques for Enhanced Wetland Inventory and Monitoring, ed. C. M. Finlayson and A. G. Spiers., pp. 119.45. Supervising Scientist Report No. 147, Canberra.

Finlayson, C M, Davidson, N C and Stevenson, N J 2001, *Wetland Inventory, Assessment and Monitoring – Practical Techniques and Identification of Major Issues*, Pp. 16-19 in: Wetlands – a Source of Life, Conclusions of the 2nd International Conference on Wetlands and Development, 10-14 November 1998, Dakar, Senegal, Wetlands International/IUCN/WWF/Ministry of Environment & Nature Protection of Senegal.

Finlayson C M., Begg, G W, Howes, J, Davies, J, Tagi, K and Lowry, J. 2002, *A Manual for an Inventory of Asian Wetlands: Version 1.0.* Wetlands International Global Series 10, Kuala Lumpur, Malaysia.

Harding, C 2002, *Wetland Inventory: Corangamite Region. A review of inventory data and research on wetlands in the Corangamite Region.* Report for the Corangamite Catchment Management Authority, Centre for Environmental management, University of Ballarat, Victoria.

Karr, J R. and Dudley D R 1981 'Ecological perspectives on water quality goals', *Environmental management.* **5:** 55-68.

Kent, D M, Reimold, R J, Kelly, J M, Tammi, C E 1992, *Coupling wetlands structure and function: Developing a condition index for wetlands monitoring*, In: *Ecological Indicators,* Volume 1, McKenzie, D H, Hyatt, D E and McDonald, V J Eds, New York Elsevier Applied Science.

Kinsgford, R T, Brandis, K, Thomas, R F, Chrigthon, P, Knowles, E and Gale, E 2004 'Classifying landform at broad spatial scales: the distribution and conservation of wetlands in New South Wales', *Marine and Freshwater Research* **55**:17-31.

Ladson, A R, Lindsay, J W, Doolan, J A, Finlayson, B L, Hart, B T, Lake, S and Tilleard, J W 1999, 'Development and testing of an Index of Stream Condition for waterway management in Australia', *Freshwater Biology* **41**:453-468

Lyon, J, Schreiber, E S G and Butcher, R 2002, *Prioritising Wetlands for management of Biodiversity Conservation*, Report to Goulburn Broken Catchment Management Authority, Arthur Rylah Institute for Environmental Research, August 2002.

Mack, J J 2001, *Ohio Rapid Assessment Method for Wetlands, Manual for Using Version 5.0,* Ohio EPA Technical Bulletin Wetland/2001-1-1. Ohio Environmental Protection Agency, Division of Surface Water, 401 Wetland Ecology Unit, Columbus, Ohio.

Mack, J J 2004, *Integrated Wetland Assessment Program. Part 4: Vegetation Index of Biotic Integrity (VIBI) and Tiered aquatic Life Uses (TALUs) for Ohio wetlands*, Ohio EPA Technical Report WET/2004-4, Ohio Environmental Protection Agency, Wetland Ecology Group, Division of Surface Water, Columbus, Ohio.

Millennium Ecosystem Assessment 2005, Ecosystems and Human Well-Being: Wetlands and Water Synthesis. World Resources Institute, Washington, DC.

Mitsch, W J, and J G Gosselink 2000, *Wetlands, Third edition*, John Wiley and Sons, New York.

Moser, M, Prentice, C and Frazier, S 1996, *A global overview of wetland loss and degradation,* In: Papers, Technical Session B, Vol 10/12B, Proceedings of the 6th Meeting of the Conference of Contracting Parties, Brisbane, Australia, 19–27 March 1996, Ramsar Convention Bureau, Gland, Switzerland, 21–31.

Natural Resource Management Standing Committee unpublished a, *Natural Resource Management Monitoring and Evaluation Framework,* http://www.deh.gov.au/nrm/monitoring/

Natural Resource Management Standing Committee unpublished b, *National Framework for Natural Resource Management Standards and Targets,* http://www.deh.gov.au/nrm/monitoring/

Ortega, M, Velasco, J, Millán, A and Guerrero, C 2004, 'An ecological integrity index for littoral wetlands in agricultural catchments of semiarid Mediterranean', *Environmental Management* **33(3)**:412-430.

Phillips, B, Begg, G, Finlayson, M, Lane, B, Bezuijen, Butcher, R, Luckacs, G Unpublished. *"Pilot testing" an approach for describing the ecological character of Australia's Ramsar sites.* Report prepared for Environment Australia under the National Wetlands Program of the Natural Heritage Trust.

Phinn, S, Hess, L and Finlayson, C M 1999, *An assessment of the usefulness of remote sensing for wetland monitoring and inventory in Australia. In Techniques for enhanced wetland inventory, assessment and monitoring,* Eds CM Finlayson & AG Spiers, Supervising Scientist Report 147, Supervising Scientist Group, Canberra, pp 44–82.

Pressey, R L and Adam, P 1995 'A review of wetland inventory and classification in Australia'. *Vegetatio* **118**:81-101

Rapport, D J 1995 'Ecosystem services and management options and blanket indicators of ecosystem health', *Journal of Aquatic Ecosystem Health* **4:** 97-105.

Ramsar Convention 2002a, *Resolution VII.10 Wetland Risk Assessment Framework,* http://www.ramsar.org/key_res_vii.10e.htm.

Ramsar Convention 2002b, *Resolution VIII.6. A Ramsar Framework for Wetland Inventory,* http://www.ramsar.org

Ramsar Convention 2005, *Resolution IX.1 Annex A. A Conceptual Framework for the wise use of wetlands and the maintenance of their ecological character*, http://www.ramsar.org/res/key_res_ix_01_annexa_e.htm.

River Murray Catchment Water Management Board unpublished, *Framework to Assess the Condition of Wetlands of the South Australian River Murray.*

Rempel, R S, Abraham, K F, Gadawski, T R, Gabor, S, and Ross, R K 1997 'A simple wetland habitat classification for boreal forest waterfowl'. *Journal of Wildlife Management* **61**:746-757.

Roth, E, Olsen, R, Snow, P and Sumner, R 1996, *Oregon Freshwater Wetland Assessment Methodology*, Oregon Division of State Lands, Salem, OR.

Spencer, C, Robertson, A I and Curtis, A 1998, 'Development and testing of a rapid appraisal wetland condition index in south-eastern Australia', *Journal of Environmental Management.* **54(2)**:143-159.

Spiers, A 1999, *Review of international/continental wetland resources*, Environmental Research Institute of the Supervising Scientist, Locked Bag 2, Jabiru, Northern Territory, 0886, Australia.

State Wetland Action Group 2002, *Wetland Action Plan 2002/03*, NSW State Wetland Action group.

Thiesing, M.A. 2001, *An evaluation of wetland assessment techniques and their applications to decision making in Practical techniques and identification of major issues*, Proceedings of Workshop 4, 2nd International Conference on Wetlands and Development, Dakar, Senegal, 8.14 November 1998, Finlayson C M, Davidson N C & Stevenson N J (eds), Wetland inventory, assessment and monitoring: Supervising Scientist Report 161, Supervising Scientist, Darwin.

Tiner, R W 1991 'The concept of a hydrophyte for wetland identification', *BioScience* **41**: 236-247.

Tiner, R W 1999, *Wetland indicators: A guide to wetland identification, delineation, classification, and mapping*. Lewis Publishers, CRC Press, Boca Roton.

Tomas. V P 1996, *Monitoring Mediterranean Wetlands: A Methodological Guide. MedWet Publication*; Wetlands International.Turner, R E, Swenson, E M and Summers, J K 1995, *Costal wetlands indicator study*, EMAP – Estuaries Louisiana Province – 1991, US Environmental Protection Agency.

United States Environmental Protection Agency 1998, *Lake and reservoir bioassessment and biocriteria, Technical Guidance Document*, US Environmental Protection Agency, Office of Water, Washington D.C EPA 841-B-98-007.

United States Environmental Protection Agency 2002a, *Methods for Evaluating Wetland Condition: Introduction to Wetland Biological Assessment*, Office of Water, US Environmental Protection Agency, Washington, DC. EPA-822-R-02-014.

United States Environmental Protection Agency 2002b, *Methods for Evaluating Wetland Condition: Using Vegetation to Assess Environmental Conditions in Wetlands*, Office of Water, US Environmental Protection Agency, Washington, DC. EPA-822-R-02-020.

United States Environmental Protection Agency 2002c, *Methods for Evaluating Wetland Condition: Developing an Invertebrate Index of Biological Integrity for Wetlands*, Office of Water, US Environmental Protection Agency, Washington, DC. EPA-822-R-02-019.

United States Environmental Protection Agency 2002d, *Methods for Evaluating Wetland Condition: Using Algae to Assess Environmental Conditions in Wetlands*, Office of Water, US Environmental Protection Agency, Washington, DC. EPA-822-R-02-021.

United States Environmental Protection Agency 2002e, *Methods for Evaluating Wetland Condition: Using Amphibians in Bioassessments of Wetlands*, Office of Water, US Environmental Protection Agency, Washington, DC. EPA-822-R-02-022.

United States Environmental Protection Agency 2002f, *Methods for Evaluating Wetland Condition: Biological Assessment Methods for Birds*, Office of Water, US Environmental Protection Agency, Washington, DC. EPA-822-R-02-023.

Washington State Department of Ecology unpublished, *Draft revision – Washington State Wetlands Rating System: Eastern Washington*. Second Edition. Publication #02-06-019. Washington State Department of Ecology, Olympia, WA. (http://www.ecy.wa.gov/biblio/0206019a.html).

WetlandCare Australia unpublished, *WetlandCare Australia's Wetland Assessment Technique Version 3.1.* WetlandCare Australia, April 2006.

Wetland Ecology Group 2003, Department of Biological Sciences, Monash University, Victoria. http://www.wetland-ecology.info/.

Wimmera Catchment Management Authority unpublished, *Wimmera Wetland Condition Assessment Report*, Technical Report by Waters Edge Consulting, May 2005.

Appendix 1

Wetland classification system used in the Directory of Important Wetlands (Environment Australia 2001).

A–Marine and Coastal Zone wetlands

1. Marine waters-permanent shallow waters less than six metres deep at low tide; includes sea bays, straits
2. Subtidal aquatic beds; includes kelp beds, seagrasses, tropical marine meadows
3. Coral reefs
4. Rocky marine shores; includes rocky offshore islands, sea cliffs
5. Sand, shingle or pebble beaches; includes sand bars, spits, sandy islets
6. Estuarine waters; permanent waters of estuaries and estuarine systems of deltas
7. Intertidal mud, sand or salt flats
8. Intertidal marshes; includes saltmarshes, salt meadows, saltings, raised salt marshes, tidal brackish and freshwater marshes
9. Intertidal forested wetlands; includes mangrove swamps, nipa swamps, tidal freshwater swamp forests
10. Brackish to saline lagoons and marshes with one or more relatively narrow connections with the sea
11. Freshwater lagoons and marshes in the coastal zone
12. Non-tidal freshwater forested wetlands

B–Inland wetlands

1. Permanent rivers and streams; includes waterfalls
2. Seasonal and irregular rivers and streams
3. Inland deltas (permanent)
4. Riverine floodplains; includes river flats, flooded river basins, seasonally flooded grassland, savanna and palm savanna
5. Permanent freshwater lakes (> 8 ha); includes large oxbow lakes
6. Seasonal/intermittent freshwater lakes (> 8 ha), floodplain lakes
7. Permanent saline/brackish lakes
8. Seasonal/intermittent saline lakes
9. Permanent freshwater ponds (< 8 ha), marshes and swamps on inorganic soils; with emergent vegetation waterlogged for at least most of the growing season
10. Seasonal/intermittent freshwater ponds and marshes on inorganic soils; includes sloughs, potholes; seasonally flooded meadows, sedge marshes
11. Permanent saline/brackish marshes
12. Seasonal saline marshes
13. Shrub swamps; shrub-dominated freshwater marsh, shrub carr, alder thicket on inorganic soils
14. Freshwater swamp forest; seasonally flooded forest, wooded swamps; on inorganic soils
15. Peatlands; forest, shrub or open bogs
16. Alpine and tundra wetlands; includes alpine meadows, tundra pools, temporary waters from snow melt
17. Freshwater springs, oases and rock pools
18. Geothermal wetlands
19. Inland, subterranean karst wetlands

C–Human–made wetlands

1. Water storage areas; reservoirs, barrages, hydro-electric dams, impoundments (generally > 8 ha)
2. Ponds, including farm ponds, stock ponds, small tanks (generally < 8 ha)
3. Aquaculture ponds; fish ponds, shrimp ponds
4. Salt exploitation; salt pans, salines
5. Excavations; gravel pits, borrow pits, mining pools
6. Wastewater treatment; sewage farms, settling ponds, oxidation basins
7. Irrigated land and irrigation channels; rice fields, canals, ditches
8. Seasonally flooded arable land, farm land
9. Canals

Appendix 2

Table 2.1: Victorian wetland classification system Corrick and Norman (1980, 1982).

Category	**Sub–category**	**Depth (m)**	**Duration of inundation**
Flooded river flats* These include many areas of agricultural land that become temporarily inundated after heavy rains or floods. Water may be retained in local depressions for just a few days or for several months.		< 2	
Freshwater meadow These include shallow (up to 0.3 m) and temporary (less than four months duration) surface water, although soils are generally waterlogged throughout winter.	1 Herb-dominated 2 Sedge-dominated 3 Red gum-dominated 4 Lignum dominated	< 0.3	< 4 months/year
Shallow freshwater marsh Wetlands that are usually dry by mid-summer and fill again with the onset of winter rains. Soils are waterlogged throughout the year and surface water up to 0.5 m deep may be present for as long as eight months.	1 Herb-dominated 2 Sedge-dominated 3 Cane grass-dominated 4 Lignum dominated 5 Red gum-dominated	< 0.5	< 8 months/year
Deep freshwater marsh Wetlands that generally remain inundated to a depth of 1 – 2 m throughout the year.	1 Shrub-dominated 2 Reed-dominated 3 Sedge-dominated 4 Rush-dominated 5 Open water 6 Cane grass-dominated 7 Lignum-dominated 8 Red gum-dominated	< 2	permanent
Permanent open freshwater Wetlands that are usually more than 1 m deep. They can be natural or artificial. Wetlands are described to be permanent if they retain water for longer than 12 months, however they can have periods of drying.	1 Shallow 2 Deep 3 Impoundment	<2 >2	permanent
Semi–permanent saline These wetlands may be inundated to a depth of 2 m for as long as eight months each year. Saline wetlands are those in which salinity exceeds 3,000 mg/L throughout the whole year.	1 Salt pan 2 Salt meadow 3 Salt flat 4 Sea rush-dominated 5 Hypersaline lake	< 2	< 8 months/year
Permanent saline These wetlands include coastal wetlands and part of intertidal zones. Saline wetlands are those in which salinity exceeds 3,000 mg/L throughout the whole year.	Shallow Deep Intertidal flats	< 2 > 2	permanent
Sewage oxidation basin These include artificial wetlands used for sewage treatment.	Sewage oxidation basin		
Salt evaporation basin These include artificial wetlands used salt concentration.	Salt evaporation basin		

Appendix 3

Table 3.1: Summary of wetland condition assessment programs/methods.

Key Agency/ Key Researcher	Scale of Project Country/region/single wetland	Resolution of assessment	Indicators used	Outputs / Comments
International programs				
Millennium ecosystem assessment	Global Sub-global	Freshwater systems	Synthesis publications produced (Millennium Ecosystem Assessment 2005)	Synthesis publications produced (Millennium Ecosystem Assessment 2005)
Ramsar wetlands Ecological character of Ramsar wetlands	International	Ramsar wetlands – wetland scale	Not defined.	Ecological character data sheets have been produced. (Phillips *et al.* unpublished). Framework for describing the ecological character of Ramsar wetlands lists ecosystem services, components and processes for potential use in a description (Department of Sustainability and Environment 2005c)
Multi-regional programs				
Mediterranean Mediterranean Wetland initiative (MedWet) formed following conference "Managing Mediterranean Wetlands and Their birds in Grado, Italy (1991). Three year testing of tools for monitoring wetland condition. Guide produced to assist in developing appropriate monitoring programs.	Multi-nation	Wetland scale	Indicators aimed at detecting the following ecological change: • Changes in wetland area • Changes in water regime • Changes in water quality • Changes due to exploitation of wetland resources	Methods manuals produced: Tomas (1996).
Asia Wetland inventory, assessment and monitoring system (WIAMS) develop for Asian wetlands, in particular Malaysian wetlands, but which can be more widely utilised. The methods and policies behind the framework are closely aligned with Ramsar convention and so the applicability is on a global to local scale and focuses on the use, functions and attributes of wetlands (Finlayson *et al.* 2002).	Multi-nation	N/A	N/A	
National programs				
Australia State of The Environment Report Australia 2001. http://www.deh.gov.au/soe/2001/inland/index.html	National	Regional wetlands and wetland species.	Decline in wetland extent Waterbird species status Abundance and distribution of frogs.	More information is available on the website: http://www.deh.gov.au/soe/2001/inland/index.html
Australia National Land and Water Resources Audit. http://audit.ea.gov.au/ANRA/docs/fast_facts/fast_facts_34.html	National	Wetland scale (all regionally significant wetlands)	No specific indicators, subjective assessment in one of four categories: Degraded; Fair; Good; Near pristine	More information is available on the website: http://audit.ea.gov.au/ANRA/docs/fast_facts/fast_facts_34.html
New Zealand Set of science-based indicators developed to monitor the condition of New Zealand wetlands. Handbook designed for managers, landowners, community groups and anyone else with a need to monitor the condition of wetlands. The handbook covers: • The approach and process involved in developing the indicators • A detailed description of each indicator and how to assign a value and tally scores to analyse the results • How the indicators can be used to answer a range of monitoring questions • How the science-based indicators relate to the other objectives and products of the Co-ordinated Monitoring of New Zealand Wetlands Project	National	All estuarine and palustrine wetlands	Change in hydrological integrity • Impact of manmade structures • Water table depth • Dryland plant invasion Change in physico-chemical parameters • Fire damage • Degree of sedimentation/erosion • Nutrient levels • von Post index Change in Ecosystem intactness • Loss in area of original wetland • Connectivity barriers Change in browsing, predation and harvesting regimes • Damage by domestic or feral animals • Introduced predator impacts on wildlife • Harvesting levels Change in dominance of native plants • Introduced plant canopy cover • Introduced plant understorey cover	Handbook produced: Clarkson *et al.* (2003)
United States Environmental Monitoring and Assessment Program (EMAP). A research program to develop tools to monitor and assess status and trends of national ecological resources. EMAP's goal is to develop the scientific understanding for translating environmental monitoring data from multiple spatial and temporal scales into assessments of current ecological condition and forecasts of future risks to our natural resources.	State and Tribe level	Wetland scale	Indices have been developed and/or recommended for the following biotic groups: • Vegetation (United States Environmental Protection Agency 2002b) • Invertebrates (United States Environmental Protection Agency 2002c) • algae (United States Environmental Protection Agency 2002d) • amphibians (United States Environmental Protection Agency 2002e) • birds (United States Environmental Protection Agency 2002f)	Reports have been produced making recommendations to the use of indicators for each assemblage.

Table 3.1 Continued**.**

Key Agency/ Key Researcher	Scale of Project Country/region/single wetland	Resolution of assessment	Indicators used	Outputs / Comments
USA (continued) Numerous rapid assessment procedures outlined in Bartoldus (1999) and Fennesy *et al*. (2004).	US States and regions.	Wetland scale	See Table 1 in main document.	
State programs				
NSW Integrated Monitoring of Environmental Flows (IMEF) program. IMEF is based on a series of scientific hypotheses about the expected outcomes or ecological benefits of various environmental flow rules for the Darling/Barwon systems. The original program was based on Spencer *et al*. (1998) and has been refined to include a broader set of indicators.	20 wetlands, approximately 12 assessed each year.	Wetland scale	The indicators will be used to assess the effectiveness of environmental performance of flow rules for regulated rivers and the Barwon Darling River. Indicators have been developed or are under development for the following biotic groups/attributes: Water quality, morphometry, inundation, vegetation, macroinvertebrates, amphibians, birds, fish.	Some methods manuals have been published (wetland morphometry, wetland inundation, wetland vegetation, waterbirds and water quality) others are in draft form (macroinvertebrates, fish and amphibians).
Department Natural Resources (formerly Department of Infrastructure Planning and Natural Resources) Regional pilot stud	Coastal floodplain and tablelands	Wetlands scale	Based on Spencer *et al* (1998) with recommendations on refinement.	Trial to assess applicability of index in other regions in NSW with aim of developing a statewide system.
Western Australia The Department of Environment and Conservation monitors 25 wheat belt wetlands for biodiversity and 100 for depth and some aspects of water quality (Butcher unpublished).	25 wheat belt wetlands for biodiversity and 100 for depth and some aspects of water quality.	Wetland scale	Waterbirds, vegetation Condition, groundwater and invertebrate monitoring.	This program focuses on measures of biodiversity rather than health, acknowledging the difficulty in defining health with such a diverse range of wetland types in WA (S. Halse, CALM, pers. comm., 2002 cited in Butcher unpublished)
Regional programs				
Corangamite CMA Review and recommendations for wetland assessment in the Corangamite CMA undertaken by Harding (2002).	CMA Region	All wetland types within Corangamite region	To be developed.	Wetlands GIS database.
Goulburn Broken CMA	CMA Region	All wetlands	N/A	No wetland condition assessment methods and/or indicators have been developed.
Glenelg Hopkins CMA	CMA Region	All wetlands	N/A	Lyon *et al*. (2002) developed a wetland prioritisation framework that included some wetland assessment. This is being reviewed by the CMA (Lyon, DSE, pers. comm.)
Wimmera CMA A rapid assessment method to provide a broad rating of wetland condition (good moderate and poor). Threats and risks were considered in the method (Wimmera CMA unpublished).	Millicent Coast Basin and Douglas Depression within the CMA boundary.	All wetlands	Many indicators trialled in pilot study. The following indicators were short-listed and tested in the final trial: • Hydrological integrity • Geomorphological integrity • Water quality • Riparian and wetland vegetation • Surrounding landuse	See Wimmera CMA (unpublished) for more information on this method.
Gippsland Lakes A review was completed by Ecos Consulting (unpublished), recommending birds and vegetation be used as indicators of wetland condition for the Gippsland Lakes. These indicators have been refined and applied to wetlands around the Gippsland Lakes by DSE (Bairnsdale).	Gippsland Lakes, Victoria	Wetland scale	To be selected from a sub-set of vegetation and bird indicators. **Vegetation**: • Wetland-zonation • Species richness • Number of Flora and Fauna Guarantee species, rare or threatened species • Health of overstorey • Number and dominance of invasive species • Vegetation that is dominated by one species • Density of vegetation **Birds**: • Diversity of feeding groups • Species diversity within species-rich feeding groups • Percent of species that are (or potentially) long-distance migrants • Cumulative frequency of occurrence of FFG, rare or threatened species • Percent of the expected species based on geographic range, wetland type, vegetated area and other variables • Proportional abundance (%) of introduced species	
River Murray Catchment Board Method developed to assess wetland condition.	Murray River wetlands within the River Murray Catchment Water Management Board	All wetlands	• Indicators comprised of habitats essential to the specific wetland type character and function. • Indicators comprised of characteristic species and processes and species and processes indicative of low disturbance and exceptional diversity.	For more information see River Murray Catchment Water Management Board (unpublished).

Table 3.1 Continued**.**

Key Agency/ Key Researcher	Scale of Project Country/region/single wetland	Resolution of assessment	Indicators used	Outputs / Comments
Murray Darling Basin Spencer *et al.* (1998) developed indicators for four wetland attributes: soils, fringing vegetation, aquatic vegetation and water. Thirteen indicators were selected based on published information 32 and the authors' experience. Two independent teams tested the index on 10 floodplain wetlands with reasonably consistent scores (Butcher unpublished).	Murray-Darling Basin	Wetland scale	• soils – bank stability, pugging by livestock, soil organic content • fringing vegetation – width, continuity, height diversity • aquatic vegetation – cover, spatial heterogeneity, attached algae • water quality – turbidity, conductivity, colour, algal bloom frequency	The wetland index described by Spencer *et al.,* (1998) may be appropriate only for permanent floodplain wetlands, further work developing a wetland condition index is required (Butcher unpublished).
Murray Darling Basin Commission: Recommended Methods for Monitoring Floodplains and Wetlands (Baldwin *et al.* 2005)	Murray River floodplain wetlands particularly Icon Sites	Wetland scale	Methods for monitoring surface water, groundwater, soil and sediment, phytoplankton, floodplain and wetland vegetation, macroinvertebrates, fish, frogs and birds.	Standard methods for biotic groups but not an index as such. See Baldwin *et al.* (2005)
Southwest Western Australia *Swan Coastal Plain, Western Australia* Swan Wetlands Aquatic Macroinvertebrate Pollution Score (SWAMPS). Purpose: Method to assist in the assessment of wetland condition of wetlands on the Swan Coastal Plain, Western Australia.	Wetlands on the Swan Coastal Plain	Wetland scale	• Biotic index based on macroinvertebrate data. • Macroinvertebrate taxa assigned numerical grades to reflect sensitivity to anthropogenic disturbance (primarily nutrient enrichment). • Family and species level grades and scores developed.	See Chessman *et al.* (2002).
Swan Coastal Plain, Western Australia Australian Wetlands Assessment and Monitoring Program (AUSWAMP). Purpose: Method to assist in the assessment of wetland condition of wetlands on the Swan Coastal Plain, Western Australia.	Wetlands on the Swan Coastal Plain	Wetland scale	• Model based on the Australian River Assessment System (AUSRIVAS). • Model developed using macroinvertebrate data from wetlands on the Swan Coastal Plain.	See Davis et al. (1999).
North coast New South Wales WetlandCare Australia Wetland Assessment Technique (WetlandCare Australia unpublished).	Open freshwater, paperbark and estuarine wetlands in north coastal NSW	Wetland scale	• Five sub indices applicable to all wetlands: connectivity, human disturbance, acid-sulfate soils, vegetation and habitat. • Additional sub-indices for the different wetland types with specific measures within each sub index (see Table 4).	See WetlandCare Australia (unpublished)
Individual wetlands				
Dowds Morass, Victoria Monash University/Victoria University (spring 2003)	Single wetland (coastal Melaleuca)	*Melaleuca* wetlands Dowd Morass, Victoria	Vegetation indicators of swamp paperbark • overstorey cover • understorey cover • number of plant species • visually estimated index of health • measures of Melaleuca recruitment	Guidelines for rehabilitation of Melaleuca swamps/wetlands
Macleods Morass, Victoria A monitoring program is being developed by East Gippsland Water for this wetland.	Single wetland			