4

Monitoring Wetlands

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Wetland biological assessment: field techniques and data interpretation

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Abstract

Biological assessment supports wetland management by revealing pressures and threats that limit biodiversity and ecosystem services or place them at risk. It can also provide feedback on the effectiveness of management interventions in sustaining or restoring wetland values. I outline field survey techniques and associated procedures of sample processing and data interpretation for seven groups of organisms that are often considered in wetland assessment and management in Australia and elsewhere: algae and cyanobacteria, water plants, aquatic invertebrates, fish, amphibians, freshwater turtles and birds. Although survey and sampling techniques are well developed for all of these biological groups, much remains to be done to develop methods for interpreting survey data that can be routinely applied to Australian urban wetlands.

Introduction

Biological assessment (bioassessment for short) makes two essential contributions to effective wetland management. First, bioassessment can help to evaluate the present condition of a wetland, and indicate the pressures and threats that may be constraining or jeopardising its ability to support biodiversity and ecosystem services. Second, bioassessment provides vital feedback on the outcomes of management interventions that are intended to sustain or improve wetland values.

While assessment of the physical and chemical properties of a wetland provides important information, it is not sufficient on its own for effective wetland management. Physical and chemical attributes of wetlands often vary greatly over time – between periods of drought and flooding, with the seasons, and even through the course of a single day. This presents great challenges for physical and chemical monitoring to be frequent enough to capture all of these changes. In addition, many wetland values depend directly on the biological community of the wetland, yet our ability to predict the structure, composition and functions of the biological community from physical and chemical monitoring data remains severely limited.

Many types of animals, plants and micro-organisms inhabit wetlands, and they all play a role in the processes of the wetland ecosystem. In this article I discuss field techniques for seven groups that have often been assessed in Australian wetlands – algae and cyanobacteria (the so-called “blue-green algae”), water plants, invertebrates, amphibians, fish, freshwater turtles and birds. I also provide comments on sample processing and data interpretation. My emphasis is on procedures for freshwater wetlands and methods may vary for saline wetlands in coastal and estuarine areas. I also do not delve into methods for measuring biologically mediated ecological processes, such as primary production and litter decomposition, which are sometimes included under the heading of bioassessment.

There is a vast array of techniques and associated technical literature on wetland bioassessment and it is not possible to list and describe all available methods in this short article. The procedures outlined below are generally ones that are popular in Australia. Rader *et al.* (2001) and Baldwin *et al.* (2005) provide in-depth reviews of monitoring and assessment methods for wetland biota from North American and Australian perspectives respectively. The United States Environmental Protection Agency has also produced a series of manuals on evaluation of wetland condition by biological and other means (available at water.epa.gov/type/wetlands/methods_index.cfm).

Throughout Australia, most forms of biological sampling and observation require permits from the relevant state and territory fisheries and wildlife agencies. These departments often publish manuals of acceptable procedures to assist with licence applications.

Algae and cyanobacteria

Phytoplankton

Microscopic algae and cyanobacteria in the water column of a wetland (phytoplankton) can be sampled by taking water samples in sampling bottles and preserving them by adding Lugol’s iodine solution. In the laboratory, the samples can be concentrated by allowing the preserved algae to settle and siphoning off the excess water. The remaining concentrated algae can then be placed in a counting chamber for identification and enumeration under a compound microscope. Unpreserved water samples can also be filtered and the filters frozen for laboratory determination of concentrations of chlorophyll and other pigments by spectrophotometry. Fluorimeters can also be used to measure chlorophyll concentrations in situ.

Because planktonic algae often occur in layers in the water column, a depth-integrated sample may be more representative than a grab sample from a single depth. An easy way to obtain an integrated sample is to lower a long plastic tube held vertically with a weight on the bottom end. Once the top of the tube reaches the water surface it is sealed with an airtight cork, and the tube is pulled upward by a cord attached to its lower end.

Hötzel and Croome (1999) provide detailed instructions for sampling phytoplankton from Australian fresh waters.

Benthic diatoms

Diverse assemblages of diatoms occur in association with other organisms on sediments and hard surfaces in wetlands. They can be sampled from rocks, wood or the stems of water plants by taking scrapings with a toothbrush, knife or sharpened ice-cream stick. Care should be taken to scrape firmly so that closely adhering (“adnate”) species are not missed. The sampling can be quantified by placing a plastic mask over the substratum and scraping only the area so delineated. The scraped algae can be rinsed into a bowl with a wash bottle of distilled water. Diatoms can also be sampled from the upper surface of sediments by placing one's thumb over the end of a pipette, lowering the other end to the sediment surface, and gradually drawing the pipette across the sediment while releasing the thumb.

Diatom samples can be preserved with Lugol's iodine or ethanol. In the laboratory, samples are usually digested with oxidising agents to remove the organic cell content. Sub-samples of the remaining frustules (shells) are placed on slides in a mounting medium for examination and counting under compound microscopes. Because diatoms are microscopic, samples are easily contaminated and it is important to ensure that all sampling and sample-processing gear is thoroughly cleaned.

Water plants (or macrophytes)

Photo point monitoring

The use of photo points is a simple technique for obtaining a visual record of changes in wetland vegetation over time. Fixed points are established with the aid of geographic positioning systems and markers, and photographs with the same field of view are obtained at suitable intervals. Michel *et al*. (2010) provide information on techniques for analysis of photo-point images.

Quadrat surveys

Surveys with quadrats (square frames) are the usual way to obtain more detailed and quantitative observations and measurements of wetland vegetation than photo points can provide. Quadrats may be placed within a wetland in various ways, for example randomly within each vegetation or habitat type that is present or at intervals along fixed survey lines (transects). The cover of each species within each quadrat is estimated visually with a rating system such as the Braun-Blanquet scale (Braun-Blanquet 1932). More quantitative information can be obtained by harvesting all of the macrophytes within each quadrat, separating the species, and drying and weighing them.

Line intercept surveys

An alternative survey technique to the use of quadrats is the line intercept method whereby transect lines are established and the species that intersect each line are recorded at regular intervals. This approach has the advantage that it avoids the need to make visual estimates of percentage cover, which can be inaccurate (Brady *et al.* 1995).

Seedbank surveys

If wetlands are dry at the time of sampling, sediment samples can be obtained and re-wetted and incubated in a laboratory or greenhouse to allow seeds to germinate. This approach can estimate the potential for vegetation to recover upon re-wetting. Brock *et al.* (1994) provide detailed guidelines for seedbank studies.

Remote sensing techniques

Developments in the acquisition and analysis of information obtained by satellites are creating novel opportunities to remotely monitor some aspects of wetland vegetation. For example, satellite imagery of wetlands can be used to map vegetation types (e.g. Jenkins and Frazier 2010) or calculate the Normalized Difference Vegetation Index, which indicates the degree of vigour with which vegetation is growing (e.g. Akumu *et al*. 2010).

Invertebrates

Plankton net sampling for microinvertebrates

Planktonic invertebrates (zooplankton) can be sampled quantitatively by pouring or pumping large, measured volumes of wetland water through a plankton net. Mesh sizes for zooplankton nets are typically around 40-50 µm but coarser mesh (e.g. 150 µm) may be used if only larger species such as crustaceans are of interest, rather than smaller organisms such as rotifers and protozoans.

Alternatively, a plankton trap (e.g. a Schindler-Patalas trap) can be used, which is an open box that can be lowered to a suitable depth and then triggered to close. The enclosed water is then filtered through mesh to concentrate the captured zooplankton into a collecting jar. Zooplankton nets can also be towed vertically, horizontally or obliquely through the water for more comprehensive but less quantitative sampling.

Formaldehyde solution is often recommended for preserving zooplankton samples prior to identification in the laboratory. However, it requires careful handling and safety procedures because it is a human carcinogen. Accordingly, 70-90% aqueous ethanol, which is a somewhat less effective but safer preservative, is often used instead.

Pond-net sampling for macroinvertebrates

Hand-held pond nets around 200-300 mm wide with mesh size of 500-1000 µm can be used to obtain semi-quantitative samples of the larger macroinvertebrates (those that can be seen with the naked eye). Sometimes these nets are used with finer mesh apertures (around 100 µm) to obtain microinvertebrates as well. Samples can be standardised by sweeping for a set period of time or over a set distance. Because invertebrate species are often associated with particular habitats (such as open water, sediments, leaf litter, logs and water plants), it is important to record and if possible standardize the habitat(s) from which samples are taken. Samples can be preserved in 70-90% aqueous ethanol for identification under microscopes in the laboratory. Washing samples through a series of nested sieves with progressively finer mesh makes it easier to pick macroinvertebrates from associated detritus, by removing fine sediment and partitioning collected material into size fractions. However, long storage and vigorous processing of ethanol-preserved samples can destroy soft-bodied animals such as worms. If the number of invertebrate specimens collected is excessive, sub-sampling methods can be employed (King and Richardson 2002).

Quantitative sampling methods for macroinvertebrates

In some cases, fully quantitative samples are required (i.e. samples that allow the calculation of the density of macroinvertebrates per square metre of wetland). One way to achieve this is to insert a section of plastic pipe into the wetland sediment so that a seal is formed, but with the top of the pipe above the water surface. The water and associated invertebrates within the pipe can then be pumped or bailed out, but care must be taken to recover invertebrates that may have burrowed into the sediment. In deeper water, various kinds of grab samplers and corers can be used to take a sample of the wetland sediment and associated macroinvertebrates. A limitation of such methods is that some fast-swimming invertebrates can be adept at avoiding the sampling gear (Cheal *et al.* 1993). These methods can also be difficult or impossible to use in dense beds of water plants, which are a key habitat for many wetland invertebrate species.

Egg-bank surveys

As for plants, sediment samples can be taken from dry wetlands and re-wetted to assess the emergence of invertebrates from desiccation-resistant eggs and hence the biological potential of the wetland (Angeler and Garcia 2005).

Fish

Sampling methods

A wide range of methods can be used to sample wetland fish, depending on the nature of the habitat and whether large fish, small fish or fish larvae are to be targeted. A range of gear is often used to obtain a more comprehensive and less biased sample than is possible with individual gear types. Common methods include the following:

- Seine nets: long rectangular nets with a row of floats on the top and weights on the bottom. They are dragged through the water to encircle fish and scoop them into a holding bag in the middle of the net.
- Gill nets: similar to seine nets but with a type of mesh that ensnares fish. They are not dragged through the water but set in place to trap fish attempting to swim through the net. Multi-panel gill nets have sections with different mesh sizes to target particular species and size classes of fish.
- Fyke nets: large cylindrical nets that are fixed in pace by tethering them to stakes. They have a series of funnels that allow fish to enter the net and proceed to a holding chamber, but make it difficult for the fish to back-track and escape the net, plus one or two long netting wings, similar to a seine net, that lead fish into the first funnel.
- Drum nets: large cylindrical nets with a funnel in each end that are set in place on the bed of the wetland. A bait may be used to attract fish into the net.
- Minnow traps: small netting traps with a funnel in each end, such as are used by anglers to obtain bait. They are suitable for catching small-bodied fish and may be set unbaited, baited with food, or with a chemical light stick inserted to attract fish.
- Quatrefoil light traps (Floyd *et al.* 1984): another type of trap for small-bodied fish that uses a chemical light stick as an attractant.
- Cast nets: circular nets with a row of weights distributed around the edge. The net is thrown so that it spreads out over the water and sinks to the bottom, whereupon it is drawn to shore by a rope to retrieve the captured fish.
- Pop nets (Mazumder *et al.* 2005): basket-shaped nets that are set collapsed on the bed of a wetland and then triggered so that the sides of the net rise to the water surface.

- Small trawl nets (similar to zooplankton nets): these can be used to collect fish larvae and buoyant eggs.
- Electrofishing: the use of an electrical current passed through the water to temporarily stun fish so that they can be scooped up with a hand-net, which is either attached to the anode of the electrofisher or separate. The unit that generates the current can be placed in a boat, on the shore, or in a backpack so that the operator can carry it around the wetland. The use of electrofishing is confined to relatively fresh waters because of the effect of salt on electrical conductivity. Electrofishing is potentially hazardous to practitioners and an Australian code of practice has been developed to reduce risks.

Captured adult fish are usually placed in a bucket or bin of water before being identified, measured, weighed and released. Larvae and eggs are normally preserved to enable identification under microscopes in the laboratory.

It is important to recognise that fish nets can easily catch and drown air-breathing aquatic animals such as turtles, water birds, platypus and native water rats. Precautions should be taken to minimise this risk such as checking nets frequently and keeping part of the net above the water surface.

Amphibians

Survey methods

Wetland surveys for frogs and toads are usually done by walking at night along set transects (e.g. around the perimeter of a wetland or across the wetland if it is shallow) and detecting amphibians with a spotlight or by listening for calls. Surveys may be standardised by distance travelled or time expended. It is important to recognise that the activity of each species varies greatly with the time of year and with weather conditions, usually being greatest after rain and on warm, still nights in the breeding season. Daytime surveys can be useful to look for diurnally active frogs such as basking species. Frogs can also be located by gently turning over logs, rocks and other forms of cover near to the water. However, the potential for this to have adverse effects on the frogs by altering their habitat, disturbing dormancy and exposing them to predators should be carefully considered.

Sound recorders can be installed in a wetland as a means of detecting calling male frogs without frequent visits to the site (e.g. Lane and Burgin 2008). Some recorders can be programmed to switch on and off at specific times and for specific intervals. The species calling and in some cases the number of individuals can be determined by listening to the recordings or by the use of sound analysis software.

Drift fences and pitfall traps are another means of collecting ground-dwelling frogs while they are on land. However, this method has been found less effective than nocturnal searches and automatic recording (Parris *et al*. 1999).

Tadpole surveys can be conducted with pond nets similar to those used to collect macroinvertebrates. These surveys can be standardised by sweeping the net at a defined number of points and for a defined period of time at each point. Various types of funnel traps, similar to those used for fish sampling, can also be employed to catch tadpoles. Searches can also be used to locate egg masses, particularly among living and dead vegetation.

Infection with chytrid fungus, a frog pathogen introduced to Australia and other parts of the world, has been implicated in declines and extinctions of some frog species. Protocols are available to minimise the risk that people conducting frog surveys will increase the transmission of this fungus (e.g. DECC 2008).

Turtles

Survey methods

Freshwater turtles can be captured with the seine, gill, fyke and drum nets that are used to catch freshwater fish. Submerged nets need to be checked frequently to prevent drowning. So-called ‘cathedral’ nets are a recent invention specifically for catching freshwater turtles. These vertical, cylindrical nets have a lower section with funnel entrances and a holder for bait for attracting the turtles, plus an upper section that is held at the water surface by floats, allowing captured turtles to breathe. These nets have the advantage that if properly set they can be left overnight without the risk of drowning.

Birds

Survey methods

For large wetlands, surveys from aircraft are a cost-effective means of monitoring populations of the more conspicuous bird species (Kingsford and Porter 2009). More localised, ground-based surveys of wetland birds typically involve counts made by observers with binoculars walking or boating over standard transects. Alternatively, counts may be made at a set of fixed points with all birds observed within a certain radius and during a certain period of time recorded. The effects of time of day and weather on bird activity need to be considered.

Interpretation of bioassessment data

Biological data arising from field surveys typically comprise lists of species or higher taxa and observations of their abundances or occurrences at survey sites. Such data are of great interest to aquatic biologists and ecologists but must be summarised and interpreted if they are to be useful for supporting wetland management. In this section I outline several approaches to interpretation of wetland bioassessment data, and illustrate them with examples of application to Australian wetlands.

Bioassessment indices

In Europe and the United States, numerous indices have been developed for summarising and interpreting data from wetland bioassessment surveys. These often take the form of 'indices of biotic integrity' (IBIs), also known as 'multimetric indices' (MMIs) (Ruaro and Gubiani 2013). These indices are created by converting survey data for a particular biological assemblage into numerous summary metrics that may express various aspects of assemblage structure (e.g. species richness and dominance), assemblage composition (e.g. absolute or relative richness or abundance of particular taxonomic or functional groups), and organism health (e.g. prevalence of disease symptoms). Those metrics that appear to respond strongly and predictably to human disturbance rather than to natural environmental gradients are standardised and summed to create a composite IBI. Thus IBIs can indicate the overall level of exposure of a wetland to human disturbance. One advantage of IBIs is that different biological assemblages may provide quite similar estimates of the level of disturbance when this approach is used, so that monitoring of multiple assemblages may not be necessary (Wilson and Bayley 2012).

Despite its growing popularity elsewhere, there has been little uptake of the IBI approach for Australian wetlands. Ling and Jacobs (2011) tested a modified Hawkesbury-Nepean Wetland Assessment (HNWA) index that has some of the attributes of an IBI. This index combines scores based on the proportions of richness and cover represented by native plant species, introduced species or minor weeds, and noxious species or major weeds. Overall index scores did not significantly correspond with a predefined classification of wetland disturbance by human activities, but rather varied among wetlands within each disturbance level.

Many other types of indices have been developed for wetland bioassessment in the Northern Hemisphere. Some of these are intended to be diagnostic in that they summarise assemblage composition according to the representation of taxa that are sensitive or tolerant to particular environmental stressors. For example, Sager and Lachavanne (2009) developed a macrophyte-based index to assess the nutrient status of Swiss ponds. This approach has seen some adoption in Australia – for instance Chessman *et al.* (2002) developed the SWAMPS (Swan Wetlands Aquatic Macroinvertebrate Pollution Sensitivity) index as an indicator of human disturbance, especially nutrient enrichment, of wetlands in the vicinity of Perth, Western Australia. This index was validated with independent data for this region, but its applicability to other parts of Australia has not been adequately assessed. Robson and Clay (2005) applied the family-level version of SWAMPS to wetlands in western Victoria, and Ling and Jacobs (2003) did the same for the Sydney region, but neither study tested the relationship of index values to water chemistry.

Significant work has been done in Australia to develop composite indices that combine bioassessment data with other information. Spencer *et al.* (1998) developed a rapid appraisal condition index based on scoring of various aspects of wetland water quality, soil, and fringing and aquatic vegetation, which they applied to permanent floodplain wetlands in the Murray-Darling Basin. Kessler (2006) created a somewhat similar index for application to urban saltmarshes in the Sydney region, incorporating scores for elements of morphology, hydraulics, human disturbance, invertebrate populations and vegetation. DSE (2005) developed the multi-attribute Index of Wetland Condition (IWC) for assessment of wetlands in the State of Victoria. This index combines scores for aspects of surrounding land use and buffer zones, wetland area and morphological alteration, hydrological modification, water chemistry (nutrients and salinity), soil physical properties and vegetation.

Although these multi-attribute indices can be easy to use, little information has been published on how they respond to specific anthropogenic pressures or management interventions, or how well they predict overall wetland biodiversity or ecosystem services. Jansen and Healy (2003) showed that wetlands with higher scores of Spencer *et al.*'s (1998) index had richer communities of frogs and tadpoles, but Suren *et al.* (2011) found that scores of a multi-attribute index of wetland condition used in New Zealand were only weakly related to diatom and macroinvertebrate assemblages.

Trait analysis

Increasing knowledge of the environmental preference and tolerance traits of Australian wetland species greatly aids data interpretation and could facilitate the development of further indices for local application. For example, the classification

Case Study: Wetlands on the Swan Coastal Plain

Before European settlement began in 1829, the Swan Coastal Plain (SCP) in the south-west of Western Australia abounded in freshwater wetlands. An estimated 70% of the original wetlands were drained and filled for agricultural and urban development, and by the 1990s many of those that remained were degraded by excessive nutrient inputs, salinization, contamination with pesticides and metals, alien species invasions, removal of fringing vegetation, groundwater pumping and wastewater disposal (Davis and Froend 1999). More recently, drying of the regional climate has emerged as an additional threat to SCP wetlands, through lowering of the groundwater table (Sim *et al.* 2013).

Biological assessment and monitoring have played an important role in determining the condition and management needs of SCP wetlands, including many urban wetlands in the city of Perth and its surrounding metropolitan area. Initial biological surveys compared the performance of different sampling methods for macroinvertebrates (Cheal *et al.* 1993) and showed how zooplankton and macroinvertebrate assemblages varied among wetlands in accordance with water chemistry, especially nutrient levels (Growns *et al.* 1992; Balla and Davis 1995). By the late 1990s, scientific understanding of the hydrology and ecology of SCP wetlands were sufficient to determine the main management requirements for wetland conservation and restoration (Davis and Froend 1999). Under the climatic drying of the 2000s, acidification emerged as an additional problem when declining wetland water levels exposed pyritic sediments to atmospheric oxidation (Sommer and Horwitz 2001). Monitoring of macroinvertebrates indicated that impacts of acidification could be reversed by artificial augmentation of water levels (Sommer and Horwitz 2009).

In the early 2000s, efforts were made to modify methods used to interpret macroinvertebrate monitoring data from Australian rivers, so that the methods could be applied to SCP wetlands. The Australian River Assessment Scheme (AUSRIVAS) was adapted to create an index comparing the observed and expected fauna of a wetland, but this index proved to be correlated with water depth and pH rather than the environmental factors of most concern such as nutrient enrichment (Davis *et al.* 2006). However a biotic index named SWAMPS (Swan Wetlands Aquatic Macroinvertebrate Pollution Score), modelled on the SIGNAL river index, proved to be strongly correlated with nutrient status as well several independent measures of human alteration of the wetland environment (Chessman *et al.* 2002; Davis *et al.* 2006). This index can be calculated at coarse taxonomic levels, making it amenable to monitoring by community groups.

Diatoms have also been used in wetland assessment and monitoring on the SCP and elsewhere in the south-west of Western Australia, with the composition of diatom assemblages related to environmental variables such as pH (Thomas and John 2010). The development of transfer functions permits the estimation of environmental variables such as salinity from the composition of diatom assemblages, an approach that can place current water chemistry in a long-term context through analysis of wetland sediment cores (Taukulis and John 2009).

of wetland plant species into functional groups according to their requirements for and tolerances of flooding and drying (Casanova 2011) is likely to be especially useful where management of water regimes is of concern. The relative richness and abundance of each functional group can indicate the long-term water regime of a wetland, and monitoring of changes in functional groups can link plant assemblage responses to hydrological management (e.g. Alexander *et al.* 2008).

Knowledge of the sensitivities of Australian wetland invertebrate species to specific environmental contaminants such as trace metals may enable these species to be used as indicators of sediment pollution in urban wetlands (Carew *et al.* 2007). The assignment of invertebrate species to groups based on traits such as dispersal mode and resistance to drying is also likely to be useful. For example, Sim *et al.* (2013) used this approach to assess responses of macroinvertebrate assemblages to climatic drying in Western Australia.

Comparisons with reference wetlands

In some cases in may be possible to identify suitable reference wetlands. These can provide a benchmark for comparing values of summary variables (e.g. biological index values, species richness, total abundance or abundance of species of particular interest) obtained in wetlands where an adverse impact is suspected. Reference wetlands can also be used to describe the target state for wetlands where management intervention is proposed to improve biodiversity or ecosystem services. Appropriate reference wetlands are often those having a catchment or surrounds with little development or other human activity. For example, Lane and Burgin (2008) compared frog assemblages between sites in urban areas of the Blue Mountains (NSW) and sites with fully forested catchments in the nearby Blue Mountains National Park. Unexpectedly, they found frog abundance and diversity to be higher at the urban sites, and suggested that chemicals in urban wastewaters might afford frogs some protection from chytrid fungus.

When making comparisons with reference wetlands it is important to take account of possible natural differences. For example, natural variation in hydroperiod (the proportion of time during which a wetland contains water) has a profound effect on the biological communities that a wetland contains. Other naturally varying factors such as temperature regime (related to elevation above sea level) and pH (which depends on geology and soil type as well as human influences) can also have a strong influence. For bioassessment of rivers and streams, predictive models are often used to combine information from a number of reference sites in order to generate site-specific reference data. This approach may have application to wetlands as well (Davis *et al.* 2006).

In many urban areas it will not be possible to find reference wetlands that have catchments or surrounds with fully natural land cover. Even if such wetlands can be found, they may not represent a realistically achievable goal for wetlands that are to be rehabilitated. In such cases it may be possible to use wetlands that are considered to have good management practices as references. In other instances, no suitable reference wetland will be available and other means of comparison will be necessary.

Analysis of trends over time

In some cases it will be possible to compare survey data obtained before and after a wetland is exposed to a human disturbance (e.g. catchment development) or before and after a management intervention. However, it is important to consider whether the change observed might have been influenced by factors other than the disturbance or intervention of interest. For example, climatic conditions might have changed from dry to wet (or vice versa) between the “before” and “after” periods. For this reason, it is desirable to monitor not only the wetland of interest but also a “control” wetland (or preferably more than one) that is initially similar to the wetland of interest but not exposed to the disturbance or intervention of concern. For example, Holland *et al.* (2009) assessed the response of river red gums to artificial watering by measuring various tree properties before and after water application in an experimental wetland and in a control wetland where the water regime was not manipulated. However, as is the case with seeking reference wetlands, there are many cases where the wetland of interest is unique and no comparable “control” wetland can be found.

In wetlands that have existed for a long time, analysis of sediment cores can be a powerful way to place the present state of a wetland in a long-term context (Gell *et al.* 2013). Sediments at different depths in the core can be dated by isotopic analysis and examined for the presence of algae, pollen and invertebrate remains. These fossils can provide an indication of previous wetland states. For example, analysis of diatom remains in a sediment core from Lake Ainsworth on the New South Wales coast revealed a saline phase in the lake’s history and thereby helped to resolve differing opinions about whether the lake had always been fresh (Tibby *et al.* 2008).

Correlation of biological assemblages with stressor gradients

Finally, if multiple wetlands occur in the region of interest, variation in biological assemblages among wetlands can be related statistically to variation in environmental factors that can be altered by management actions. For instance, Parris (2006) used Bayesian Poisson regression modelling to relate urban frog assemblages to pond size, isolation and bank form in the Greater Melbourne area. Techniques of multivariate analysis such as ordination can be used to simultaneously relate multiple species to multiple environmental variables. For example, Rawson *et al.* (2010) used this type of analysis to relate macroinvertebrate assemblages to sediment chemistry of urban wetlands within Sydney Olympic Park.

A potential risk with basing management actions on correlative analyses is that a correlation does not necessarily signify a cause-and-effect relationship. For example, Havens (1999) found that the biomass of fish in Florida lakes was positively correlated with nutrient levels and the amount of algal growth, suggesting that lake fertilization would be an appropriate management approach if the aim were to increase the fish catch. However, lakes with a low abundance of fish were also more acidic, suggesting that physiological stress might instead be limiting fish production and that lake neutralization might therefore be a better management strategy. Improving understanding of mechanisms of cause and effect, for example through controlled experiments, can therefore be important to selecting the appropriate management response.

Conclusions

This brief overview illustrates the wide variety of biological assemblages that can be sampled to assess or monitor the condition and values of a wetland and its responses to management interventions, and the diversity of approaches that can be undertaken to interpret bioassessment data. For the most part, the latter are still at an early stage of development and testing in Australia, and substantial scientific advances in this field can be expected in the years to come. It is difficult to provide general advice on which methods to use because the appropriate choice will inevitably depend on the wetland values that are of most interest and concern to wetland managers and the wider community, the factors that are constraining or threatening those values, and the resources and skills that are available to undertake the assessment. These factors will vary greatly from one situation to another. Consequently, obtaining expert advice tailored to the circumstances at hand will generally be the safest approach.

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