Integrating scientific assessment of wetland areas and economic evaluation tools to develop an evaluation framework to advise wetland management

Jackie Robinson, Jared Dent and Gabriella Schaffer

The University of Queensland, School of Economics, Brisbane, Qld. Australia 4072 (email: robinson@uq.edu.au).

Abstract

Wetland ecosystems provide society with a range of valuable ecosystem services. However, wetlands worldwide are experiencing increasing pressure from a number of sources, caused by an interrelated combination of market failure and policy intervention failure. Whatever the cause, the result is massive degradation and loss of these ecosystems and ultimately, loss of their services. To better manage wetlands the availability of sufficient relevant and reliable scientific information is required together with an assessment tool capable of providing meaningful evaluations of the consequences of management. Current assessments of wetlands are often biased towards either economic or scientific issues, with limited attempts at integration. Evaluations that neglect integration overlook the complexity of wetland ecosystems and have failed to sufficiently protect these areas. This paper reviews the literature to propose an evaluation framework which combines a scientific assessment of wetland function with cost utility analysis (CUA) to develop a meaningful trade-off matrix. A dynamic approach to wetland assessment such as the hydro geomorphologic method (HGM), developed by the US Army Corps of Engineers, offers the opportunity to consider interrelationships between ecosystem process and functions and the resulting ecosystem services. CUA facilitates the evaluation of projects where the consequences of investment or no investment are complex and difficult to value in monetary terms. The evaluation framework described in this paper has the potential to deliver an integrated wetland management tool. However, for this potential to be realised, targeted interdisciplinary research by scientists and economists is required.

JEL:

Keywords: Wetlands, ecosystem function, hydro geomorphologic method, cost-utility analysis, trade-off matrix

1. Introduction

The integrity of ecosystems world-wide is at risk from agricultural and industry activities, encroachment from urban settlement as well as from global climate change. The ecosystem processes and functions that take place within and between the structures that make up the stock of natural capital (including estuaries, wetlands, forests, soils and oceans) provide a flow of essential goods and services for human societies ranging from food production, drinking water and clean air to the provision of recreational opportunities, all of which contribute to the economic and social welfare of society. The natural processes and functions provided by natural capital are becoming increasingly degraded. This paper explores the possibilities and limits of current approaches to ecosystem service assessment to suggest an evaluation framework for integrated wetland management.

Wetlands are complex, multifunctional and highly dynamic ecosystems (Mitsch and Gosselink 1993). Currently, neither a universally agreed definition nor a uniform classification of wetland types has been established. The Ramsar Convention on Wetlands (www.ramsar.org) provides a widely accepted but broad definition of wetlands which include riverine environments; floodplains; lakes and swamps; as well as salt marshes; shorelines; and coral reefs.

Wetlands worldwide are under increasing pressure. The literature suggests that wetland degradation is the result of an interrelated combination of market failure leading to policy intervention failure. In addition, the literature suggests structural or institutional causes, such as the absence of appropriate and enforceable property rights, conflicting stakeholder preferences, and, difficulty in defining the precise boundaries of wetlands (e.g., Adger and Luttrell 2000; Turner et al. 2003a; Turner et al. 2000).

Information failure, cited as a source of market failure, is primarily associated with the difficulty of assessing and valuing ecosystem services provided by wetlands. The complexity, multi-functionality and dynamic character of wetlands (Mitsch and Gosselink 1993) require a large volume of credible information to adequately assess wetland function, information which is currently rarely available and expensive to acquire. Coupled with this is the non-market and public good characteristic of wetland services which has led to their over-use and mismanagement resulting in degradation and irrecoverable loss. Reasons cited in the literature for intervention failure include the incompatibility of concepts and methods used in science, economics and policy-making and the unmanageable number and complexity of management policies resulting in conflict and contradiction between different uses for wetlands (for example, nature protection versus development) ((Turner et al. 2003a).

Current approaches towards the development of evaluation and planning tools in wetland management are often biased in favour of either economic or scientific issues. The scientific studies tend to be focused on specific aspects of a wetland (such as the salt marshes; sea grasses; riparian area or river systems), on specific functions (such as groundwater recharge) or specific problems (such as water quality; pollution) (see for example, EHMP 2005; Laegdsgaard 2006; Roise et al. 2004; Smith et al. 2007).

The economic studies are primarily concerned with attaching monetary values to wetland services concentrating on specific services provided by a wetland (such as recreational use or commercial fishing) as input into a cost-benefit analysis (Acharya 2000; Hein et al. 2006; Howarth and Farber 2002; Turner et al. 2004; Winkler 2006). On their own, these approaches are limited in their usefulness for policy makers and have failed to adequately protect wetland ecosystems.

This paper begins with a review of the scientific and economics literature dealing with approaches assessing wetland functional capacity, the services that result and the threats to wetlands. It then considers techniques currently adopted for evaluation of wetland management and proceeds to propose an evaluation framework which integrates scientific and socio-economic considerations.

2. Previous studies and current approaches

This section critically reviews a number of studies, both scientific and economic, with a view to the identification of a broad framework for evaluation of wetland management.

2.1 Assessment of functional capacity

The Ecosystem Health Monitoring Program (EHMP 2005), managed by the Moreton Bay Waterways and Catchment Partnership (Healthy Waterways), provides a regional assessment of ecosystem health for the waterways in southeast Queensland draining to Moreton Bay, and monitors improvements in water quality achieved through pollution management. The program is based on waterways classification as well as on mapping of wetland inventory and evolution. It measures and reports annually on changes in a number of biophysical indicators impacted by human activities. The assessment solely uses biophysical indicators, which are not directly related to or linked with socio-economic indicators. This limits its applicability for integrated natural resource management. However, the program serves as a credible and reliable data-base for scientific information which monitors waterway health in south east Queensland and provides a credible basis for further studies towards integrated wetland management.

Another approach to scientific assessment of wetlands is the hydro geomorphic (HGM) approach, which was designed by the US Army Corps of Engineers to assist US policies such as the Clean Water Act (Clairain 2002). The HGM approach is a collection of scientific concepts and methods to measure the capacity of a wetland, as a whole, to perform specified functions. A functional capacity index (FCI), based on a biophysical assessment of wetland attributes, summarises the capacity of a wetland to perform specific functions, relative to reference wetlands. It is both a data-based as well as a reference-based approach (Smith 2001) and is thus characterized by a relatively high level of objectivity. It considers interrelationships between a range of functions provided by wetlands, for example, functional capacity contributing to fish habitat and functional capacity contributing to clean water to assign an index to the overall health of a wetland ecosystem.

The FCI index, ranging from 1.0 to 0.0, is expressed as a defined relationship between a function and a number of variables that determine the integrity of the performance of the function (Smith et al. 1995). A FCI of 0.1 implies that the wetland function operates at a minimal, essentially immeasurable level, but retains the potential for recovery, whereas in the case of a FCI of 0.0 the wetland function is no longer operational and has lost the potential for recovery (permanent change) (Smith et al. 1995).

The HGM assessment is not specific to an individual function but the whole wetland ecosystem. The complexity of the interrelationships is expressed by using some variables, such as riparian vegetation, in more than one function which is an acknowledgement that the functions are not independent of each other (Brinson et al. 1995).

The underlying principles of this concept provide the opportunity to set reasonable safety levels (management constraints) to ensure resilience and thus sustainability for individual functions. Setting management constraints supports reducing the risk of a permanent loss of individual wetland functions. An unsustainable increase in one function could lead to a decrease in other functions, which in turn would most likely have a negative effect on the function under consideration. Therefore, it is crucial to set reasonable management constraints not only for individual functions but for the whole wetland ecosystem to reduce the risk of a permanent loss of wetland functioning, and thus services.

The HGM approach is based on the assumption that wetlands, which have not been exposed to long-term anthropogenic degradation, exhibit the highest functional capacity.

Potential applications of the HGM approach include, among others, the assessment of potential impacts of a proposed project on wetland areas as well as of impacts of a completed project; the identification of possibilities to minimize impacts of a proposed project; and the comparison of wetland management alternatives (Smith et al. 1995). Wetland off-set policies including wetland mitigation banking have been implemented in the US as a central platform for their no net loss goal for wetland management (Shabman and Scodari, 2005). The complexity of the HGM approach together with the assumptions required to calculate functional capacity could limit its usability as a wetland evaluation tool.

The Ecosystem Services Project (CSIRO 2001) provided an inventory of ecosystem goods and services in the Goulburn Broken Catchment, Victoria as a basis for developing sustainable land management practices. The major task of this project was the assessment of interactions between ecosystem services and the multiple benefits they provide to identify those services critical for the catchment. This approach considers benefits for society (through an evaluation of the relative importance of services); risks to ecosystem resilience (through the evaluation of the impact of land-use/ industry on the availability of the services); and feasibility of management responses (manageability of land-use/ industry). Thus, it accounts to some extent for the bi-directional relationship between services and land-use/ industry.

Based on this study, which is focused on socio-economic issues, further research undertaken by the Ecosystem Services Project (CSIRO 2003) estimated benefits of ecosystem services in several case studies representing a range of spatial scales and ecological processes. The study emphasised the need to carefully define ecosystem services and the underpinning biophysical processes, the importance of stakeholder involvement and consideration of the interrelationships between a range of ecological, economic and social values.

2.2 Service assessment

Due to the complexity of wetlands information about the relationships between functions and services at differing scales is limited. As discussed by de Groot et al. (2002), these relationships are likely to be non-linear, one function often supports more than one service and many services require a bundle of supporting functions to be operational. Definition of the relationship between functions and services provided by recent studies (de Groot et al. 2002; Turner et al. 2004) is non-quantitative and does not consider the relative importance of functions in relation to service availability. For example, a small change in the functional capacity of one function (for example fish habitat) might decrease the availability of a service (commercial fishing) far more than a large change in functional capacity of another function. Such models are important steps towards a better understanding of these complex interrelationships.

Ecosystems often exhibit non-linear behaviour once a critical threshold has been violated. Therefore, relatively small changes in ecosystem conditions can result in dramatic or even irreversible changes in ecosystem functioning and thus in the availability of ecosystem services (Limburg et al. 2002). By virtue of this behaviour, Farber et al. 2002 distinguish between efficiency values of services in the linear, marginal region and sustainability values of services in the non-linear, non-marginal region of ecosystems. They argue that depending on the existing ecosystem conditions sustainability values may be more important to society than efficiency values since they prevent the ecological and economic systems from a possible collapse.

Howarth and Farber (2002) discuss the risk of adverse decision making in resource management caused by uncertainty associated with critical thresholds. They argue that limitations in scientific understanding carry the risk of dramatic costs as a result of irreversible degradation of ecosystems. Therefore, the concepts of resilience (Barbier et al. 1994) and strong sustainability (Howarth 1997) and their potential to complement resource management to maintain functionality under a range of shock conditions are frequently discussed in the respective literature (e.g., Howarth and Farber 2002). A decision rule suggested by Farber et al. 2002, a concept not new to economists, is to implement safety standards to maintain the functionality of an ecosystem if the economic costs are reasonable. However, the term ‘reasonable’ is subject to interpretation and depends, among other things, on the value of the ecosystem in question. See Ciriacy-Wantrup (1963) for more discussion about this concept.

The interrelationship between functions and services is complex and further complicates assessment of ecosystem services. In most cases one function supports more than one service (e.g., the function *maintain characteristic hydrological regime* may support the service *drinking water supply* as well as the service *provision of fish habitat*) and most services require a bundle of supporting functions to be operational (e.g., the function *maintain characteristic biochemical* as well as the function *processes maintain characteristic hydrological regime* may be necessary to support the service *provision of fish habitat).*

Definitions of the relationship between functions and services are still non-quantitative in nature and do not consider the relative importance of a function in relation to service availability. However, qualitative approaches are important steps towards a better understanding of the complex interrelationships between functions and service provision. If it is at least possible to qualitatively relate the main functions necessary to produce a specific service at a specified scale some insight into the behaviour of services due to a change in functional capacity can be obtained. Assuming that in general the availability of a service will decrease with a reduction in functional capacity such models could be useful to evaluate the consequences of alternative wetland management options, even though this is likely to be relevant only at the extreme and any estimates of consequences would be attached with a degree of uncertainty. Further interdisciplinary studies conducted by scientists and economists are required to quantitatively examine the interrelationship between functions and services. Achievements in this respect are likely to have the potential to improve the effectiveness and efficiency of wetland management.

2.3 Assessment of threats to wetlands

Approaches concentrating on the evaluation of only those ecosystem services which are pressured or threatened by anthropogenic impacts avoid some of the problems associated with the need to estimate a total value of ecosystems. For example, recent studies exploring approaches towards the management of coastal wetlands are focused on managing causes and consequences of environmental change (Turner et al. 2004; Turner 2000).

The modelling framework for the Turner et al (2004) study was based on the concept of functional diversity defined as "the variety of different responses to environmental change" (Turner et al. 1998:8) and combines a natural system model with a human activity model (input-output model). It models marginal changes in environmental processes as a result of environmental pressures (e.g., increase of nutrient run-off) driven by socio-economic changes, so called driving forces (e.g., intensification of agricultural activities). Such environmental alterations cause changes in social welfare, which are assumed to trigger management actions.

To identify the pressures and their impact on a wetland ecosystem a clarification of the complex interrelationships between dynamic wetland functioning; environmental pressures; and socio-economic drivers was required. For this purpose Turner et al. (2004) suggest the application of the driver–pressure–impacts–response (D-P-S-I-R) framework as a scoping device. Furthermore, they emphasize the importance of considering impacts of global environmental changes (e.g., climate change) to make such models meaningful.

The main shortcoming of this approach is the need to assign a monetary value to the benefits obtained from wetland services. The apparent need to estimate a monetary value for ecosystem services constrains the evaluation to considering only the threats and management of threats where the impact can be valued.

Approaches such as those suggested by Turner et al. (2004) go someway towards integrated wetland management as they provide a framework to conduct a threat assessment to quantify the biophysical effects of pressures and the subsequent increase or decrease in functional capacity of wetland functions. However, modelling a change in functional capacity requires quantifying the impacts on each variable defining the function models.

Wetland ecosystems are frequently characterized as ephemeral landscape features, that is, over time existing wetlands vanish while new ones emerge (Orme 1990). In this context, Constanza et al.(1990) highlight the importance of distinguishing the effects of anthropogenic impacts from natural changes. Knowing whether changes are caused by natural forces or human driven processes is crucial to predict the probable consequences of management actions and thus to guide the selection of management options. However, an estimation of the future state of a wetland due to natural evolution or higher scale anthropogenic impacts is an extremely difficult task. Developing if-then scenarios may be a possible approach to consider wetland variability and reduce uncertainty. Further scientific studies are required.

2.4 Approaches to evaluation of wetland management

Cost-benefit analysis (CBA) is considered the standard evaluation approach in natural resource management. However, CBA has been increasingly criticised when the resource management issues are complex and uncertain and where non marketed costs and or benefits are involved in the evaluation. Further discussion about general problems and limitations of CBA in the context of natural resource management are discussed elsewhere (Graves 2007).

An increasingly adopted approach to valuation of environmental improvement which provides valuable information for evaluation, particularly those adopting CBA, is choice modelling (CM) (Alvarez-Farizo et al. 2007; Carlsson et al. 2003; Robinson et al. 2008). CM is a stated preference approach that can be used for quantifying benefits of marginal changes in the availability of ecosystem goods and services, which are not traded in the market and have no market value. CM estimates implicit prices in monetary terms using choice experiments (Carlsson et al. 2003). Implicit prices indicate the worth of environmental improvements for an individual (consumer surplus). It is therefore is an interesting approach for this study as it allows comparison of consumer surplus with management costs for alternative management scenarios. This is of particular importance since resources are frequently limited and management decisions are often accompanied by high opportunity cost. Furthermore, evaluating the consumer surplus of different stakeholder groups provides an insight into service preferences and distributional effects. However, insufficient knowledge of the relationship between functions and services and thus between functions and benefits limits the information base on which the choices are made. This carries the risk of misinterpretations made by respondents of CM surveys resulting in misleading information and consequently adverse decision-making.

One approach to ecosystem evaluation that has gained increasing recognition in the literature is cost–utility analysis (CUA). CUA, initially applied in health economics (Drummond et al. 1997), is now increasingly adopted in ecological economics (Cullen et al. 2001). CUA differs from CBA as it measures only costs in monetary units. Benefits are evaluated in non-monetary terms based on the utility function providing relative values for alternative management scenarios. The possibility to compare costs with utility supports informed decision-making in natural resource management particularly when monetary values for benefits are not available. In this way CUA provides the opportunity to include a number of non-market measures of benefits from natural resource improvement in the same evaluation such as reduced nutrient load as well as number of native fish species and length of river with riparian vegetation. This removes the need to use non-market-valuation techniques to assign a monetary value. Applying CUA to resource management problems requires the estimation of costs for alternative management scenarios.

CUA has recently been used as a decision support tool to maximize total utility (in terms of a total environmental benefit score) from selected natural resource management projects, given a specified budget constraint (Hajkowicz et al. 2007).

King et al. (2000) suggest a methodology to develop wetland value indices based on the FCI (see the discussion on the HGM approach, section 2.1). These value indices are weighted aggregate scores assessing service level, nominal service value, risk adjusted service value and preference-weighted service value. In their study, King et al. 2000 suggest criteria such as habitat, development and socio-economic characteristics, scarcity of services, availability of substitutes, population served, costs of service access and preferences to evaluate benefits from wetland services. However, the reliability of information with respect to the relationship between functions and services as well as between services and benefits defines the significance of the calculated wetland value indices. Since knowledge about the relationship between functions and services is still very limited the obtained numeric results may bear the risk of pseudo accuracy. In addition, a single index could mask a potential problem within the wetland where one function dominates the wetland at the expense of other, possibly critical functions.

3. Proposed conceptual model to support integrated wetland management

Based on the findings from the review, a conceptional model comprised of seven modules has been developed (see figure 1). This section describes the design, function and relevance of each module as well as the interrelationships between them.

The modules are:

1. Assessment of the current condition of wetland functions (*functional assessment*)
2. Assessment of current and planned anthropocentric threats to future availability of wetland functions based on a sensitivity analysis to select relevant functions and threats (*threat assessment*)
3. Assessment of relationships between selected functions and services (*service assessment*)
4. Assessment of magnitude, particularly direction, and distribution of benefits provided by these services (*benefit assessment*)
5. Appraisal of alternative management scenarios by evaluating their impact on functions/ services/ benefits and management costs using CUA (*management assessment*)
6. Development of trade-off matrices as a decision support tool

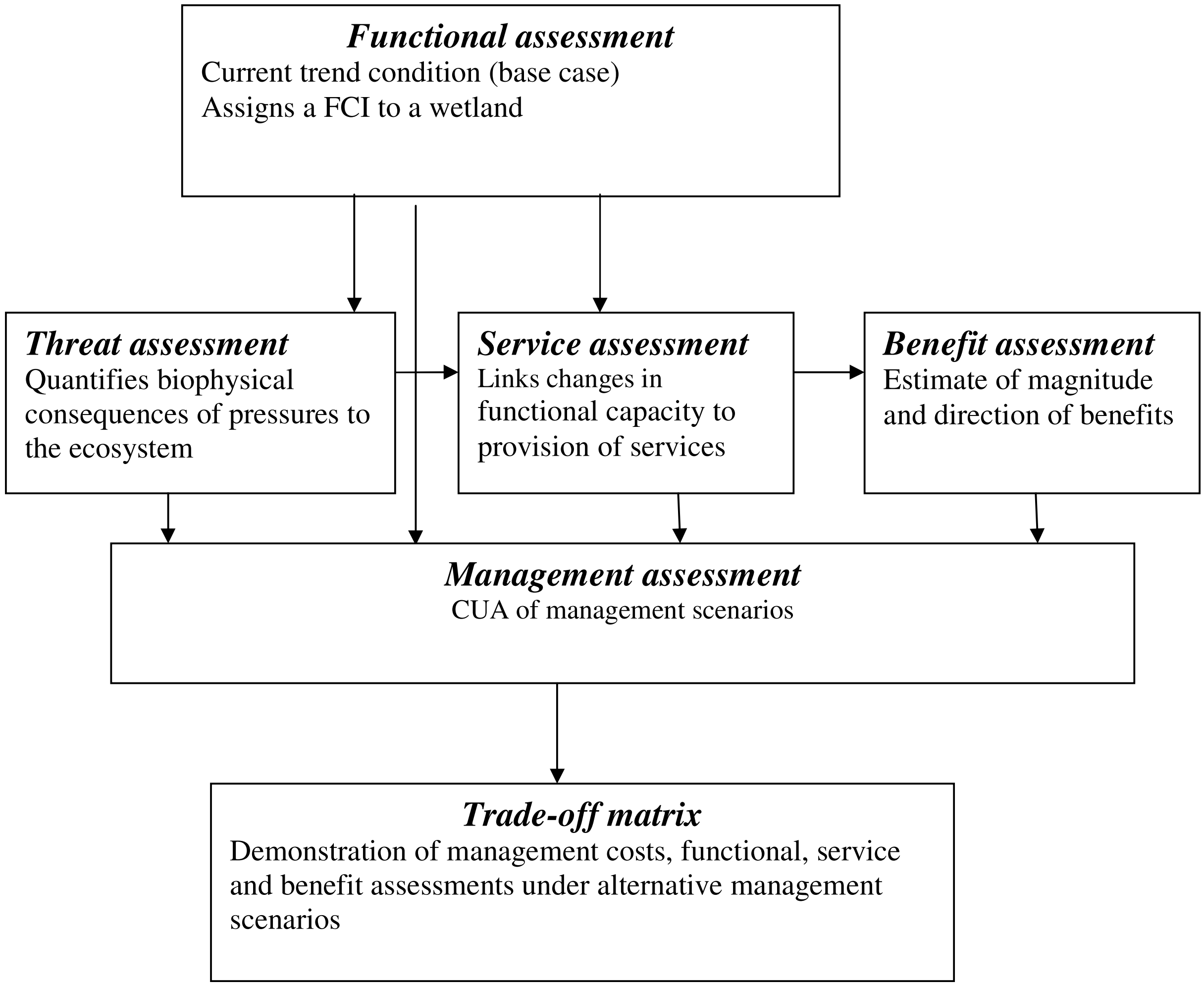

Figure 1: Conceptual model for integrated wetland management

The ***functional assessment*** requires an evaluation of the biophysical conditions for relevant wetland functions under present conditions (base case scenario) based on available science.

The purpose of the ***threat assessment*** is to quantify the biophysical consequences of pressures and the subsequent change in the condition of wetland functions combining a natural system model (biophysical approach) with a human activity model. Conducting a sensitivity analysis to identify the most damaging pressures (threats) and the most sensitive functions. The results provide the basis for a management strategy focused on socio-economic pressures posing a threat to wetlands and their subsequent ability to maintain functions and hence services. The assessment of wetland functions has to be done against the background of natural wetland evolution as well as against anthropogenic impacts caused at a higher spatial scale outside the reference area. Distinguishing those impacts from anthropogenic impacts at the defined management scale is crucial for the benefit assessment and the validation of the effectiveness and efficiency of management alternatives.

The ***service assessment*** links changes in the condition of functions identified through the threat assessment to changes in service availability. Wetland services provide a wide range of benefits to society. An assessment of changes in these benefits (***benefit assessment***) provides additional information about the consequences of change in the functional capacity of a wetland. The objective of a benefit assessment, given the limited availability of information, can only be to provide an indication about the magnitude, particularly direction, and distribution of benefits in order to appraise the consequences of changes in service availability due to different management scenarios

The ***management assessment*** proposed uses CUA to assess alternative management scenarios with respect to their impact on wetland functions and their management costs. In this study, CUA is based on a *functional assessment* (evaluation of current conditions), *threat assessment* (evaluation of trend conditions to identify the greatest threats and most sensitive functions to be managed) as well as on the identification and cost of alternative management scenarios. Using CUA, changes in utility can be evaluated as changes in (1) conditions of relevant wetland functions (*functional assessment*), (2) availability of related services (*service assessment*) and (3) magnitude, particularly direction, and distribution of benefits (*benefit assessment*). Finally, comparing cost-utility for alternative management scenarios provides the opportunity to prioritise management of wetlands.

Presentation of the information from the CUA facilitates the appraisal of inherent trade-offs associated with alternative management options under alternative assumptions. ***Trade-off matrices*** at alternative temporal and spatial scales exhibiting respective changes in management costs, functional assessment, service assessment and benefit assessment allow comparison of the same management scenarios under alternative assumptions. Trade-off matrices for alternative stakeholder groups exhibiting respective changes in consumer surplus reveal inherent trade-offs between long run and short run interests and conflicting preferences between stakeholder groups.

4.0 Conclusion

This paper proposes that an evaluation approach combining an economic evaluation (CUA) with a scientific approach to assess wetland functioning (such as the HGM approach) has the potential to improve wetland management. Such an approach facilitates the identification of the trade-offs between the ecological sustainability of a wetland, in the form of functional capacity and the services subsequently produced and wetland development applications which could provide increased economic growth and social equity.

A dynamic and quantitative functional assessment such as HGM offers the opportunity to consider interrelationships between functions and services produced and therefore has the ability to address the complexity, multi-functionality and dynamic nature of wetland systems. However, there are a number of limitations. The major limitations include the lack of information identifying thresholds for resilience to sustain wetland integrity; the restriction of functional approaches to wetland assessment that rely solely on wetland functioning within a regional subclass; and, the difficulties in estimating the future state of a wetland due to natural evolution and anthropogenic impacts at higher spatial scales.

CUA has been identified as a promising approach to evaluate the consequences of development in wetland areas. However, existing explanations about the relationship between functions and services are non-quantitative in nature and do not consider the relative importance of a function in relation to service availability. Furthermore, the information to correlate wetland integrity (including thresholds for wetland resilience) with service availability is severely limited. Consequently, utility can only be evaluated in terms of functional capacity (qualitatively related to services). This means that wetland functioning has to be managed to maintain all aspects of wetland integrity, that is, managing all threats which have a significant impact on the functions considered in the framework. It is important therefore to monitor individual changes in functional capacity rather than providing a single aggregated and/or weighted index. This could mask a potential problem within the wetland where one function dominates the wetland at the expense of other, possibly critical functions and thus carries the risk of adverse decision-making.

Matrices for alternative management scenarios for identified stakeholder groups exhibiting respective changes in consumer surplus have the potential to reveal conflicting preferences and inherent trade-offs between long run and short run interests. Trade-off matrices at alternative temporal and spatial scales exhibiting respective changes in management costs, consumer surplus and related service importance, allow a comparison of the management scenarios under alternative assumptions.

A lack of information presently constrains the usability of the proposed evaluation framework. Nevertheless, the framework has the potential to provide useful information to support informed decision-making for specific management problems. Further interdisciplinary research conducted by scientists and economists is needed to provide the necessary information to exploit the potential opportunities and expand the usability of the framework. Future research is required to (1) assess wetland functioning at a landscape scale; (2) provide reliable estimation of the future state of a wetland due to natural evolution and anthropogenic impacts at higher spatial scales; (3) provide quantitative estimates of relationships between functions and services; and (4) estimate the level of correlation between wetland integrity (including thresholds for wetland resilience) and service availability. Achievements in this respect are likely to improve the effectiveness and efficiency of wetland management.

References

Acharya, G. 2000. 'Approaches to valuing the hidden hydrological services of wetland ecosystems', *Ecological Economics*, 35: 63-74

Adger, W.N. and Luttrell, C. 2000. 'Property rights and the utilisation of wetlands', *Ecological Economics*, 35: 75-89.

Alvarez-Farizo, B., Hanley, N., Barberán, R. and Lázaro, A. 2007. 'Choice modelling at the "market stall": individual versus collective interest in environmental valuation', *Ecological Economics*, 60: 743-751

Barbier, E.B., Burgess, J.C. and Folke, C. 1994. *Paradise lost? The ecological economics of biodiversity*. Earthscan, London

Brinson, M.M., Rheinhardt, R.D., Hauer F.R., Lee, L.C., Nutter, W.L., Smith, R.D. and Whigham, D. 1995. *A guidebook for application of hydrogeomorphic assessments to riverine wetlands*. Technical Report WRP-DE-11 (operational draft). US Army Corps of Engineers. Wetland Research Program. Waterways Experiment Station, Vicksburg, Massachusetts.

Carlsson, F., Frykblom, P. and Liljenstolpe, C. 2003. 'Valuing wetland attributes: an application of choice experiments', *Ecological Economics*, 47: 95-103

Ciriacy-Wantrup, S.V. 1963. *Resource conservation: economics and policies*. Division of Agricultural Sciences, University of California, University of California Press

Clairain, E.J.Jr. 2002. *Hydrogeomorphic approach in assessing wetland functions: guidelines for developing regional guidebooks. Chapter 1: Introduction and overview of the hydrogeomorphic approach*. ERDC/EL Technical Report 02-3. US Army Corps of Engineers. Wetland research program. Vicksburg, Massachusetts.

Constanza, R., Sklar, F.H. and White, M.L. 1990. 'Modeling coastal landscape dynamics', *BioScience*, 40(2): 91-107.

CSIRO Sustainable Ecosystems (ed.) 2003. *Natural values: Exploring options for enhancing ecosystem services in the Goulburn Broken Catchment.*

CSIRO Sustainable Ecosystems (ed.) 2001. *Natural assets: An inventory of ecosystem goods and services in the Goulburn Broken Catchment.*

Cullen, R., Fairburn, G.A. and Hughey, K.F.D. 2001. 'Measuring the productivity of threatened species programs', *Ecological Economics*, 39: 53-66

deGroot, R.S., Wilson, M.A. and Boumans, R.M.J. 2002. 'A typology for the classification, description and valuation of ecosystem functions, goods and services', *Ecological Economics*, 41: 393-408

Drummond, M., Torrance, G.H. and Mason, J. 1997. *Methods for the economic evaluation of healthcare programs* (2nd edition). Oxford University Press, Oxford

EHMP 2005. *Ecosystem Health Monitoring Program) 2003-2004 technical report*. Moreton Bay Waterways and Catchment Partnership: Brisbane

Farber, S.C., Constanza, R., Wilson, M.A. 2002. 'Economic and ecological concepts for valuing ecosystem services', *Ecological Economics,* 41: 375-392

Graves, P. 2007. *Environmental economics: a critique of benefit-cost analysis*. Rowman & Littlefield Publishers, Lanham, MD

Hajkowicz, S., Higgis, A., Williams, K., Faith, D.P. and Burton, M. 2007. 'Optimisation and the selection of conservation contracts', *The Australian Journal of Agriculture and Resource Economics*, 51: 39-56

Hein, L., vanKoppen, K., deGroot, R.S. and vanIerland, E.C. 2006. 'Spatial scales, stakeholders and the valuation of ecosystem services', *Ecological Economics*, 57: 209-228

Howarth, R.B. 1997. 'Sustainability as opportunity', *Land Economics*, 73: 569-579

Howarth, R.B. and Farber, S. 2002. '*Accounting for the value of ecosystem services', Ecological Economics*, 41: 421-429

King, D.M., Wainger, L.A., Bartoldus, C.C. and Wakeley, J.S. 2000. *Expanding wetland assessment procedures: linking indices of wetland function with services and values*. ERDC/EL Technical Report 00-17. US Army Corps of Engineers. Wetland Research Program. Engineer Research and Development Centre Vicksburg, Massachusetts

Laegdsgaard, P. 2006. 'Ecology, disturbance and restoration of coastal saltmarsh in Australia: a review', *Wetlands Ecology and Management*, 14: 379-399

Limburg, K.E., O'Neil, R.V., Constanza, R. and Farber. S. 2002. 'Complex systems and valuation', *Ecological Economics*, 41: 409-420

Mitsch, W.J. and Gosselink, J.G. 1993. *Wetlands*. 2nd edition. Van Nostrand Reinhold: New York.

Orme, A.R. 1990. 'Wetland morphology, hydrodynamics and sedimentation'. In *Wetlands: A threatened landscape*. Basil Blackwell: Cambridge (UK) and Oxford

Ramsar, http://www.environment.gov.au/water/topics/wetlands/ramsar-convention/index.html

Robinson, J., Clouston, B., Suh, J. and Chaloupka, M. 2008. Are Citizens' Juries a useful tool for assessing environmental value? *Environmental Conservation,* 35 (4): 351-360.

Roise, J.P., Gainey, K.W. and Shear, T.H. 2004. 'An approach to optimal wetland mitigation using mathematical programming and geographic information system based wetland function estimation', *Wetlands Ecology and Management*, 12: 321-331

Shabman, L., and Scodari, P. 2005. 'The Future of Wetlands Mitigation Banking", *Choices*, 20 (1): 65-70.

Smith, M.J., Schreiber, E.S., Kohout, M., Ough K., Lennie, R., Turnbull, D., Jin, C. and Clancy, T. 2007. 'Wetlands as landscape units: spatial patterns in salinity and water chemistry', *Wetlands Ecology and Management*, 15: 95-103

Smith, R.D. 2001. H*ydrogeomorphic approach in assessing wetland functions: guidelines for developing regional guidebooks. Chapter 3: developing a reference wetland system*. ERDC/EL Technical Report 01-29. US Army Corps of Engineers. Wetland Research Program. Engineer Research and Development Centre, Vicksburg, Massachusetts.

Smith, R.D., Ammann, A., Bartoldus, C. and Brinson, M.M. 1995. *An approach for assessing wetland functions using hydrogeomorphic classification, reference wetlands, and functional indices*. Technical Report WRP-DE-9. US Army Corps of Engineers. Wetland Research Program. Waterways Experiment Station, Vicksburg, Massachusetts.

Turner, R.K., Bateman, I.J., Georgiou, S., Jones, A., Langford I.H., Matias, N.G.N. and Subramanian, L. 2004. 'An ecological approach to the management of a multi-purpose coastal wetland', *Regional Environmental Change,* 2-3: 86-99.

Turner, R.K., van den Bergh, J.C.J.M. and Brouwer, R. 2003a. 'Introduction'. In *Managing wetlands. An ecological economics approach*. Edited by R.K. Turner, J.C.J.M. van den Bergh and R. Brouwer. Edward Elgar: Cheltenham, Northhampton: 1-16.

Turner, R.K., Paavola, J., Cooper, P., Farber, S, Jessamy, V. and Georgiou, S. 2003b. 'Valuing nature: lessons learned and future research directions', *Ecological Economics*, 46: 493-510

Turner, R.K. 2000. Integration natural and socio-economic science in coastal management`, *Journal of Marine Systems,* 25: 447-460.

Turner, R.K., van den Bergh, J.C.J.M., Söderqvist, T., Barendregt, A., van der Straaten, J., Maltby, E. and van Ierland, E.C. 2000. 'Ecological-economic analysis of wetlands: scientific integration for management and policy', *Ecological Economics*, 35: 7-23.

Turner, R.K., Adger, W.N. and Lorenzoni, I. 1998. *Towards integrated modelling and analysis in coastal zones: principles and practices*. LOICZ reports and studies no. 11. LOICZ International Project Office. Netherlands Institute for Sea Research, Texel

Winkler, R. 2006. 'Valuation of ecosystem goods and services. Part 1: An integrated dynamic approach', *Ecological Economics*, 59: 82-93