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Review

A conceptual basis for the wise use of wetlands in northern Australia – linking information needs, integrated analyses, drivers of change and human well-being

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Abstract. Australia's north supports many wetlands. The biodiversity of these wetlands is highly regarded, but many are increasingly being affected by well recognised pressures that result in adverse change in their ecological character. The extent of the knowledge base and causes of adverse change in Australia's tropical wetlands are reviewed with an emphasis on the linkage between direct and indirect drivers of change. Within the context of the existing knowledge base, an integrated model for collecting information on the ecological character of tropical wetlands is proposed. The model encompasses hierarchical and multi-scalar approaches to wetland inventory, assessment and monitoring and was developed largely from research undertaken in northern Australia. It is based around the concepts of wise use and maintenance of the ecological character of wetlands, which in turn emphasises the value of wetlands to people through the delivery of ecosystem services. A broader conceptual framework linking ecosystem services and human well-being to the condition of wetlands is introduced as a forerunner to considering research needs for tropical Australian wetlands. The integrated model and framework entail community consultation and the involvement of stakeholders in decisions about wetland research and management. In conclusion, it is emphasised that the maintenance of the ecological character of the wetlands of northern Australia is a task for wetland managers, users and owners in collaboration with scientists from many disciplines.

Extra keywords: ecological character, sustainable development, tropical wetlands, wetland inventory and assessment, wise use.

Introduction

Internationally it has been recognised as inconceivable that a structured wetland-management regimen can be effectively implemented across a diverse and large landscape without knowing the extent, condition and value of the resource (Ramsar Convention Secretariat 2004; Finlayson *et al*. 1999, 2002*a*). Unfortunately, this is the situation that exists across much of northern Australia – the information base covering Australia's northern wetlands has major inadequacies and gaps and there are few comprehensive descriptions of the ecological character of the wetlands (Whitehead and Chatto 1996, 2001; Finlayson *et al*. 1997; Spiers and Finlayson 1999). This does not mean that information and data do not exist or that the wetlands are not recognised as valuable – they are valued for many reasons and over the past few decades there have been specific investigations and general reviews of the biodiversity (species and habitats) and pressures on some of northern Australia's wetlands, especially those in the northernmost part of the Northern Territory (Finlayson *et al*. 1997; Storrs and Finlayson 1997; Cowie *et al*. 2000). These authors have documented the extent of available information on the value and character of wetlands and pointed out important gaps.

Given this situation, we consider the gaps and issues raised in past reviews, including those covering the drivers of adverse change in wetlands, with an emphasis on the concepts of wise use and ecological character (as developed by the Ramsar Convention on Wetlands) and value of adopting integrated approaches for obtaining further information. In doing this we also emphasise the value of wetlands and the ecosystem services (as defined by the Millennium Ecosystem Assessment 2003) they deliver to people. We contend that these concepts provide a basis for enhancing the wise use of wetlands in northern Australia through increased attention to integrated analyses for addressing information needs, drivers of change, and the value of wetlands for people.

Extent of wetlands in northern Australia

The inadequacy of the information base for effective wetland management in Australia has been previously outlined (Spiers

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Table 1. Wetland areas for northern Australia and Kakadu National Park calculated from 10 different datasets (from Lowry and Finlayson 2004)

Data source	Northern Australia		Kakadu National Park	
	Area of swamp and land subject to inundation (km^2)	Total wetland area (all classes) (km^2)	Area of swamp and land subject to inundation (km^2)	Total wetland area (all classes) (km^2)
1. AUSLIG 250k Topographic data	51 495	98 704	2429	2886
2. Directory of important wetlands	16 472	30 948	2248	2694
3. Digital chart of the world	54 912	70 078	2840	2906
4. Matthews Natural Wetlands	35 649	35 649	3799	3799
5. Land Systems	–	–	3426	3426
6. DISCover Land Cover – using IGBP legend	–	4727	–	42
7. Global 4-min Landcover[A]	0	0	0	0
8. Olsons vegetation[A]	0	0	0	0
9. CSIRO Wetland database	5796	18 539	0	502
10. Lehner Inland Water	–	16 356	–	44
Range	0–54 912	0–98 704	0–3799	0–3799

[A] This dataset has a category for wetlands – although none are identified within the study area! –, No data available.

and Finlayson 1999; Watkins 1999). This applies equally, if not more, to northern Australia, where past reviews have highlighted shortfalls in the data resource (Whitehead and Chatto 1996, 2001; Finlayson *et al*. 1997; Finlayson and Lukacs 2004). This does not mean that specific surveys have not been conducted, they have and some taxa and locations are now particularly well investigated (Cowie *et al*. 2000). The information gaps are in part a consequence of the extent and nature of the terrain, much of it isolated and rugged with many challenges for ground-based scientific survey. It is also a consequence of the absence of a holistic or coordinated structure.

Given the absence of a structured inventory and mapping base for northern Australian wetlands, Lowry and Finlayson (2004) assessed the extent of wetlands using 10 different datasets that have previously been used for wetland inventory. They focussed on two broad classes of wetlands, 'swamps', and 'land subject to inundation' and assessed the areal extent at two scales (Table 1). The range of areal values for the area known as the wet–dry tropics (covering ~2 045 700 km^2; Fig. 1) varied from 0 to 98 700 km^2 and illustrates the variability that exists between datasets. Further assessment of the features of each dataset (e.g. the scale and means of delineating wetlands and the exact purpose the data was collected) is required before a reliable estimate of the extent of wetlands in northern Australia can be provided.

Despite the inadequacy of the information base it is known that many wetlands in northern Australia have been lost and degraded. Formally documented information about wetland loss and degradation is available for parts of northern Queensland (Finlayson and Lukacs 2004):

- 50% of large ephemeral wetlands on the Burdekin river floodplain (Lukacs 1995);
- 65% of freshwater wetlands on the Johnstone river floodplain (Russell and Hales 1993);
- 54% of freshwater wetlands on the Russell–Mulgrave river floodplain (Russell *et al*. 1996*a*);
- 65% of freshwater wetlands on the Moresby river floodplain (Russell *et al*. 1996*b*);
- 71% of Melaleuca and palm swamps on the Tully–Murray rivers floodplain (Tait 1994).

Similar data on the condition of wetlands in other areas are not available despite ample evidence of degradation, for example, owing to invasive species and pollution (Finlayson *et al*. 1997). As formal guidance for undertaking standardised wetland inventory within Australia does not exist, a hierarchical and multi-scalar approach used for wetland inventory in Asia (Finlayson *et al*. 2002*b*; Fig. 2) has been used to derive minimum data fields for describing the condition of wetlands in northern Australia (Table 2). It is recommended that these data fields are considered when undertaking further wetland inventory in northern Australia and that both biophysical and managerial data are collected in an integrated manner when looking at the condition of wetlands.

Ecological character

The concept of ecological character, introduced in the text of the Ramsar Convention in 1971, is widely accepted as a basis for the wise use of wetlands globally (Ramsar Convention Secretariat 2004: handbook 8, page 9). The information fields outlined in Table 2 as a basis for wetland inventory provide an adequate initial description of ecological character. Ecological character is defined as:

> "*the sum of the biological, physical, and chemical components of the wetland ecosystem, and their interactions, which maintain the wetland and its products, functions, and attributes*".

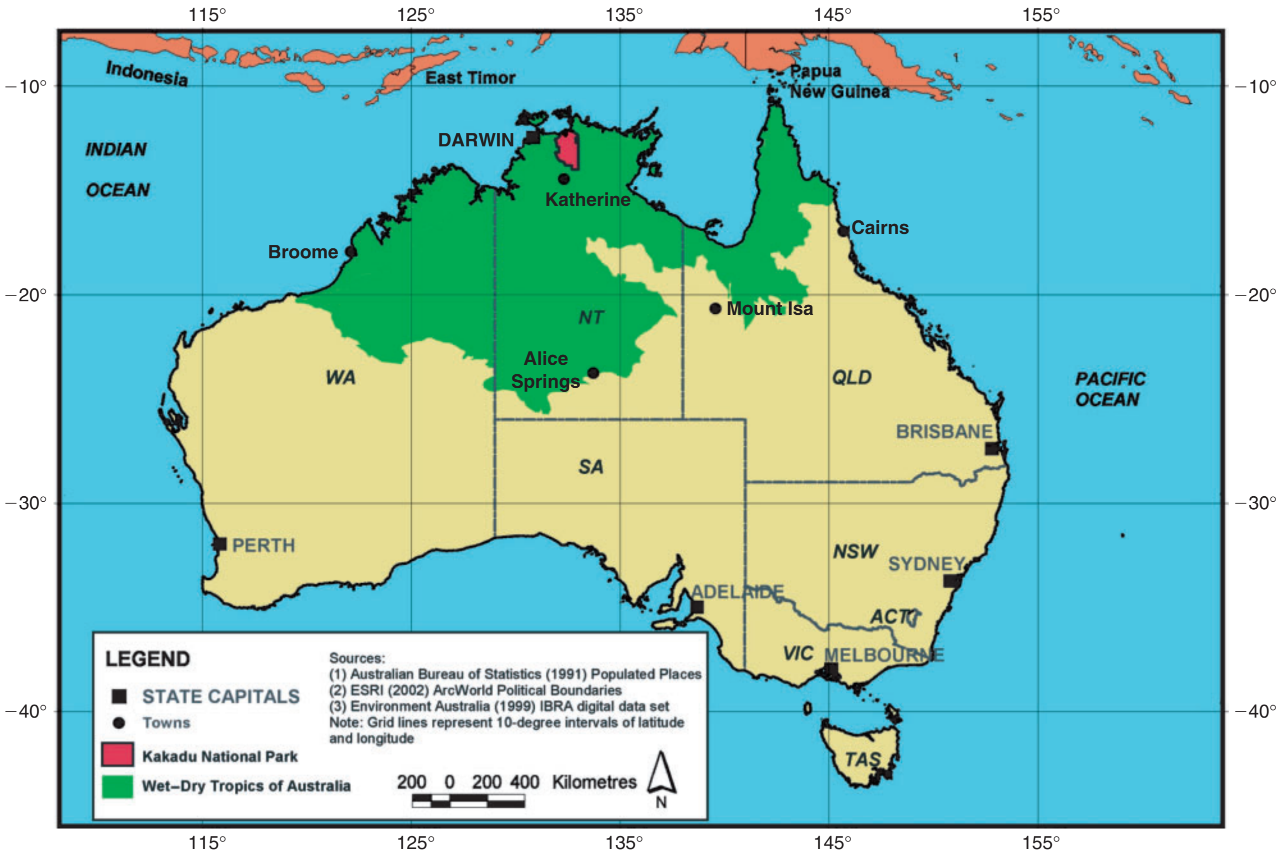

Fig. 1. Northern Australia encompassing the wet–dry tropics as defined by Finlayson *et al*. (1997) and showing the location of Kakadu National Park (from Lowry and Finlayson 2004).

Table 2. Minimum data fields for biophysical and management features of wetlands (derived fromFinlayson *et al*. 2002*b*)

Biophysical features	Management features
Site name (official name of site and catchment)	Land use – local, and in the river basin and/or coastal zone
Area and boundary (size and variation, range and average values)*	Pressures on the wetland – within the wetland and in the river basin and/or coastal zone
Location (projection system, map coordinates, map centroid, elevation)*	Land tenure and administrative authority – for the wetland, and for critical parts of the river basin and/or coastal zone
Geomorphic setting (where it occurs within the landscape, linkage with other aquatic habitat, biogeographical region)*	Conservation and management status of the wetland – including legal instruments and social or cultural traditions that influence the management of the wetland
General description (shape, cross-section and plan view)	Ecosystem services provided by or derived from the wetland – including provisioning, regulating, cultural and supporting services
Climate – zone and major features	Management plans and monitoring programmes – in place and planned within the wetland and in the river basin and/or coastal zone
Soil (structure and colour)	
Water regime (periodicity, extent of flooding and depth, source of surface water and links with groundwater)	
Water chemistry (salinity, pH, colour, transparency, nutrients)	
Biota (vegetation zones and structure, animal populations and distribution, special features including rare/endangered species)	

* These features can usually be derived from topographical maps or remotely sensed images, especially aerial photographs.

This definition contains a clear link between the components and processes and the ecosystem services (referred to as the 'products, functions, and attributes') delivered by a wetland. Recent discussion within the context of the Millennium Ecosystem Assessment (Reid 2000; Stokstad 2005; http://www.millenniumassessment.org/, verified April 2005) has made more explicit the linkage between ecosystem services and ecological components and processes. Thus, a redefinition has been proposed to ensure ecosystem services are seen as central to the concept of ecological character and not just dependent on the ecological components and processes (Finlayson and D'Cruz 2005). This is in line with the definitions of wise use and sustainable utilisation used by the Convention (Ramsar Convention Secretariat 2004: handbook 1, page 4):

"*their sustainable utilisation for the benefit of humankind in a way compatible with the maintenance of the natural properties of the ecosystem*",

Sustainable utilisation is, in turn, the:

"*human use of a wetland so that it may yield the greatest continuous benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations*".

As these definitions provide a holistic base for managing wetlands by making explicit the link between wetland use and maintenance of ecological character, it is recommended that they form the main tenet of efforts to make wise use of wetlands in northern Australia. As a consequence, further inventory, assessment and management should address not only the ecosystem components and processes that characterise a wetland, but also the services that they deliver. These services include: food and fresh water, regulation of floods and tidal surges, groundwater recharge, sediment retention and detoxification of pollutants, as well as many cultural and aesthetic values, and tourism opportunities (Finlayson and D'Cruz 2005).

Key pressures and drivers of change

General analyses and reviews have identified a suite of pressures faced by wetlands in northern Australia. These have focussed mainly on biophysical pressures that are or are likely to affect the ecological condition of the wetland. Finlayson and Rea (1999*a*) contended that in addition to addressing the apparent and highly visible causes of change in wetlands, it was necessary to also address the underlying and less visible causes. In line with the Millennium Ecosystem Assessment (2003), these pressures are referred to respectively as 'direct' and 'indirect' drivers where every direct driver is the outward expression of one or more indirect drivers. The drivers of change in tropical wetlands are discussed after consideration of the value of risk assessment approaches for providing information on major drivers of change.

Risk assessment of direct drivers

In recent years, there has been a move towards using risk assessment to provide wetland managers with the best available information on the causes of change in wetlands. The framework for risk assessment adopted by the Ramsar Wetlands Convention (van Dam *et al*. 1999) has been used in northern Australia to assess the risk associated with several direct drivers of change in wetlands, including invasive species (cane toads (*Bufo marinus*) – van Dam *et al*. 2002*a*; mimosa (*Mimosa pigra*) – Walden *et al*. 2004) and the herbicide tebuthiuron (van Dam and Finlayson 2004). A further example is provided by an analysis of likely ecological consequences of water-development activities in the Daly basin in the Northern Territory using an assumed development scenario (Begg *et al*. 2001).

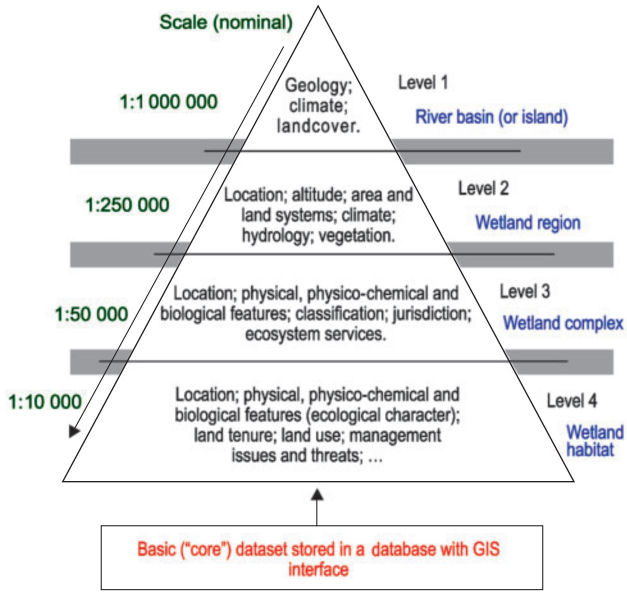

Fig. 2. Hierarchical framework for wetland inventory (from Finlayson *et al*. 2002*b*).

The framework is purposefully broad and can accommodate both qualitative and quantitative analyses and, as with many risk-assessment models, contains the following broad steps:

(*1*) *Identification of the problem* – identify the nature of the problem and develop a plan for the remainder of the assessment, including the objectives and scope.
(*2*) *Identification of adverse effects* – evaluate the likely extent of adverse change.
(*3*) *Identification of the extent of the problem* – estimate the likely extent of the problem.
(*4*) *Identification of the risk* – integrate the results from the above steps.
(*5*) *Risk management and reduction* – make decisions to minimise the risks without compromising other societal, community or environmental values.
(*6*) *Monitoring* – verify the effectiveness of the risk-management decisions.

The further use of risk assessment is recommended as a basis for making informed decisions about management choices affecting wetlands and for identifying monitoring and research priorities in a consistent manner. This is in line with recommendations for assessing environmental risks associated with irrigation development in northern Australia (Hart 2004).

Direct drivers of change in wetlands

Finlayson *et al*. (1988) identified the following as key direct drivers of change in Northern Territory wetlands:

(*1*) Feral animals – especially water buffaloes (*Bubalus bubalis*), pigs (*Sus scrofa*) and cane toads (*Bufo marinus*);
(*2*) Alien plants – especially mimosa (*Mimosa pigra*), salvinia (*Salvinia molesta*), water hyacinth (*Eichhornia crassipes*), paragrass (*Brachiaria* (*Urochloa*) *mutica*), and parkinsonia (*Parkinsonia acutea*);
(*3*) Water pollution – from mineral extraction and processing and agricultural chemicals;
(*4*) Mangrove destruction – from nutrient enrichment, embankments, reclamation and stormwater runoff;
(*5*) Saltwater intrusion;
(*6*) Tourism and recreational activities; and
(*7*) Pastoral activities – clearing, grazing and the presence of introduced pastoral species.

Subsequent reviews have repeated this list and added further invasive species, e.g. the floodplain grass, olive hymenachne (*Hymenachne amplexicaulis*) and the aquatic cabomba (*Cabomba caroliniana*) (I. D. Cowie, personal communication), emphasised the importance of changes in fire regimes and hydrological regulation, and the projected consequences of climate change. These direct drivers have been explored in various site-based analyses and, in some cases, comprehensive databases now exist (e.g. management of specific invasive species – Cook *et al*. 1996; Rea and Storrs 1999; and uranium mining – Humphrey *et al*. 1999; Gardner *et al*. 2002). Other causes of change are being assessed, but not necessarily in a consistent manner (e.g. the potential impact of climate change – Eliot *et al*. 1999). It is anticipated that climate change will not only affect the biological, chemical and physical features of wetlands, but will also interact strongly with other pressures on wetlands with the resultant synergistic, antagonistic or cumulative effects being only cursorily known (van Dam *et al*. 2002*b*).

In terms of managing wetlands it is recommended that further and more quantitative risk assessments of the direct drivers are undertaken and linked with ecological (e.g. covering energy and nutrient dynamics) and population models for selected species. In this manner, it may be possible to rapidly gain more insight into complex issues, such as the interaction between large populations of waterbirds and various plant species, including invasive weeds, and changes in fire patterns. Although some risk assessments have recently been undertaken (see above), these have not been linked with ecological models of population dynamics and energy and nutrient pathways. Neither have they been undertaken within a whole-ecosystem and adaptive-management framework – they have tended to be isolated and reactionary.

Indirect drivers of change in wetlands

The extent to which indirect drivers affect wetlands in northern Australia has not been widely assessed. Papers collated by Finlayson and Rea (1999*b*) illustrated that indirect drivers were important across Australia, but analyses specific to the social and economic decisions that most affect wetlands in northern Australia are sparse. Given recent decisions to further decentralise the distribution of national funding for natural resource management, it could be very useful to ascertain the likely effects of local social and economic drivers on wetlands. At an international level, the Millennium Ecosystem Assessment has recently moved forward the debate about conservation of biodiversity and sustainable use by explicitly making a link between ecosystem condition and human well-being and the relationship between direct and indirect drivers of change (Millennium Ecosystem Assessment 2003). However, there is little evidence that these concepts will have an affect at the local level, where more immediate economic factors are likely to be considered.

The underlying causes of wetland loss and degradation (primary drivers) that are most relevant to wetlands in northern Australia (Finlayson *et al*. 1997; Storrs and Finlayson 1997) are: a lack of public and political awareness of wetland values; a lack of political will for wetland conservation and restoration; over-centralised planning processes; historical legacies of land tenure and use; weak and poorly resourced conservation institutions; sectoral organisation of decision-making; and alliances that promote policies and studies rather than action. To prevent further loss and degradation of wetlands in northern Australia, these underlying, and often less visible, indirect causes must be assessed and addressed. Addressing the indirect causes at the same time as the direct causes are addressed will require extensive collaboration with stakeholders and decision-makers who themselves may not be aware of the value of wetlands and the reasons for maintaining or restoring them. Communication, education and public awareness will be important components of the partnerships that will be required to ensure this is successful.

Coordinated and integrated approaches for wetland assessment

Given the complex of issues that affect wetland policy and management in northern Australia and the inadequacy of the information base, it is proposed that management of wetlands is contained within a framework that supports integration and learning and covers both direct and indirect pressures. These concepts build on guidance presented by the Ramsar Wetlands Convention for (*i*) better engagement with local people, and (*ii*) an integrated framework for collecting further information on wetlands (Ramsar Convention Secretariat 2004).

A model for a multi-scalar wetland inventory, assessment and monitoring scheme has been developed using internationally agreed concepts and the definitions shown below as well as expertise and experience from northern Australia (Finlayson *et al*. 1999):

Wetland inventory: *the collection and/or collation of core information for wetland management, including the provision of an information base for specific assessment and monitoring activities.*

Wetland assessment: *the identification of the status of, and threats to, wetlands as a basis for the collection of more specific information through monitoring activities.*

Wetland monitoring: *collection of specific information for management purposes in response to hypotheses derived from assessment activities, and the use of these monitoring results for implementing management. (Note that the collection of time-series information that is not hypothesis-driven from wetland assessment should be termed surveillance rather than monitoring.)*

The model has been refined on several occasions, with the latest version being shown in Fig. 3. It comprises four triangles that place wetland inventory and monitoring either side of wetland assessment, with the latter being sub-divided into components – with wetland risk assessment and economic evaluation being shown as examples. The model is used to emphasise that although wetland inventory, assessment and monitoring are discrete components, they are inter-connected and can operate at very different scales. It is suitable for evaluating landscape features, and for assessments at catchment and sub-catchment scales. With due attention being given to the scale and means of analysis, it can further be used for monitoring the retreat of a wetland boundary, or ecological changes resulting from wetland degradation and fragmentation, climate change, fire, or invasive species. At a catchment scale, it can be used to provide information as part of national assessments, land and water audits, or state-of-the-environment reporting. The key messages being portrayed are based on the issue of scale and thus the level of accuracy and precision as required for an identified purpose.

A key issue, therefore, is to promote inventory, assessment and monitoring across common scales to avoid information being collected at one scale and inappropriately being used to make decisions or choices at another scale. These concepts are supported by recommending core data fields suited to each scale. The latter has been recommended for wetland inventory based on experience in northern Australia and elsewhere (see Finlayson *et al*. 2002*a*; Lowry and Finlayson 2004; van Dam and Finlayson 2004). For wider application in northern Australia, it is recommended that further attention is directed towards determining the most appropriate scales and data categories for analyses required for decision-making (e.g. how useful are existing mapping and biophysical databases for local versus national assessments and monitoring?) for drivers of change that operate at relatively local (e.g. water pollution) or landscape scales (e.g.

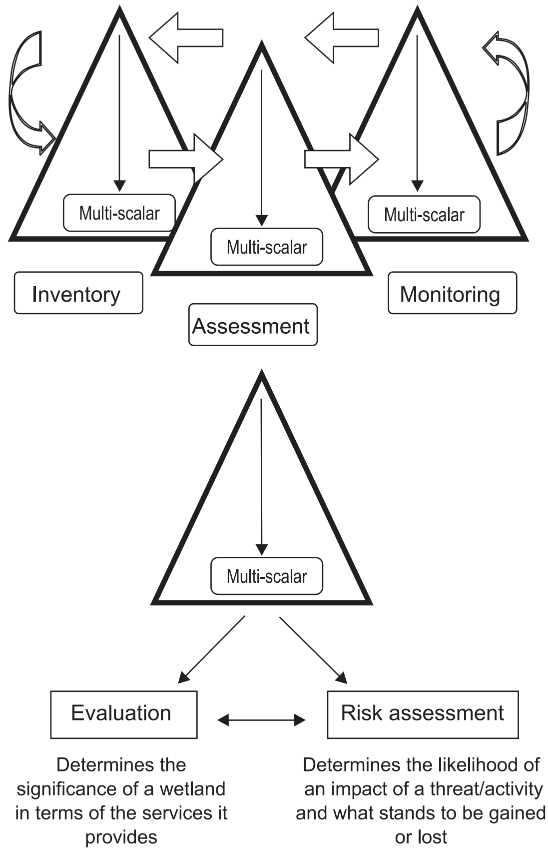

Fig. 3. Model framework for wetland inventory, assessment (risk assessment and economic evaluation) and monitoring.

weed invasion) and whether it is cost effective to collect such information.

The model as presented does not outline the exact nature of techniques that can be used – there are many and they are purpose-driven and may require substantial expertise. Whether this expertise is available is an issue that already exists in northern Australia.

Framework for wise use of wetlands

In a wider context, the Ramsar Convention has proposed the development of a conceptual framework for making wise use of wetlands (Finlayson *et al*. 2005); this is applicable in northern Australia. The framework encompasses the topics addressed above and covers e.g. the status and trends within wetlands, direct and indirect drivers of change, technical methods and data management, and the well-being of people through the provision and maintenance of wetland services. In particular, the framework links the causes of adverse change with the maintenance of the ecological character of the wetlands and encourages the identification of strategies or interventions to maintain or restore links between wetlands and people and hence support the wise use of wetlands.

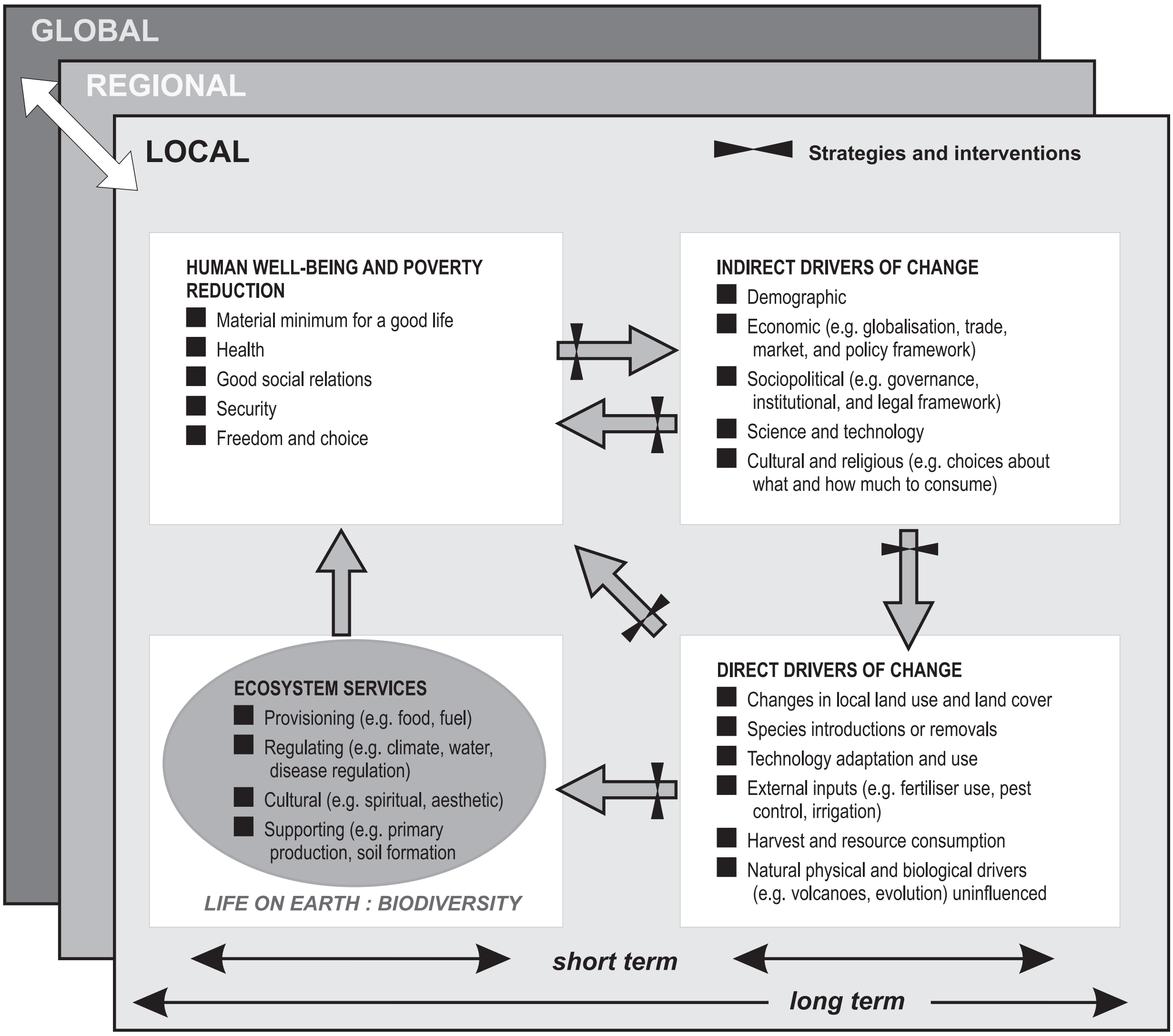

Fig. 4. Millennium Ecosystem Assessment conceptual framework (adapted from Millennium Ecosystem Assessment 2003).

The framework is based on that presented by the Millennium Ecosystem Assessment (Fig. 4) and, as with the model proposed for integrated assessment, it is applicable at multiple scales. It contains four components – indirect drivers, direct drivers, ecosystems and their services, and well-being and poverty reduction. All except the latter have been discussed above within the context of northern Australia. The conceptual linking of ecosystem condition and human well-being has been implicit in wetland management in northern Australia, but there are few analyses where ecosystem services and the well-being of humans are at the centre of the analysis. For the framework to be applied, further analyses will require a more explicit recognition that the maintenance of wetlands is intertwined with the provision of ecosystem services that support the well-being of people. Thus, more integration between programmes that address the individual components of the framework is required at multiple scales. A conceptual shift in attitudes may be required to ensure that the wider implications for human well-being are considered alongside those of the more traditionally considered ecological components of any particular wetland or complex of wetlands. This includes involving local communities in such programmes (Finlayson 2003).

Finlayson and D'Cruz (2005) point out that there has, in recent years, been increased interest in the development of mechanisms to encourage and support the capacity of local communities to contribute to the management of wetlands, particularly where local knowledge and experience can be constructively used (Ramsar Convention Secretariat 2004). Recognition of the beneficial outcomes that can occur when local people are involved in the management of wetlands now underpins efforts by the Ramsar Convention to encourage best management practices. All too often, however, the involvement of local communities has not occurred or has not been effective; a situation that occurs in northern Australia (Carbonell *et al*. 2001).

Research required on ecological components and processes

The above sections have focussed on management issues, in particular information needs and data-related mechanisms for maintaining the ecological character of wetlands in northern Australia. In particular, the need for effective, and thus integrated, wetland inventory and assessment has been advocated. There is also a need to acquire new information and undertake specific research to resolve ecological uncertainties and unknowns. Thus, specific research is still required, including that into ecological techniques and approaches that can support effective data collection, as well as the interactions between ecosystem services and human well-being. As the latter has not been widely addressed, it is not included in the listing given below; however, it does require urgent consideration through appropriate fora.

The listing below of research topics for northern Australian wetlands is derived from a national listing provided by the Australian Society for Limnology (2000). Key research topics for northern Australian wetlands include:

(*1*) Water for environmental benefits – ecological responses to variation in flows, including underground water and dry-season base flows; water requirements for aquatic species; and techniques for determining water allocations that meet multiple objectives.
(*2*) Pollution (including salinisation) of wetlands – ecological responses to nutrients and pollutants; pollution pathways and interactions; and techniques for rapid and early detection of pollution.
(*3*) Grazing in wetlands – assessment of the effects of introduced pasture species, including disruption to nutrient and energy flows.
(*4*) Riparian vegetation – ecological links between energy and nutrients pathways.
(*5*) Invasive species – ecological impacts of invasive species; biology of invasive species; techniques for effective control; and early warning and prevention of invasion.
(*6*) Climate change and sea-level rise – techniques for integrated vulnerability assessment; techniques for mitigation of climate change; and assessment of adaptation options.

In addition, there is a broad need for techniques for rehabilitating degraded habitats. Relative priorities for the above listed research topics have not been identified because this is best done through consultation processes involving stakeholders and local communities in particular. In this respect, decisions about the future of wetlands in northern Australia should be made fully through consultative processes and not by ecological scientists in isolation of stakeholders or indeed from scientists from other disciplines.

Maintenance of the ecological character of the wetlands of northern Australia is a task for wetland managers, users and owners in collaboration with scientists from many disciplines.

References

The Australian Society for Limnology (2000). Australia's Aquatic and Wetland Resources: the Critical Challenges. Available online at: http://www.asl.org.au/asl_poldoc_challenges.htm, verified April 2005.

Begg, G. W., van Dam, R. A., Lowry, J. B., Finlayson, C. M., and Walden, D. J. (2001). Inventory and risk assessment of water dependent ecosystems in the Daly basin, Northern Territory, Australia. Supervising Scientist Report 162. Supervising Scientist, Darwin.

Carbonell, M., Nathai-Gyan, N., and Finlayson, C. M. (2001). 'Science and Local Communities: Strengthening Partnerships for Effective Wetland Management.' (Ducks Unlimited Inc.: Memphis, TN.)

Cook, G. D., Setterfield, S. A., and Maddison, J. (1996). Scrub invasion of a tropical wetland: Implications for weed management. *Ecological Applications* **6**, 531–537.

Cowie, I. D., Armstrong, M. D., Woinarski, J. C. Z., Brocklehurst, P. S., Short, P. S., and Dunlop, C. R. (2000). An overview of the floodplains. In 'Floodplain Flora: A Flora of the Coastal Floodplains of the Northern Territory, Australia'. (Eds I. D. Cowie, P. S. Short and M. Osterkamp Madsen.) pp. 1–33. (Australian Biological Resources Study: Canberra.)

Eliot, I., Finlayson, C. M., and Waterman, P. (1999). Predicted climate change, sea level rise and wetland management in the Australian wet-dry tropics. *Wetlands Ecology and Management* **7**, 63–81. doi:10.1023/A:1008477110382

Finlayson, C. M. (2003). The challenge of integrating wetland inventory, assessment and monitoring. *Aquatic Conservation*. *Marine and Freshwater Ecosystems* **13**, 281–286. doi:10.1002/AQC.598

Finlayson, C. M., and D'Cruz, R. (2005). Inland water systems. In 'Millennium Ecosystem Assessment, Volume 1, Conditions and Trends, Millennium Ecosystem Assessment: Strengthening Capacity to Manage Ecosystem Sustainably for Human Well-being'. (Island Press: Washington, DC.) (In press.)

Finlayson, C. M., and Lukacs, G. P. (2004). Status of wetlands in northern Australia 2004. In 'Protecting the Values of Rivers, Wetlands and the Reef, Conference Abstracts, Papers, Posters and Presentations, Townsville, Australia, November 2001'. (Eds N. Dawson, J. Brodie, G. Rayment and C. Porter.) (Department of Natural Resources and Mines: Brisbane.)

Finlayson, C. M., and Rea, N. (1999*a*). Reasons for the loss and degradation of Australian wetlands. *Wetlands Ecology and Management* **7**, 1–11. doi:10.1023/A:1008495619951

Finlayson, C. M., and Rea, N. (Eds) (1999*b*). Reasons for the loss and degradation of Australian wetlands. *Wetlands Ecology and Management* **7**(1–2). Special Issue. (Kluwer Academic Publishers: Dordrecht.)

Finlayson, C. M., Bailey, B. J., Freeland, W. J., and Fleming, M. (1988). Wetlands of the Northern Territory. In 'The Conservation of Australian Wetlands'. (Eds A. J. McComb and P. S. Lake.) pp. 103–116. (Surrey Beatty and Sons: Sydney.)

Finlayson, C. M., Hall, R. N., and Bayliss, B. L. (1997). Regional review of wetland management issues: wet–dry tropics of northern Australia. Land and Water Resources Research and Development Corporation Occasional Paper 03/97. LWRRDC, Canberra.

Finlayson, C. M., Davidson, N. C., Spiers, A. G., and Stevenson, N. J. (1999). Global wetland inventory – status and priorities. *Marine and Freshwater Research* **50**, 717–727. doi:10.1071/MF99098

Finlayson, C. M., Davidson, N. C., and Stevenson, N. J. (2002*a*). Wetland inventory, assessment and monitoring – practical techniques and identification of major issues: summary. In 'Wetland Inventory, Assessment and Monitoring: Practical Techniques and Identification of Major Issues'. (Eds C. M. Finlayson, N. C. Davidson and N. J. Stevenson.) pp.130–136. Report 161. Supervising Scientist, Darwin.

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

Finlayson, C. M., D'Cruz, R., and Davidson, N. C. (2005). 'Wetlands & Water: Ecosystem Services and Human Well-being.' (Island Press: Washington, DC.) (In press.)

Gardner, S., Finlayson, C. M., and Pidgeon, R. (2002). Description and literature review of the flora and vertebrate fauna of Magela Creek, Alligator Rivers Region, northern Australia. Supervising Scientist Report 169. Supervising Scientist, Darwin.

Hart, B. T. (2004). Environmental risks associated with new irrigation schemes in northern Australia. *Ecological Management & Restoration* **5**, 106–110. doi:10.1111/J.1442-8903.2004.00184.X

Humphrey, C. L., Thurtell, L., Pidgeon, R. W. J., van Dam, R. A., and Finlayson, C. M. (1999). A model for assessing the health of Kakadu's streams. *Australian Biologist* **12**, 33–42.

Lowry, J., and Finlayson, C. M. (2004). A review of spatial data sets for wetland inventory in northern Australia. Supervising Scientist Report 178. Supervising Scientist, Darwin.

Lukacs, G. (1995). Wetlands of the lower Burdekin region, north Queensland. In 'Wetland Research in the Wet-dry Tropics'. (Ed. C. M. Finlayson.) pp. 86–94. Supervising Scientist Report 101. Supervising Scientist Group, Canberra.

Millennium Ecosystem Assessment (2003). 'Ecosystems and Human Well-being: A Framework for Assessment.' (Island Press: Washington, DC.)

Ramsar Convention Secretariat (2004). 'Ramsar Handbooks for the Wise Use of Wetlands. 2nd edn.' (Ramsar Convention Secretariat: Gland, Switzerland.)

Rea, N., and Storrs, M. J. (1999). Weed invasions in wetlands of Australia's top end: reasons and solutions. *Wetlands Ecology and Management* **7**, 47–62. doi:10.1023/A:1008425109473

Reid, W. V. (2000). Ecosystem data to drive hard choices. *Issues in Science and Technology* **XVI**, 37–44

Russell, D. J., and Hales, P. W. (1993). Stream habitat and fisheries resources of Johnstone River Catchment. Department of Primary Industries, Northern Fisheries Research Centre, Cairns.

Russell, D. J., Hales, P. W., and Helmke, S. A. (1996*a*). Stream habitat and fish resources in the Russell and Mulgrave Rivers Catchment. Department of Primary Industries, Northern Fisheries Research Centre, Cairns.

Russell, D. J., Hales, P. W., and Helmke, S. A. (1996*b*). Stream habitat and fish resources of the Moresby River Catchment. Department of Primary Industries, Northern Fisheries Research Centre, Cairns.

Stokstad, E. (2005). Taking the pulse of the Earth's life-support systems. *Science* **308**, 41–43. doi:10.1126/SCIENCE.308.5718.41

Spiers, A. G., and Finlayson, C. M. (1999). An assessment of the extent of wetland inventory data held in Australia. In 'Techniques for Enhanced Wetland Inventory, Assessment and Monitoring'. (Eds C. M. Finlayson and A. G. Spiers.) pp. 1–43. Supervising Scientist Report 147. Supervising Scientist Group, Canberra.

Storrs, M. J., and Finlayson, C. M. (1997). Overview of the conservation status of wetlands of the Northern Territory. Supervising Scientist Report 116. Supervising Scientist, Canberra.

Tait, J. P. (1994). Lowland habitat mapping and management recommendations: Tully–Murray Catchments. Report to Cardwell shire catchment Coordinating Committee. Department of Primary Industries, North region, Cairns.

van Dam, R. A., and Finlayson, C. M. (2004). Developing local capacity and ensuring relevance in risk assessment for tropical wetlands. *SETAC Globe* **February 2004**, 36–38.

van Dam, R. A., Finlayson, C. M., and Humphrey, C. L. (1999). Wetland risk assessment: a framework and methods for predicting and assessing change in ecological character. In 'Techniques for Enhanced Wetland Inventory, Assessment and Monitoring'. (Eds C. M. Finlayson and A. G. Spiers.) pp. 83–118. Supervising Scientist Report 147. Supervising Scientist Group, Canberra.

van Dam, R. A., Walden, D., and Begg, G. W. (2002*a*). A preliminary risk assessment of cane toads in Kakadu National Park. Supervising Scientist Report 164. Supervising Scientist Division, Darwin.

van Dam, R., Gitay, H., Finlayson, M., Davidson, N. J., and Orlando, B. (2002*b*). Climate change and wetlands: impacts, adaptation and mitigation. Background document (DOC.SC26/COP8–4) prepared by for the 26th Meeting of the Standing Committee of the Convention on Wetlands (Ramsar Convention) held in Gland, Switzerland, 3–7 December 2002.

Walden, D., van Dam, R., Finlayson, M., Storrs, M., Lowry, J., and Kriticos, D. (2004). A risk assessment of the tropical wetland weed Mimosa pigra in northern Australia. Supervising Scientist Report 177. Supervising Scientist, Darwin.

Watkins, D. (1999). Review of wetland inventory information in Oceania. In 'Global Review of Wetland Resources and Priorities for Inventory'. pp. 493–526. Supervising Scientist Report No. 144. Supervising Scientist, Canberra.

Whitehead, P. J., and Chatto, R. (1996). Northern Territory. In 'A Directory of Important Wetlands in Australia, 2nd edn'. pp. 119–175. (Australian Nature Conservation Agency: Canberra.)

Whitehead, P. J., and Chatto, R. (2001). Northern Territory. In 'A Directory of Important Wetlands in Australia, 3rd edn'. pp. 47–54. (Environment Australia: Canberra.)

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