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A review of wetland inventory and classification in Australia

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Abstract

Studies of wetlands in Australia, as in other countries, have taken a wide variety of approaches to defining, surveying and classifying these environments. Past and current approaches in Australia are reviewed for each of the States and Territories which provide the context for much of the natural resource investigation in the country. While there are obvious advantages of national, and perhaps international, agreement on definition and types of wetlands, a variety of approaches to inventory and classification will always be necessary for particular purposes. More fundamental than general agreement on approaches is the need for wetland scientists and managers to maximise the accuracy of survey information, to test the assumptions involved in the use of classifications, and to ensure that the classifications they use are the most appropriate for their purposes. The issue of a global wetland classification scheme is discussed on the basis of a representative range of views by Australian wetland workers.

Introduction

The processes of inventory and classification of wetlands influence our perceptions of an important natural resource. Methods for inventory determine the accuracy and precision of information on wetlands and its utility in all aspects of planning, management and conservation. The choice of how to group wetlands into types with some homogeneity of features important to particular tasks is also critical. The wrong choice will produce classes which are not informative about processes or the distribution, in time and space, of the features of interest.

Scientists and managers have for many years applied a wide variety of approaches to inventory and classification of wetlands. At least in Australia, and perhaps in other parts of the world, there has been little exchange of ideas on the appropriateness of particular approaches for particular purposes. Much of the Australian literature in this field has limited circulation and meetings of specialists to discuss techniques are uncommon. A review of past approaches and current thinking therefore has two advantages: it facilitates communication between individuals and groups; and it can identify problems to be addressed.

This review briefly describes the environmental and political setting of Australian wetlands and discusses the problems of defining wetlands and identifying their boundaries. The main review of activities is structured according to the separate States and Territories as these provide the political, administrative and geographical context for most surveys and classifications. This is followed by a section that attempts to synthesise the information from the review and finishes with a summary of Australian views on standardised global approaches.

The setting for Australian wetlands

Environmental overview

Much of the surface geology of Australia is ancient and many of the soils and landforms are millions of years old. The topography is, therefore, mainly subdued with a major system of highlands, the Great Dividing Range, close to the eastern seaboard and several range systems in the west (Fig. 1). Australia has been divided into twelve major drainage divisions (Fig. 2) comprising varying numbers of basins (Australian Water Resources Council 1976).

Australia spans 32 degrees of latitude and, although the range of climates is less than on other continents, there is still substantial variation in temperature and rainfall regimes (Linacre & Hobbs 1977). Most of the continent is arid or semi-arid. Median annual rainfall in Australia shows a concentric pattern with the highest falls around the coastal fringes (Fig. 3). Seasonality of rainfall varies strongly and is summarised for drainage divisions in Table 1. Rainfall variability in Australia is very high by world standards (Stafford Smith & Morton 1990) and is also distributed concentrically with highest values in the lowest rainfall regions (Paijmans *et al.* 1985). The trend in annual potential evaporation, too, is roughly the reverse of that for median rainfall. These patterns in rainfall and evaporation lead to large differences in average annual runoff between the twelve drainage divisions (Table 1) and a great diversity of water regimes in Australian wetlands, from permanent to seasonal at various times of year to irregularly filled at different average frequencies (Finlayson 1991).

The general aridity of the inland by no means indicates a lack of wetlands. The semi-arid areas that are penetrated by major rivers from the eastern highlands have long been recognised as containing extensive and biologically productive wetlands (Frith 1967). Evidence is also accumulating for the great extent and significance, on a world scale, of wetlands still further into the arid interior (Halse 1990; Kingsford *et al.* 1991; Kingsford & Porter 1993).

For many estuarine and nearshore marine wetlands, other factors are important in influencing their development and composition. Davies (1986) has suggested a broad categorisation of the Australian coastline into four segments – warm temperate humid, warm temperate arid, tropical arid and tropical humid. Within each segment there is a broad similarity of climate, wave energy, tidal regime, coastal landforms and biota. Around much of the coast there are micro- or meso-range tides, but in the north and north-west macrotidal ranges, up to 11 metres, prevail. The lateral extent of intertidal wetlands is therefore much greater in the tropics than on the temperate coasts.

Political divisions

The Commonwealth of Australia consists of six States – New South Wales, Queensland, South Australia, Tasmania, Victoria and Western Australia – and two mainland Territories – the Australian Capital Territory and Northern Territory (Fig. 2). Australia administers three subantarctic islands, Macquarie Island (politically part of Tasmania) and Heard and Macdonald Islands in the Indian Ocean as well as a number of subtropical and tropical islands and reefs. In addition, the Australian Antarctic Territory is one of the largest territorial claims on the Antarctic continent.

Most issues concerning the management and conservation of land or water resources are the responsibility of the separate States and Territories which vary considerably in their legislative and bureaucratic mechanisms for planning, conservation, land use control and resource management. The dispersion of involvement with wetlands is even greater when the particular concerns of agencies are considered. Barson & Williams (1991) identified 57 State or Territory agencies with responsibilities for wetlands, either because they have charters for management of natural resources or because their activities affect wetlands. As in other continents subdivided into states or nations, the Australian State and Territory borders have little to do with natural boundaries such as geological discontinuities, catchments or river systems. Many wetlands that have similar requirements for management and conservation are therefore placed under different administrations and covered by different approaches to inventory and classification.

The national government (the Commonwealth of Australia) does, however, play a role in wetland issues. Australia has entered into several international treaties and agreements dealing with environmental matters and, under the Constitution, takes on powers in respect of these. Examples are the Ramsar Convention and the Japan-Australia Migratory Bird Agreement. The Commonwealth also has a role in coordinating and promoting initiatives in surveys of natural resources as well as their management and conservation and is responsible for developing and maintaining major environmental data bases (see Michaelis & O'Brien 1988; Bridgewater 1991 for reviews).

Concerns about wetlands

European settlement of Australia was accompanied by massive loss and disturbance of natural habitats, including wetlands. Drainage and other modifications of wetlands on the coastal floodplains and other high-rainfall areas, where the bulk of the population has always been concentrated, proceeded rapidly from the

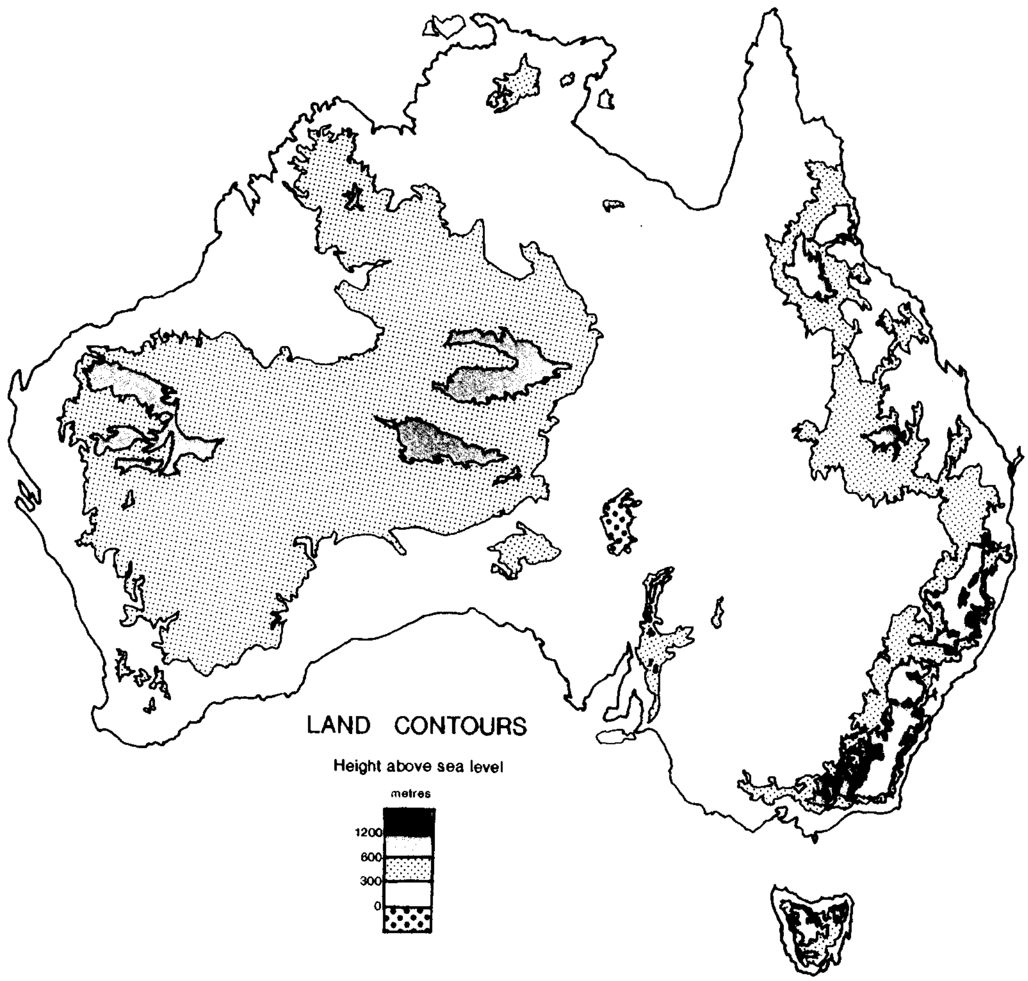

Fig. 1. Generalised relief map (from Department of Minerals and Energy 1973). This map has been derived from a Crown Copyright map and has been reproduced with the permission of the General Manager, Australian Surveying and Land Information Group, Department of Administrative Services, Canberra, ACT.

early years of settlement (Pressey & Middleton 1982; Middleton *et al.* 1985). Vast areas of wetlands were modified by domestic stock as pastoralism became the most widespread land use in the hinterland (Beadle 1948; Williams 1962; Wimbush & Costin 1979a, b). Soon afterwards, regulation of coastal and inland rivers changed the main channels and associated floodplain habitats both hydrologically and biologically (Walker 1985). Many other changes followed, including chemical pollution, burning, sedimentation, extraction of water, introduction and translocation of plants and animals, and recreation activities (see McComb & Lake 1988 for reviews).

By the late 1960s, the extent of wetland loss and damage had come to general notice, at least in the densely settled regions (Riggert 1966; Goodrick 1970). At about the same time, the importance of estuarine wetlands for maintaining fisheries was being promoted (Pollard 1976). Research on waterfowl in the Murray-Darling Basin led to the realisation that wetlands could be damaged indirectly by changing river regimes (Frith & Sawer 1974). Campaigns by non-government organisations and increasing concern in conservation agencies over loss and alteration of wetlands led to much activity in survey and classification in the late 1970s and 1980s (Fig. 4).

The increase in survey activities and classifications of wetlands has been accompanied by moves to protect wetlands from a variety of threatening processes. The conservation of wetlands by reservation and management of processes is now a major concern in Australia. As well as formal reservation, regulatory mecha-

Fig. 2. Borders of States and mainland Territories and boundaries of Australian drainage divisions as defined by the Australian Water Resources Council (1976). 1: North-East Coast Division (450 705 km^2, 46 river basins); 2: South-East Coast Division (273 553 km^2, 39 basins); 3: Tasmanian Division (68 200 km^2, 19 basins); 4: Murray-Darling Division (1 062 530 km^2, 26 basins); 5: South Australian Gulf Division (82 300 km^2, 13 basins); 6: South-West Coast Division (314 090 km^2, 19 basins); 7: Indian Ocean Division (518 570 km^2, 10 basins); 8: Timor Sea Division (547 050 km^2, 26 basins); 9: Gulf of Carpentaria Division (638 460 km^2, 28 basins); 10: Lake Eyre Division (1 170 000 km^2, 7 basins); 11: Bulloo-Bancannia Division (100 570 km^2, 2 basins); 12: Western Plateau Division (2 455 000 km^2, 9 basins). This map has been derived from a Crown Copyright map and has been reproduced with the permission of the General Manager, Australian Surveying and Land Information Group, Department of Administrative Services, Canberra, ACT.

nisms and management protocols are covering increasing numbers of sites. These include listing of wetlands under the Ramsar Convention and other international agreements (Bridgewater 1991; Australian Nature Conservation Agency 1993), environmental allocations of water by bodies such as the Murray-Darling Basin Commission (Close 1990; Murphy 1990), and water management trials along the Murray River in South Australia. Recent measures to regulate potentially damaging activities in wetlands include State Environmental Planning Policy (SEPP) 14 in coastal New South Wales and the Environmental Protection (Swan Coastal Plain Lakes) Policy in Western Australia.

What is a wetland and where are its edges?

Differences in definitions of the term 'wetland' are universal. Australia has no nationally agreed definition of wetland (Barson & Williams 1991) and, even within a single State on Territory, different agencies employ different definitions for their own purposes and legislation. This leads to inconsistencies in the scope of surveys and classifications and is a source of considerable confusion to the public.

Why define wetlands?

If management and conservation were applied equally to all components of the landscape, wetlands would not

Table 1. Rainfall seasonality and runoff in drainage divisions (data from Paijmans *et al.* 1985)

	Drainage division	Rainfall seasonality	Average depth of runoff/yr (mm)
1.	North-East Coast	VMS-MS	183
2.	South-East Coast	SUW	144
3.	Tasmania	UW	730
4.	Murray-Darling	ASUW	21
5.	South Australian Gulf	AW	12
6.	South-West Coast	VMW-MW	23
7.	Indian Ocean	A	8
8.	Timor Sea	VMS	136
9.	Gulf of Carpentaria	VMS	91
10.	Lake Eyre	AS	3
11.	Bulloo-Bancannia	AS	5
12.	Western Plateau	A	0

VMS - very marked summer rainfall
VMW - very marked winter rainfall
MS - marked summer rainfall
MW - marked winter rainfall
S - summer rainfall
U - uniform rainfall
W - winter rainfall
A - arid zone rainfall

have to be separated from the other components with which they interact physically, chemically and biologically. Moreover, the many habitats often grouped together as wetlands are not a natural, homogeneous group. Many have more in common with non-wetland habitats than with each other. However, because of the history of mismanagement of many wetland types, the distinctive characteristics and management needs of most types, the specific charters of some agencies dealing with fisheries and wildlife, and the great momentum of the wetland conservation lobby, wetlands are most often surveyed and classified in isolation. The problem of definition then arises.

The planning instruments that have been applied to wetlands need lines on maps or some consistent definitions. This can limit the interpretation of wetlands to areas that can be reliably distinguished from terrestrial habitats on aerial photographs (Winning 1991a; Adam 1992), perhaps leading to the disappearance of surrounding habitats with less legal standing, regardless of conservation significance or their interactions with the wetlands themselves. In some cases, as in the Environmental Protection (Swan Coastal Plain Lakes) Policy in Western Australia, the focus has narrowed to only a subset of areas that would typically be regarded as wetlands. Constraints on land use under such regulations mean that definitions have considerable economic and political significance, as in the United States (Bohlen 1991; Kusler 1992).

The recent emphasis on Total Catchment Management in Australia (e.g. Soil Conservation Service 1987) avoids treating wetlands in isolation. It can consider the conservation needs of other habitats and address external influences on the wetlands themselves.

Australian definitions of wetlands

'Wetlands are quirks and local aberrations of the hydrological cycle which differ from their surroundings by the persistent presence of free water' (Paijmans *et al.* 1985). These authors of the only Australian overview of wetland distribution define wetlands broadly as land permanently or temporarily under water or waterlogged, stipulating that temporary wetlands must have surface water or waterlogging of sufficient frequency and/or duration to affect the biota. They also note that inland basins that might only fill once in several decades should also be included because these areas support a distinctly aquatic biota at these times. Their

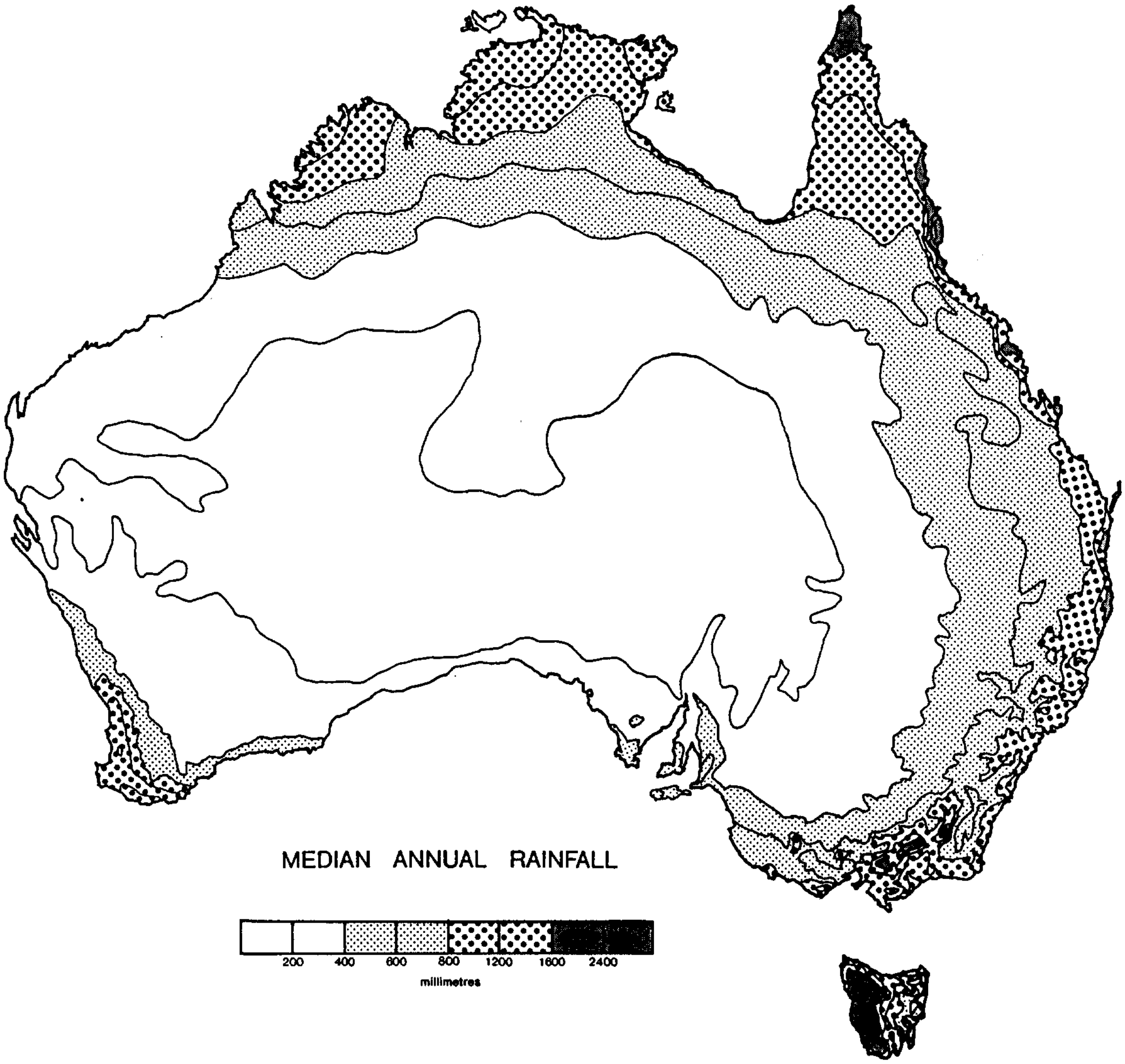

Fig. 3. Distribution of median annual rainfall (from Snowy Mountains Engineering Corporation 1983). This map has been derived from a Crown Copyright map and has been reproduced with the permission of the General Manager, Australian Surveying and Land Information Group, Department of Administrative Services, Canberra, ACT.

definition includes open and vegetated basins, floodplains, stream channels, tidal flats and coastal waterbodies. Many Australian surveys of wetlands have omitted flowing waters and free-draining floodplains although, in reality, there is a spectrum of hydrological and biological conditions between flowing and still water, and many important interconnections between stream channels, floodplains and associated basins (Bren & Gibbs 1986; Mitsch & Gosselink 1986; Boulton & Lloyd 1992). Otherwise, the definition of Paijmans *et al.* (1985) broadly matches most interpretations of wetlands adopted in Australian surveys. Even so, Australian definitions differ widely in detail.

Most Australian interpretations of wetland depart substantially from the much broader Ramsar defini-

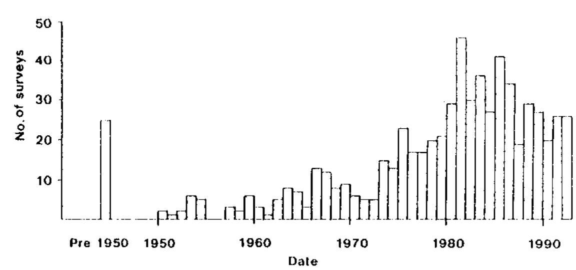

Fig. 4. Dates of completion or publication of wetland surveys and classifications in Australia.

tion (UNESCO 1971): 'areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed 6 m'. Many Australian wetland surveys have excluded artificial water bodies and most have restricted their coverage of marine areas only to the intertidal areas of soft sediments (Barson & Williams 1991; Pressey *et al.* in press). Coral reefs have seldom been regarded as wetlands in Australia and the six metre demarcation is problematical, not only for reefs but for seagrass beds which extend down to at least twenty metres depth in some areas (Coles *et al.* 1992).

Many delegates at a wetlands workshop in 1991 organised by the Bureau of Rural Resources opted to use the Ramsar definition because of its wide application overseas and for the sake of having a definition that could be promoted for consistent use. However, its general acceptance is still uncertain and a variety of definitions are still in use.

Wetland boundaries

The problem of delineating wetlands is partly solved by defining the types of environments to be considered but, even when a definition has been adopted for the purposes of survey, the edges of wetlands are not always easy to identify. This leads to problems of credibility and to uncertainties over ownership and the application of land use controls. Deciding on the exact extent of wetlands can also be expensive when consultants are needed to interpret definitions, as for Federal regulations in the United States (Kusler 1992).

The position of a wetland boundary can become crucially significant where legal instruments are applied. Knights (1991) considered that most of the existing wetland mapping in New South Wales was not precise enough to support legal protective mechanisms. For this type of regulation, a legal fiction is required – an immovable boundary sharply defined on paper and on the ground. In reality, wetlands and adjacent landward or seaward habitats are connected by a variety of processes, and wetland boundaries are often diffuse and fluctuate through time (Howard-Williams 1991; Winning 1991a). In many areas, short-term fluctuations in wetland boundaries could be insignificant compared to those that might result from climate change and rises in sea level (Bryant 1990; Burchmore 1990). While the importance of buffer zones around wetlands is often recognised, the functions and processes of wetland buffers are poorly understood, leading to arbitrary recommendations on their width and composition (Lane 1991).

Wetland inventory and classification in Australia

A review of Australian approaches to wetland inventory and classification is largely a review of activities in each separate State and Territory. Such a piecemeal approach does not give an overview of natural regions or particular management concerns (Bowman & Whitehead 1989), but the fact remains that the States and Territories are the framework within which inventory and classification of wetlands and other natural resources proceed. Some surveys and proposals for classification do transcend political borders, however, and these are reviewed in a separate section.

The review has a number of existing compilations to draw from, notably those of McComb and Lake (1988) and Donohue and Phillips (1991). The summaries below, as well as being based on many other reports and papers, also contain more recent information gathered in mid-1992. This was obtained by writing to some 68 wetland scientists and managers throughout Australia to ask for information on current activities and methods and for views on the feasibility and desirability of global standards for inventory and classification.

The summaries in the following sections refer only to some of the studies and findings on wetland inventory and classification in Australia. A much more comprehensive list of surveys and classifications is in a bibliography compiled as a basis for this paper (Pressey *et al.* in press). Terms used to describe the scale and detail of surveys follow those of Dent and Young (1981): reconnaissance – typically 1:250 000; broad ('semi-detailed') – 1:100 000 to 1:50 000, detailed – 1:25 000 to 1:10 000; and intensive – finer than 1:10 000. Wetland inventories or surveys are studies that have mapped and described the wetlands of an area, although not all have focused on wetlands specifically. Wetland classifications are any attempts, intuitive or numerical, to group wetlands with common characteristics or to identify the types of environments and biota they contain.

National or multi-State surveys and classifications

Several studies have produced overviews of the types of wetlands occurring throughout Australia. Those by Briggs (1981), Beadle (1981) and Brock (1994) are based on different definitions of vegetation types. Timms (1992a) has proposed a classification of lakes based on geomorphic origin, drawing mainly from examples in Australia. Limnological overviews are also emerging (De Deckker & Williams 1986 and references therein). In their review of wetlands in temperate Australia, Jacobs and Brock (1993) used a framework that was primarily geographical with subcategories based on geomorphology, vegetation and water regime. Paijmans *et al.* (1985) developed a classification that was designed to be interpreted from reconnaissance-scale topographic maps which they used to map the occurrence and density of wetlands across the country. This work followed an assessment of the feasibility of a more detailed national inventory (Paijmans 1978a). Another national perspective is the recent Directory of Important Wetlands in Australia (Australian Nature Conservation Agency 1993), a compilation of information and references on 520 wetlands or wetland complexes.

Some of the surveys and classifications concentrating on estuarine wetlands have transcended State and Territory boundaries. A national inventory of Australian estuaries and enclosed marine waters was completed in 1989 (Bucher & Saenger 1989, 1991), generating a data base on 783 estuaries and embayments and their catchments. Information from this data base and the coastal components of the survey of Paijmans *et al.* (1985) have been summarised by the Resource Assessment Commission (1993). Surveys and classifications of estuarine wetlands most often focus on the three main vegetation types: seagrass, mangrove and saltmarsh, although unvegetated, hypersaline flats are extensive in northern Australia (Bucher & Saenger 1991) and might be functionally important for nutrient cycling in coastal waters (Ridd *et al.* 1988).

Australia is a major centre of diversity for seagrasses. Most seagrass beds are dominated by a single species so the widely used informal classifications recognise dominants. Multi-State studies include those on distribution, habitats and species of seagrasses (Poiner *et al.* 1989; Shepherd & Robertson 1989; West *et al.* 1989), the dynamics and decline of seagrasses in a broad context (Clarke & Kirkman 1989; Shepherd *et al.* 1989), and faunal assemblages (Bell & Pollard 1989; Howard *et al.* 1989).

Australia is also a major centre of mangrove diversity with nearly 40 species. The area of mangroves exceeds 11 000 square kilometres, the majority in the tropics (Galloway 1982; Galloway *et al.* 1984). Distinctions between mangrove types include the phytosociological classification of Bridgewater (1985), the subdivision by Saenger *et al.* (1977) of mangrove coasts into biogeographic provinces and, like Love (1981), discussions of different zonation patterns. Galloway (1982) separated mangrove coasts into sections with relatively consistent geomorphological features.

Despite the popular perception that saltmarsh is the temperate replacement of mangrove vegetation, most of the Australian saltmarsh occurs in the tropics (Bucher & Saenger 1991). Bridgewater (1982) and Adam *et al.* (1988) have identified phytosociological types and Saenger *et al.* (1977) and Bridgewater (1982) have subdivided saltmarsh coasts biogeographically.

A few surveys of inland wetlands, aside from the national overviews, have also straddled State borders, including two studies of the Murray River system. The first of these (Pressey 1986) covered mainly floodplain basins and developed specific classifications of geomorphology and hydrology. The second concerned riparian vegetation (Margules & Partners and others 1990), using numerical classification of floristic site data and interpretation of aerial photographs for dominant species and structure.

In another multi-State survey, Paijmans (1978b) covered four extensive areas in New South Wales and Queensland, classifying wetlands broadly according to association with streams, tidal influence and physiography. Since 1983, there has been an annual aerial survey of waterbirds in eastern Australia that also provides data on the number and water area of wetlands (e.g. Kingsford *et al.* 1991). For the eastern coastline, Timms (1986) synthesised the limnological information available on dune lakes and distinguished six types based mainly on geomorphic position and hydrology. Ponder (1986) has compiled information on the mound springs of the Great Artesian Basin, covering parts of Queensland, New South Wales and South Australia, and reviewed variations in physical, chemical and biological features. Areas in both Victoria and New South Wales have been covered by Johnston and Barson (1993) in tests of the Landsat Thematic Mapper for identifying major wetland plant communities.

Antarctica and subantarctic islands

Antarctica is the driest continent, although its icemass contains some 70% of the world's fresh water. Most of its surface is ice-covered, but there are limited areas of exposed rock and ice-free ground (Walton 1984). One of these is the Vestfold Hills, site of the Australian Davis Station. Within this area of about 400 km^2 are a number of lakes, some fresh and others saline or hypersaline (Adamson & Pickard 1986).

The subantarctic islands are subject to cold, wet and windy climates. Macquarie and Macdonald Islands have no permanent snow cover whereas Heard Island, which rises to about 2750 m, has only about 15% snow-free ground (Walton 1984). The vascular flora of all the subantarctic islands is small (Wace 1960). The wetland vegetation of Macquarie Island includes a range of mires, drainage channels and lakes and is described by Selkirk *et al.* (1990). The less extensive area of wetland vegetation on Heard Island has been described by Hughes (1987).

Australian Capital Territory

Although the smallest of the States and Territories of the Australian land mass, the pattern of wetland surveys in the Australian Capital Territory is similar to most of the others – there has been no comprehensive survey of wetlands and the available information comes from a variety of studies that have addressed wetlands at different scales and for different purposes (Williams 1991). The major lentic wetlands in the region are the open waters and fringing shallows of the manmade urban lakes in Canberra and the subalpine and montane bogs and fens of the ranges. The urban wetlands are also being augmented by ongoing construction of ponds to trap sediments from eroding catchments.

Information is very incomplete on the higher altitude bogs and fens of the Territory and the neighbouring areas of New South Wales and Victoria so the ACT Parks and Wildlife Service has recently compiled a report on these habitats (Evans & Keenan 1992) as a basis for further documentation and survey.

New South Wales

The general types of wetlands in the State have been defined in several broad geographic subdivisions. Those of Goodrick (1983) and Pressey and Harris (1988) are similar to the major elements of Jacobs' (1983) more detailed breakdown of the State's wetlands according to vegetation. They were followed by the comprehensive classification of Winning (1988) who divided the State into physiographic regions, each with systems and subsystems having distinct hydrology and geomorphology. The most detailed State-wide classification of wetlands is based on geomorphology and was proposed by Riley *et al.* (1984). Roy (1984) proposed a classification of New South Wales estuaries based on two criteria: entrance conditions at the time of formation and degree of infilling.

Pressey & Harris (1988) found that the coastal wetlands of the State are relatively well known, having been covered completely in several surveys, from reconnaissance to detailed in scale, and partly by localised detailed and intensive studies, mostly north of Sydney. A long-established classification of coastal wetlands came from the survey by Goodrick (1970) and is based mainly on vegetation and water regime. Subsequent studies have used different methods for inventory and classification and focused on particular wetland types. For example, Griffith (1984) identified plant associations in the coastal dune formations, West *et al.* (1985) mapped the broad types of estuarine vegetation for the whole coast, and Pressey (1989) listed a set of attributes of wetlands larger than 0.1 ha on the Clarence floodplain. The only overall survey after Goodrick's (Adam *et al.* 1985) mapped the boundaries of certain types of coastal wetlands, without classifying or describing them, as a basis for regulating land use.

The diversity of wetlands on the ranges and tablelands reflects local and regional differences in climate, geology, landform and hydrology. Only localised areas have been surveyed in any detail and there are large gaps even in the coverage of reconnaissance and broad-scale surveys and in knowledge of the variation in wetland types. One of the few extensive surveys is that of peatlands by Hope and Southern (1983).

A general picture of the occurrence and types of wetlands in inland New South Wales has been provided by reconnaissance-scale mapping of land systems, recurring patterns of landform, soils and vegetation (Walker 1991). The land system approach has also been adapted to identify wetland systems in the northwest of the State (Goodrick 1984) and on part of the Gwydir River (State Pollution Control Commission 1978). With concern over the effects of river regulation and other environmental changes, the inland riverine wetlands are the subjects of increasing numbers of broad-scale surveys, based on interpretation of aerial photographs and selective field visits. Most of these have been undertaken by the Department of Water Resources, previously the Water Resources Commission (e.g. Water Resources Commission 1986; Green 1992), with classification derived from dominant vegetation and hydrology and a total area surveyed in the order of 1.5 million hectares. The non-riverine wetlands of the inland, apart from those in the far northwest, remain poorly known.

In other recent work, Timms (1992b) sampled 102 lakes in New South Wales to produce a summary of ecological condition, covering the range of geomorphic types roughly in proportion to abundance. Future survey work will include further inland and coastal studies by the Department of Water Resources (P. Wettin, Department of Water Resources, pers. comm.). In addition, the Fisheries Research Institute of the Department of Fisheries has plans to re-map estuarine wetlands as well as deepwater marine habitats with more emphasis on field verification than in the earlier coverage (R. West, Fisheries Research Institute, pers. comm).

Northern Territory

Finlayson *et al.* (1988a) summarised the information on the Northern Territory's wetlands up to that date, using a framework of wetland types similar to that used nationally by Paijmans *et al.* (1985). Saltmarshes were poorly known. Mangrove areas were much more thoroughly investigated with broad-scale mapping complete for the whole coastline and relationships with environmental factors identified. The mangrove areas of the Alligator Rivers region had been surveyed in more detail. Seasonally-covered floodplains are those on the lower reaches of rivers draining to the coast and include two, on the South Alligator River and Magela Creek, that had been intensively studied (e.g. Williams 1979; Finlayson *et al.* 1988b). Knowledge of the extensive and intermittent swamps and lakes of the drier parts of the Territory was relatively poor, with only very general or localised descriptions published. In these regions, as in the monsoonal north, reconnaissance-scale surveys (e.g. Mabbutt 1962) have provided overviews of the distribution, geomorphology and vegetation of wetlands.

Recent work by the Conservation Commission of the Northern Territory has involved further floristic surveys of the northern floodplains followed by numerical classification of sites into plant communities (e.g. Whitehead *et al.* 1990; Wilson *et al.* 1991). Large areas of seasonal floodplains remain unsurveyed in eastern Arnhemland. The swamp forests, dominated by *Melaleuca*, have been covered only incidentally by floodplain surveys and there are plans for a more comprehensive inventory (P. Whitehead, Conservation Commission, pers. comm.). Another gap in knowledge in the north is the nature and distribution of small ephemeral wetlands in the river headwaters and the hinterland. An ongoing project is developing methods for monitoring ephemeral wetlands across the Australian subhumid tropics using NOAA satellite imagery (M. Fleming, Conservation Commission, pers. comm.).

A problem for description and classification of the non-tidal wetlands in the Territory is temporal change, not only in the intermittent streams and basins of the inland, but in the seasonal floodplains of the north which dry and reflood annually (Fleming 1991). Further work on the floodplains might lead to a classification scheme with a stochastic element (P. Whitehead, pers. comm.) to define an envelope within which the community composition of a site would move as factors like water depth and salinity varied.

While having to deal with these year-to-year changes, inventory for management must be sensitive to medium-term (say 5–10 year) variation due to the effects of feral buffalo or salinity encroachment (B. Wilson, Queensland Department of Environment and Heritage, pers. comm.). This gives surveys a monitoring role for demonstrating trends in the features considered important for conservation.

Queensland

The first overview of wetlands in Queensland was compiled by Stanton (1975) and this is still the only overall mapping exercise of the State's wetlands. This study was a reconnaissance of 'significant' wetlands based on interpretation of aerial photographs and previous field experience. The survey identified 142 wetlands or wetland aggregations in the State, estimated to be at least 90% of the total extent and to represent all types. The wetland classification was at four hierarchical levels. Tidal wetlands were subdivided only once according to vegetation, but inland wetlands were separated according to salinity, water regime and a combination of geomorphology and rainfall. The exercise was assisted by previous reconnaissance surveys (e.g. Christian *et al.* 1953; Queensland Division of Land Utilisation 1974).

Over a decade later, Stanton's (1975) work still formed an important basis for the review of Queensland wetlands by Arthington & Hegerl (1988). These authors used a subdivision of the Queensland mainland into twelve biogeographic regions by Stanton & Morgan (1977) to structure their compilation of information and reservation status. They listed many surveys and classifications of a more localised and intensive nature than Stanton's earlier work, most of which covered parts of the coastal strip in more southern latitudes. They also listed the types of inland wetlands in Queensland according to vegetation structure and floristics.

Arthington (1988) reviewed the types of lakes in the tropics and subtropics of the State.

There is considerable ongoing work to document the State's estuarine wetlands by the Queensland Department of Primary Industries. Although extensive, some of these surveys have produced detailed (Olsen *et al.* 1980) or broad-scale maps (Danaher & Luck 1991). The more recent work has focused on seagrass areas and has involved methods ranging from point sampling by divers (Coles *et al.* 1992) to satellite imagery (Lennon & Luck 1990). Another major estuarine program is a joint project by the Australian Littoral Society and the Queensland Department of Environment and Heritage to compile a data base on intertidal wetlands by summarising all available information on each area (E. Hegerl, Australian Littoral Society, pers. comm.).

The largest current survey is by the Department of Environment and Heritage in the Gulf Plains Biogeographic Region in the north-west. This involves delineation of wetlands from classified satellite imagery, in some cases assisted by interpretation of aerial photographs, and field description of selected sites. Classification of wetlands is modified from Cowardin *et al.* (1979) and the new framework is being proposed for State-wide use (Johnston 1991; Blackman *et al.* 1992). Associated with this work is a project on the Burdekin River floodplain managed from James Cook University. Wetlands will be classified numerically when chemical and biological data are compiled, although classification is complicated by within- and between-year variation in water levels and biota (R. Congdon, James Cook University, pers. comm.). Survey work in the coastal south-east of the State by the Queensland University of Technology is concentrating on *Melaleuca* swamps (J. Davie, Queensland University of Technology, pers. comm.).

South Australia

The most comprehensive listing of wetlands in South Australia is by Lloyd & Balla (1986) who extended the work of Lloyd (1986) to identify about 1500 wetlands or wetland complexes State-wide, over 500 of which were known well enough to be rated for environmental significance. They classified inland wetlands into four types – swamps, lakes, rivers and springs – subdivided according to salinity and water regime.

Lothian and Williams (1988) provided an overview of the wetlands of the State. They adopted an informal regional framework for their compilation but, within regions, recognised the same wetland types as Lloyd (1986). In the 80% of the State north of (drier than) the 250 mm isohyet, they identified three broad types of wetlands: mound springs, the natural surface discharge sites of artesian water, which have been well surveyed and documented (Greenslade *et al.* 1985); the vast complex of channels and basins in the far north-east that receives water from rivers rising in Queensland and which had not been surveyed in any detail at that time; and the salt lakes, many of which have been sampled limnologically (Williams 1981; De Deckker 1983). The many other wetlands in the arid part of the State, scattered through regions without major lakes or streams, were apparently poorly known, although these are numerous and extensive (Jessup 1951).

In the southern agricultural region, wetlands were generally more thoroughly surveyed than those further north. Wetlands in the south-east of the region are relatively well known (see Jones 1978). Five other wetland environments had been surveyed in some detail, although with various purposes and methodologies: the Coorong, a major lagoon complex in the south-east; the floodplain of the Murray River, the only major river in the State (Thompson 1986); the Murray's terminal lakes; small estuaries of minor coastal streams; and nine small, protected coastal embayments.

The gaps in the survey coverage of South Australian wetlands were highlighted again in Drewien's (1991) review. The uneven coverage reflects the urgency for specific information for planning decisions (A. Jensen, G. Drewien, Department of Environment and Planning, pers. comm.). Even in the best known regions there is a need for detailed or intensive, localised surveys for decisions on management and conservation. A high priority is to repeat Thompson's (1986) Murray survey and update assessments of conservation value. Intensive work is also underway in the South-East where rising groundwater will affect many wetlands. Large flows into the wetland complexes of the Cooper and Warburton Creeks in recent years have stimulated greater interest in the north-east of the State. A broad-scale survey of part of the Cooper system began in 1991, based on aerial photography and ground truthing and is using the Ramsar definition and classification of wetlands.

Tasmania

Much of the knowledge of Tasmanian wetlands comes from systematic surveys between 1978 and 1980 of most of the enclosed natural wetlands of the lowlands and the Bass Strait Islands and some of the wetlands of the eastern Central Plateau (Kirkpatrick & Tyler 1988). The surveys covered some 530 wetlands and concentrated on macrophytic vegetation (see Kirkpatrick and Harwood 1981, 1983a, b for botanical details) but also included morphology, water regime, chemistry and other attributes. Data from these surveys were used to classify the wetlands similarly to those in Victoria (Corrick & Norman 1980) using water depth, permanence, salinity and vegetation structure. Kirkpatrick and Tyler (1988) produced summary maps of the occurrence of wetland classes which also include types not covered by the ground surveys of inland wetlands: artificial impoundments, natural wetlands of the glaciated high country, tidal saltmarsh (see Kirkpatrick & Glasby 1981) and shallow estuarine waters.

Tasmania has been relatively well explored limnologically and perspectives are available on salinity, nutrient status, optical properties and temperature regimes, among other attributes (e.g. Bowling *et al.* 1986, 1993; Tyler 1974, 1993). The diverse geomorphic origins of many wetlands have also been described. Wetlands of glacial origin are common, the island having been glaciated at least three times in the last 2–3 million years (Jennings & Ahmad 1957; Davies 1967). Kirkpatrick and Tyler (1988) have described informally some of the chemical, physical and geomorphological types of waterbodies in the State.

More recent inventories of selected wetlands (Blackhall 1986, 1988) involved field visits to each site and described them in terms of habitat features likely to reflect diversity or abundance of waterbirds. Several other surveys have covered specific types of wetlands. Whinam *et al.* (1989) described a survey of *Sphagnum* peatlands that was followed by numerical classification according to floristics and invertebrates. Pannell (1992) surveyed the swamp forests of the State and classified them numerically into floristic communities. Jarman *et al.* (1988) have completed a survey and classification of buttongrass moorlands. Other recent work on Tasmanian wetlands has been summarised by Blackhall (1991).

The Tasmanian Department of Parks, Wildlife and Heritage has begun a computerised database which currently holds information on about 800 sites and will be progressively updated and extended (Atkinson 1991). Several wetland types, including flowing waters, have been under-represented in surveys. Temporal variation is seen as a problem for both inventory and classification and there are plans to regularly monitor about 100 wetlands around the State (S. Blackhall & J. Atkinson, pers. comm.). All the sites in the data base have been reclassified using the Ramsar system as an interim framework pending more general agreement on a national classification scheme.

Victoria

A detailed survey of Victorian wetlands began in 1975 in the Gippsland region (Corrick & Norman 1980) and has since covered the whole State. Wetlands were located on aerial photographs and with ground surveys and information on many was collected in the field. The classification scheme was specific to the project and oriented toward use by birds. It has six categories for natural wetlands, based on water regime and salinity, with subcategories determined mainly by dominant vegetation. The distribution and other characteristics of wetlands surveyed up to December 1985 have been summarised by Norman and Corrick (1988). Additional information has come from landscape and vegetation mapping by the Land Conservation Council and Soil Conservation Council (e.g. Land Conservation Council 1987 and see Smith 1975 for early references).

Major gaps in detailed survey coverage in Victoria are the bogs and fens of the high country, although several vegetation and soil studies have described these and outlined categories (e.g. Costin 1962). Other gaps include wet heaths, flowing waters and inshore areas such as sea grass beds (P. S. Lake, Monash University, pers. comm.). As in other States, detailed data on flora, fauna, geomorphology and limnology are lacking for most wetlands. The extensive limnological work undertaken in Victoria has concentrated on lakes (see Bayly & Williams 1973; De Deckker & Williams 1986 for reviews).

A Wetlands Unit has been established within the Department of Conservation and Natural Resources with responsibilities including co-ordination of inventory, developing a wetland classification system, and establishing a data base (Shaw 1991). Further detailed surveys of wetlands have been undertaken in some regions including the western areas of Melbourne (e.g. Schulz *et al.* 1991) and parts of the Murray Valley (Lugg *et al.* 1989; Lloyd *et al.* 1991). Another recent survey, by Deakin University, was a compilation exercise to identify gaps in the types of wetlands included in National Estate listings (Deluca & Williams 1992).

The Wetlands Unit has identified a minimum data set to standardise inventory and allow a more detailed classification of wetlands (M. Beilharz, Deakin University, pers. comm.). The classification is hierarchical with several sequential criteria – geology, geomorphology, water regime, water chemistry and vegetation – and is applied within broad physiographic regions. The data on each criterion remain discrete and can be merged or rearranged to produce classes with different compositions for various purposes. Consideration is also being given to developing wetland classes that incorporate the variability inherent in many wetlands.

Western Australia

Lane and McComb (1988) concluded that 'no authoritative inventory of the total wetland resources of either the State, or any sizable region of the State, has yet been attempted'. The lakes and estuaries of the Swan Coastal Plain around Perth were the first to be surveyed by Riggert (1966), applying the classification scheme of Martin *et al.* (1953) based primarily on vegetation, water regime and salinity and emphasising use by waterfowl. Subsequent surveys have also concentrated on this region because of the ongoing impacts of urban, industrial and agricultural developments.

The Water Authority of Western Australia has made substantial progress in surveying and classifying wetlands in the south-west coastal regions, including the Perth-Bunbury area (LeProvost, Semeniuk & Chalmer 1987). New wetland maps for the whole of the Swan Coastal Plain have been prepared using the classification of Semeniuk (1987), based principally on water regime and landform. Suites of wetlands with common or inter-related features are referred to as 'consanguineous' assemblages (Semeniuk 1988) and have been mapped as wetland domains. The classification can be complemented with a system based on vegetation pattern and form (Semeniuk *et al.* 1990). Another major mapping exercise on the Swan Coastal Plain was completed by the Environmental Protection Authority to delineate lakes for protective regulation of activities. Possible further work by the Water Authority includes detailed wetland mapping in the Albany-Esperance region and the northern part of the Perth Basin, and hydrographic mapping for the wheatbelt (A. Hill, Water Authority of Western Australia, pers. comm.).

In the south-west, recent surveys by the Department of Conservation and Land Management have led to classification of wetlands according to use by waterbirds (Halse *et al.* 1993a, Storey *et al.* 1993). Similar work is proceeding with data on aquatic invertebrates (Growns *et al.* 1992). The agreement between waterbird and invertebrate classifications varies with geographical scale and the types of wetlands being considered (S. Halse, Department of Conservation and Land Management, pers. comm.). There are ongoing aerial surveys of waterbirds and wetlands (Halse *et al.* 1992) and vegetation surveys of selected wetlands have led to informal descriptions of types (Halse *et al.* 1993b).

Estuarine wetlands have been surveyed and classified in several parts of the State (e.g. Backshall & Bridgewater 1981, Semeniuk & Wurm 1987; Semeniuk & Semeniuk 1990). The wetlands of the arid interior, while explored ornithologically, are largely unsurveyed except for isolated areas (Halse 1990) or regions covered by reconnaissance-level land inventory (Speck *et al.* 1964).

Summary of Australian studies and future directions

Number and coverage of studies

The bibliography compiled as background to this review (Pressey *et al.* in press) contains over 600 entries, most of which have been produced since the mid-1970s (Fig. 4). While some of the studies listed represent a common approach applied in stages or to different areas, the sheer number of references indicates a wide diversity of ideas on survey and classification.

The wetlands near the main population centres, scattered around the coastal fringes, have been surveyed most thoroughly and in most detail, sometimes repeatedly at different scales (Paijmans *et al.* 1985; Winning 1991b). Recognition of wetland loss and degradation in regions like the Murray-Darling Basin or north coastal Queensland has stimulated survey and conservation efforts distant from the cities but there remain vast tracts of the country in which the distribution and nature of wetlands are poorly known. In most cases, the need for knowledge is driven by perceived threat – 'community awareness about the need for conservation grows in inverse proportion to the area, status or condition of the components of our natural heritage' (Lothian & Williams 1988).

Given the inertia of bureaucracies and the perennial lack of resources for surveys of wetlands that are politically insignificant, governments and resource agencies will not necessarily respond in a timely and appropriate fashion to the need for information as a basis for management. A review mechanism is necessary to identify critical gaps in the survey coverage in relation to management needs and potential threats to wetlands. This should probably be done at both Commonwealth and State/Territory levels and should guide the allocation of funds.

Approaches to inventory

Within and between States and Territories, past, present and planned methods for inventory vary widely. One interpretation of this variety is that surveys are unco-ordinated and chaotic. While a case can certainly be made for more coordination, there are also good reasons for different approaches. First, the design of any survey is a response to several factors – the types of wetlands involved, the sorts of information required, the geographical scope of the study, the available funds and time, the type and level of expertise of the personnel, and their exposure to particular techniques and views. A wide variety of survey approaches is therefore inevitable.

Another reason for variation is that surveys of some regions span more than twenty years so differences in priorities and approaches are to be expected. Through the information they provide and the critical review they undergo, surveys give new perspectives on the way later ones should be done. A diversity of survey approaches over time, even applied to the same area, is therefore desirable if techniques are to evolve. In addition, there are many cases of reconnaissance or broad-scale surveys providing the rationale and the framework for subsequent, more detailed surveys.

It is not possible or desirable for all surveys to be standardised according to the data collected, accuracy, resolution, and precision of mapped boundaries. Indeed, in view of the gradual and fluctuating nature of wetland edges, the establishment of precise but biologically meaningless boundaries might have limited use. Pressure from agencies for neatness of coverage and uniformity of approach would stifle innovative methods and go unheeded by those facing particular management problems which could not be catered for by the 'standard' approach.

Four developments in Australian wetland survey which would be useful are:

1. regular meetings of scientists and managers involved in undertaking wetland surveys or using survey information;
2. the collation of geographical data bases of inventories that indicate survey type and quality (Knights 1991) as a basis for systematic assessments of priority areas; ideally, these collations should take a broad view of what constitutes a wetland survey;
3. establishment of a minimum data set for inventory, regardless of scope and purpose, emphasising the importance of collecting primary rather than classified data wherever possible so that options for later uses are maximised (see McComb & Lake 1988; Barson & Williams 1991);
4. most importantly, investigation of ways to make survey information more accurate: important sources of inaccuracy include temporal change, the use of untested predictive indices for attributes that are difficult to measure directly, and the collection of data without validation from aerial photographs and satellite imagery.

Approaches to classification

There is a similar diversity of approaches to classification. The earlier classifications of wetlands were primarily concerned with habitat for waterbirds (Riggert 1966; Goodrick 1970; Corrick & Norman 1980). These were followed by other schemes that attempted to categorise wetlands more generally. The Water Authority has taken the lead in wetland mapping in Western Australia and is committed to the locally derived classification scheme of Semeniuk (1987). A major project in the Gulf Country of Queensland is using the approach of Cowardin *et al.* (1979) developed in the United States. The Australian scheme of Paijmans *et al.* (1985) has been used to summarise the categories of wetlands in the Northern Territory. The Tasmanian inventory and new work in South Australia are using Ramsar types. With slight modifications, the Ramsar classes are also being used in the Directory of Australia's Important Wetlands sponsored by the Australian National Parks and Wildlife Service. In Victoria, there are plans to replace an existing State-wide classification (Corrick & Norman 1980) by a more detailed approach developed specifically for the needs of the new Wetlands Conservation Program. There is a plethora of additional classifications used in each of the States and Territories, including an increasing number of numerical analyses applied after collection of data in the field. There is also a growing recognition of the problems posed by temporal dynamics for classification schemes. New approaches incorporating temporal change could emerge in the near future.

The variety of classifications could also be used to support calls for co-ordination and uniformity of approach. This would be a simplistic view of the situation. There is no doubt that a national system of classification would be useful for communication and comparison. More important, however, is the need to see classifications in two ways: (1) as hypotheses about the way in which the features of wetlands are arranged in space and time; and (2) as responses to the need for particular types of information for particular purposes, dependent also on the geographical scale of the study and the variability of the wetlands. Time and energy spent in imposing uniform approaches would be better spent in tackling these more important issues.

Techniques are available now to measure the extent to which classifications do the jobs they are meant to do (e.g. Pressey & Bedward 1991a, b; Bedward *et al.* 1992) and these approaches will continue to improve. Advances are also being made in *exploring* wetland data rather than simply slotting wetlands into pigeonholes. Numerical classifications of plant and invertebrate data are giving new pictures of wetland types in several States and will allow established schemes to be assessed critically.

The issue of whether a national classification scheme should be adopted is still unresolved in Australia, although it has obvious benefits for overviews of wetland resources and communication about management and conservation. Despite the apparent commitment of several agencies to different classifications, there is scope for developing a broad, flexible approach for national communication. A useful one might be similar to that recently developed in Victoria with two key elements: the use of several broad criteria including geomorphology and hydrology which are recorded independently and so can be applied individually or in various combinations; and an optional framework of environmental regions that can be used to stratify the classification geographically.

Global standards for inventory and classification?

Nearly all of the responses from wetland scientists and managers on the questions of global standards concerned only classification. However, given the many factors that influence the approach taken to wetland inventory and the wide diversity of inventory methods currently used to achieve diverse goals, it is safe to conclude that a standardised inventory approach would not be feasible within any of the Australian States or Territories. The chances of a global approach being adopted seem remote. Ongoing discussions in Australia on the issue of minimum data sets in wetland inventory, however, could lead to more national integration of survey results.

On a global classification scheme, there was a wide variety of responses, with some respondents posing arguments for and against. Positive views, less than half the responses, acknowledged that there would be benefits for international communication, comparisons, exchange of ideas on problems and solutions, use in extensive surveys, and summaries of characteristics and trends, particularly for countries linked by migratory species or conservation treaties. International consistency could, for example, allow some formal assessment of the conservation status of international flyways. Two respondents commented that a global system would have some heuristic value in understanding types of Australian wetlands and highlighting information needs. Other perceived benefits included the establishment of concise technical definitions, less time spent debating the merits of alternative approaches, the possibility of better approaches being adopted, and the improvement of global data sets for modelling climate change, for example in relation to methanogenesis.

Negative responses were slightly in the majority. An important argument was that classifications are no more than tools to understand variation for a particular management or conservation purpose and should be developed specifically – a single classification could not serve all needs and, in areas where wetlands were not well known, could confuse and hinder conservation efforts. In the same vein, others were concerned that a standard scheme would impose inappropriate or suboptimal methods on scientists and managers while stifling the development of approaches responsive to particular problems. Several people considered that classifications should be developed that specifically address the temporal variability of many Australian wetlands, as well as hydrologically variable wetlands in other countries. Another view was that classifications should be developed from data on the features of concern, perhaps iteratively as more information comes to hand.

If an attempt is made to apply a global classification in Australia, it should be as flexible as possible. Global comparability would be best achieved with a broad system based primarily on factors like climate, water regime and geomorphology, preferably recorded independently. So, if necessary, all wet tropical wetlands could be identified independently of geomorphology or all floodplain wetlands could be identified independently of climate. The use of common terms like marsh or bog in any global system should be accompanied by precise definitions to facilitate consistent application.

The problem would then be to identify more detailed types which would be useful as indicators of biological characteristics and management needs. It might be possible to make a broad global subdivision useful in national, regional and local contexts by stratifying the broad types geographically, as in the biophysical approach of Stanton and Morgan (1977) in Queensland, and within major coastal environments for estuarine and marine wetlands. This would allow data on the classes to be used at several geographical levels: without stratification for global statistics, and with various levels of physical or biogeographic stratification to achieve greater homogeneity for specific purposes.

While acknowledging the potential benefits of a global classification, it is important to recognise that the real work of wetland classification is to assist with the management and conservation of the resource in many ways and at many scales. There is and will continue to be a need for various approaches to inventory and classification that are geared to particular problems. It is therefore critical that any agreement on a global scheme, if forthcoming, does not interfere with their development. Adherence to a single scheme for convenience and uniformity ignores the most fundamental fact about classifications – that they are simply ways of representing processes or patterns of selected features in time and space. To be sure that they are effective in this, and therefore reliable bases for conservation and management, scientists and managers must put much more effort into testing and refining classifications.

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