AQUATIC CONSERVATION: MARINE AND FRESHWATER ECOSYSTEMS
Aquatic Conserv: Mar. Freshw. Ecosyst. **14**: 413–433 (2004)
Published online 1 June 2004 in Wiley InterScience
(www.interscience.wiley.com). DOI: 10.1002/aqc.618

CASE STUDIES AND REVIEWS

Defining the ecological values of rivers: the views of Australian river scientists and managers

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ABSTRACT

1. The first step in making a case for river conservation is to define the particular values and attributes that describe conservation significance.
2. Australia's rivers vary widely in their characteristics and ecological communities. The conservation values of Australian rivers have not been well articulated.
3. A survey of Australian river scientists and managers was undertaken to identify the criteria and attributes of rivers of high ecological value. This was the first attempt to establish a baseline for defining natural conservation values for Australian rivers.
4. The final list comprised five broad criteria with a total of 47 attributes considered to be indicators of high ecological value. These included not only biotic values, but also values attributed to river hydrology, geomorphology, instream processes, and landscape functions.
5. The list of criteria and attributes provides a context from which specific values may be drawn to assess conservation values of rivers for particular purposes.

KEY WORDS: river conservation; identification; conservation criteria; opinion survey

INTRODUCTION

Background

There is increasing worldwide concern for the loss of river landscape and biodiversity values. Allan and Flecker (1993: 32) suggest that, in the 'biodiversity crisis', attention has been focused on tropical moist forests, with perhaps a growing interest in ocean conservation, but 'freshwater systems have received less attention ... and rivers and streams perhaps least of all'. This neglect, they claim, is despite the fact that 'running waters harbour a diverse and unique panoply of species, habitats, and ecosystems, including some of the most threatened species and ecosystems on earth, and some of those having greatest value to human

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Received 5 June 2002
Accepted 8 December 2003

society'. Concern about conservation values of rivers is confounded by issues of providing clean and adequate water supplies, exemplified by the European Union Water Framework Directive (European Communities, 2000) and similar legislative and policy strategies elsewhere. River management agendas tend to be dominated by issues of maintaining water quality and quantity, which, although these provisions may assist in conservation of aspects of the river environment, do not necessarily specifically target conservation values.

International agreements for protection of biodiversity, notably the Convention on Biological Diversity, encompass all ecosystems, but few countries are addressing biodiversity conservation in freshwater systems, especially rivers, in any systematic way. Development of the theory and practice of conservation has indeed been dominated by terrestrial ecology (Dunn, 2003), and only in recent years has attention turned to issues of systematic conservation management of river systems (Boon *et al*., 1992, 2000; Moyle and Yoshiyama, 1994; Boon *et al*., 2000; Georges and Cottingham, 2002; see Biodiversity Convention website: www.biodiv.org/decisions (22 May 2001). The special difficulties and constraints that affect protection of fluvial systems have been noted (Ladle, 1991) but not addressed in a strategic fashion. The lack of progress on river conservation is mirrored by a lack of progress towards appropriate conservation assessment methodologies for river systems. For example, techniques for assessment of biodiversity 'mostly deal implicitly if not explicitly with terrestrial ecosystems' (UNEP, 1997).

In arguing the case for river conservation, Boon (1992) suggests that rivers must be considered from a five-dimensional perspective. Drawing on Ward's (1989) four-dimensional model to describe river ecosystems, Boon (1992) claims that, in making a case for river conservation, a fifth 'conceptual' dimension must be added. This fifth dimension should address questions of philosophy, policy and practice. Boon's (1992) questions include: 'Why are we concerned about conservation?' and 'What are we trying to conserve?'.

These questions have been debated over the years for terrestrial systems, and the responses are continually evolving. Once driven largely by so-called 'rare' species, often charismatic megafauna that attract the public eye, the conservation agenda has now broadened its focus. The importance of conservation at an ecosystem level is recognized, as well as the need to protect representative systems even where these are apparently de-pauperate compared with highly diverse systems. Species that contribute to understanding Earth history and contribute genetic diversity, such as endemic taxa or remote populations, are also now considered of conservation significance (WCMC, 1998).

'Conservation value', or what is considered important in the ecological sense, may be at least partly reflected in legislation or policy. International agreements, such as the Ramsar Convention (Ramsar Convention Bureau, 1996) and World Heritage Convention (World Heritage Operational Guidelines website: www.unesco.org/whc/opgutoc.htm (18 March 2003)) lay out a series of criteria by which value is defined for assessment purposes. At national level, Australia has a suite of criteria for natural values for sites to be listed in the Register of the National Estate. Similar approaches occur elsewhere, e.g. the selection of Sites of Special Scientific Interest (SSSIs) in Britain (Nature Conservancy Council, 1989).

None of these agreements or programmes has been particularly shaped with rivers in mind, and, in some instances, the criteria and thresholds may be difficult to adapt to river systems. For example, the Ramsar Convention has its origin in the protection of bird habitats, and this is still reflected in the bias of the criteria and thresholds. The guidelines for SSSIs do make specific references to river systems, and several British rivers have met the criteria for listing (Nature Conservancy Council, 1989; Boon, 1991).

Protocols designed to assess conservation values and/or status can *de facto* demonstrate what may be the values considered significant for conservation or protection. Conservation assessment protocols designed specifically for rivers include the System for Evaluating Rivers for Conservation (SERCON: Boon *et al*., 1994, 1997, 2002) for Britain, O'Keeffe's 'expert system' approach for South Africa (O'Keeffe *et al*., 1987), progress towards a protocol for assessment of New Zealand rivers (Collier, 1993), and a broader classification scheme for US rivers to implement the Wild and Scenic Rivers Act (1968). Although there are some common themes amongst the conservation criteria adopted in these various approaches, there are also differences in the scope of criteria, the scale of analysis, and the emphasis given to the various elements.

The Australian context

Australia is the driest of the inhabited continents (Lake, 1995; White, 2000). It has the lowest percentage of rainfall as run-off, the least amount of water in its rivers, and the most variable rainfall and stream flow in the world (Finlayson and McMahon, 1988; Puckridge *et al*., 1998). These characteristics create rivers of varied and distinctive hydrology. In addition, inland streams have high natural salinity and turbidity, with the chemistry often dominated by sodium chloride rather than the more usual calcium or magnesium carbonates (DEST, 1996). A range of climates, from wet tropical to cold temperate and even alpine, provides various temperature regimes for the associated biota.

Australia's freshwater biota has several distinctive features. Many invertebrate species, genera, and some families are endemic to the country or a region within it (Environment Australia, 1997; WCMC, 1998; Wilson and Johnson, 1999; Zwick, 2000). Several groups that are generally widespread worldwide are absent from Australian rivers, whereas a few families have adapted to a wider range of habitats (Blyth, 1983; Lake *et al*., 1985; Lake and Marchant, 1990). The fauna is characterized by flexible life histories, probably in response to the extreme variability of climatic influences (Hynes and Hynes, 1975; Lake *et al*., 1985; Lake, 1995; White, 2000). Australia's rivers are considered to have high conservation values, but these are yet to be protected in any systematic way. 'There is little direct activity in reserving river conservation areas at the national level in Australia' (Schofield *et al*., 2000). Protection of water quality and quantity may have consequences for conservation of river ecosystems, but this is incidental to the primary purpose for the respective legislation (Schofield *et al*., 2000).

The State of the Environment Report (DEST, 1996) paints a bleak picture of the environmental status of Australia's rivers. In the 200 years since white settlement, land clearance, water regulation, impacts on water quality, river engineering, and introduced species have had a massive impact on natural riverine and floodplain environments. The report suggests that 'most rivers in the lowlands and in agricultural catchments are degraded, with moderate to severe disturbance of riparian and channel habitats as well as increases in salinity, decreases in flow, changes in flow regimes and increased sediment loads' (DEST, 1996). Australia has the highest per capita water storage of all countries in an effort to moderate the impact of its variable rainfall (DEST, 1996). Water storage for power generation, water supply, and irrigation has permanently altered the nature of many of the largest rivers. This has had consequences not only for instream processes and biota, but also for floodplains and wetlands. The river systems of the more populous coastal plains in all parts of the country exhibit the greatest modifications to the natural condition; in contrast, some rivers in sparsely inhabited parts of the country may remain in virtually natural condition.

The major focus of general conservation effort in Australia on a national scale has been expressed through threatened species legislation (EPBC, 1999), the Biodiversity Strategy (EA, 1998) and Regional Forest Agreements (RFAs: www.rfa.gov.au (22 July 2003)). Commonwealth legislation for nationally listed threatened species and ecosystems is now incorporated under the Environment Protection and Biodiversity Conservation (EPBC) Act 1999 and this legislation is mirrored at state level with similar acts for locally listed species. Under the EPBC Act, some 24 freshwater fish species are listed, along with numerous frogs and some freshwater reptiles. Invertebrates are poorly represented (14 species) given their overall number of species, with just six aquatic taxa listed, including five Tasmanian endemic decapod crustaceans (Environment Australia Threatened Species website: http://www.ea.gov.au/biodiversity/threatened/communities/index.html (17 July 2003)). Several aquatic sites are listed as threatened ecosystems; these are all very small-scale and highly specialized habitats, such as mound springs and aquatic root mat communities (http://www.ea.gov.au/biodiversity/threatened/communities/index.html (17 July 2003)).

The National Reserves Program is a major element of the Biodiversity Strategy, signed in compliance with the international convention (EA, 1998). This program sets out as a priority the establishment of representative 'terrestrial and marine reserves', and it appears that freshwater reserves do not fall within its ambit. The RFAs (www.rfa.gov.au (22 July 2003)) are designed to protect Comprehensive Adequate and Representative ('CAR') forest reserve systems. The National Reserve System is fostering programmes to protect a range of other ecosystems, such as grasslands, wetlands, and marine reserves, but the Commonwealth Government has lagged behind in any attempts to protect river systems. One major practical impediment to progress is the absence of clear criteria for conservation values and assessment frameworks for river conservation planning.

Any conservation efforts in Australia are complicated by constitutional issues. Although the Commonwealth (federal) government may set directions, policies, and strategies for conservation, the responsibility for land and water management lies with each State. Efforts of the Commonwealth Government may be frustrated by a range of institutional barriers stemming from the consequences of the political, legislative, and administrative structure (Maher and Associates, 2000; Schofield *et al*., 2000). Thus, nomination for listing of sites on public land under the Ramsar Convention must be agreed between the respective State Government and the Commonwealth Government. Protection of river conservation values may also be compromised by Commonwealth agreements with the States under Water Reform Agenda (COAG, 1994; Cullen *et al*., 2000) and consequent water reform activities targeting water development with only limited consideration of provisions for 'the environment'. General Commonwealth and State policy commitments to the protection of biodiversity have yet to be translated into strategy and action with respect to freshwater habitats (Schofield *et al*., 2000).

If the case for conservation of rivers is to be promoted then it is important to establish what we are trying to conserve (Boon, 1992). This needs to be done in collaboration with a representative range of people involved with rivers in Australia to ensure that the distinctive characteristics and behaviour of Australian rivers are captured. Values identified for rivers should also reflect the wider conservation agendas and strategies. A shared view of ecosystem values is important as the basis for pressure for protection and conservation in management. Some shared understanding of river values will underpin design of appropriate assessment strategies, act as a checklist to ensure that important values are not overlooked in conservation management, and provide the basis to evaluate conservation effort.

The purpose of the study

The purpose of the study was to canvass opinions on what constitutes the 'ecological value' of rivers. The results of the study would provide a picture of the scope of ecological values of rivers to inform conservation endeavours and processes in Australia. It was not intended to provide a format for river assessment, although the evidence the research provided could be used to formulate the development of a range of assessment protocols.

Expert opinion has been used in the development of river assessment protocols. O'Keeffe *et al*. (1987) sought the views of 'all ecological workers and professional conservationists on river systems in South Africa'. The number of respondents is not specified, but the maximum number of responses to any single item is 17. Respondents were asked to weight the relative importance for conservation from a list of river attributes grouped as attributes of the river, the catchment, and the biota. Both positive and negative aspects were included. In New Zealand, a conference workshop of the Limnological Society in 1987 arrived at six criteria that could be used to assess aquatic reserve value (Collier, 1993). This conceptual framework was explored by Collier and McColl (1992), and a second Limnological Society workshop in 1991 addressed the issue of defining descriptors that could be used in an assessment (Collier, 1993). Further refinement of the proposed descriptors and weightings was undertaken by a survey of 36 limnologists, which yielded 29 responses (Collier, 1993). Respondents were asked to provide ratings for lists of descriptors for four criteria: degree of modification; diversity and pattern; rarity and unique features/species; and fragility. Additional descriptors could also be offered, although these were not used in the subsequent river trial assessment.

The Project Development Group formulating the SERCON protocol devised a provisional list of attributes and then sought the views of a Specialist Group on the appropriateness for the river evaluation scheme (Boon *et al*., 1997). The Specialist Group comprised more than 150 individuals and 25 organizations spanning a wide range of expertise relevant to conservation (Boon *et al*., 1997). Attributes were grouped under five categories: physical descriptors; catchment characteristics; physical and chemical characteristics of channel and floodplain; biotic characteristics; and aquatic impacts. The group was asked to register acceptance or rejection of each one. A broad degree of approval resulted from the 123 responses received. Further refinement of the criteria and attributes led to the final SERCON protocol. This has six conservation criteria (physical diversity, naturalness, representativeness, rarity, species richness and special features), along with a set of attributes for an assessment of impacts (Boon *et al*., 1997). A revised version, SERCON 2, has recently resulted from a review of the assessment protocol (Young Associates, 1999). The core principles remain, with the main structural difference to the criteria being the combination of most species attributes in the criteria naturalness and representativeness (Boon *et al*., 2002).

No exercise to define conservation values for Australian rivers has been undertaken. The RFAs (www.rfa.gov.au (22 July 2003)) might be considered the only parallel in terrestrial systems. Criteria to assess forest values were developed through expert panels, workshops, and other consultative processes, and these yielded some criteria that are not evident in any of the international river assessment protocols. These included biogeographic values (endemism, relict populations), maintenance of long-term ecological processes (such as places important for vegetation succession), important natural history sites (type localities, scientific reference sites) and landscape-scale values (old growth forests, natural landscapes).

In attempting to contribute to a general framework for river conservation in Australia, a number of questions emerge. Are the kinds of values reflected in river assessment protocols developed overseas relevant and adequate for Australian rivers? Are conservation values identified for forests also important for river conservation in Australia? Are there other values that have emerged as the concepts of biodiversity conservation generally have evolved? More specifically, are some values considered irrelevant or of higher importance than others? Do people with different discipline backgrounds, interests, or roles have different perceptions of what is important?

The study set out to provide some answers to these questions and, in at least a preliminary way, promote and stimulate debate on systematic approaches to river conservation in Australia.

METHODS

The general strategy

The purpose of the study was to gather opinions on what constitutes values worthy of conservation for Australian rivers. The notion of conservation value was limited only to 'ecological value' and did not include other potential conservation values, such as historic or cultural significance. Opinions were sought from people considered to have an interest in, or experience of, river conservation.

The major focus of this study was a survey of river scientists and managers from across Australia. Non-probability purposive sampling (May, 1997), also known as purposeful sampling (Patton, 1990), was adopted as the survey strategy. Non-probability sampling is used where there is no clear sampling frame; that is, the size of the target population is unknown. This approach can be justified on the criterion of 'fit for the purpose' of the research. In this case, it was not readily possible to delimit the target population of respondents, broadly defined as people who were likely to have views about, experience of, or interest in river conservation. The sampling was purposive; that is, the selection of target respondents is made according to a particular characteristic (May, 1997) and, in this case, translated in practical terms to those with expertise in river ecology or responsibility for river management, including water policy and planning.

The study was guided by a Reference Group that acted both as an expert panel in the development of the items in the survey questionnaire and as a source of information about potential survey respondents. The iterative use of the Reference Group in all stages of the research also contributed to the quality control and validity of the survey process (Bradshaw and Stratford, 2000). The project Reference Group included river experts from different states in Australia and with experience in rivers in different climate zones. The expertise of group members brought a range of scientific perspectives on rivers: floodplain rivers, tropical rivers, river geomorphology, invertebrates, fish, and river management. The Reference Group operated by tele-conference and e-mail because of the costs and logistics of Australia-wide representation on the group.

Steps in the study

Possible conservation criteria were extracted from a range of sources relating to both river assessment specifically and more general conservation assessment processes. These sources included: published approaches to assessment of river values (O'Keeffe *et al.*, 1987; Collier, 1993; Boon *et al.*, 1994, 1997); international agreements and national policies (Ramsar Convention Bureau, 1996; EA, 1997, 1998); and strategic approaches to conservation assessment for other ecosystems, notably forests and marine reserves (Gubbay, 1995; ANZEEC, 1998; www.rfa.gov.au (22 July 2003)). The Commonwealth Register of the National Estate (Australian Heritage Commission Act, 1975) was another source of potential conservation criteria and values for Australia's natural heritage. The register lists sites in a similar way to the SSSIs in Britain (Nature Conservancy Council, 1989). A draft list of criteria and attributes was compiled by integrating relevant criteria and values from all these sources. The draft list categorized ecological values in five groups or broad criteria: naturalness, diversity, rarity, representativeness, and other special values. Under each criterion a suite of attributes for elements of river ecosystems was defined.

The list of candidate criteria and attributes was reviewed by the project Reference Group. The broad criteria were agreed and some new attributes were contributed by the Reference Group, particularly relating to inherent hydrogeomorphic values and characteristics and to functional aspects of rivers. Attributes relating both to instream function and the role of rivers within the landscape were also added. As a result of input from this expert group, a revised draft list was produced which formed the basis of a questionnaire offered to river scientists and managers.

The questionnaire was designed using largely closed questions; that is, questions requiring a specific response rather than open-ended answers. Each approach has advantages and disadvantages (May, 1997). For the purposes of this study, the advantages of closed questions (constraining responses, consistency, forcing answers, efficiency of analysis) outweighed the advantages offered by use of open-ended questions (individual interpretations and in-depth responses).

A list of known researchers, including names of Australian scientists taken from contributions to the recent limnological literature, and key personnel in river management agencies (State government authorities) was compiled in collaboration with the project Reference Group. 'River managers' included senior government agency water policy and planning officers. Government agencies also have their own limnological research staff. 'Ecology' of rivers was interpreted in the broadest possible sense, including river geomorphology, landscape-scale issues, floodplains, and river processes. Efforts were made to ensure all States were represented amongst targeted recipients, although of course many Australian researchers have interests and knowledge that extend beyond their home state boundaries.

In a covering message explaining the purpose and nature of the study, it was also suggested that the survey could be forwarded to others who might be interested, or to more appropriate individuals in the case of management authorities. This 'snowball' sampling is an addition to the purposive sampling where the target group may be widely distributed or not readily accessed (Patton, 1990; May, 1997). It was used in this instance to attempt the widest possible distribution and inclusive response. A further extension to this approach used the facilities of the list-server of the Australian Society for Limnology (ASL). This was considered by the project Reference Group to be the sole professional body with appropriate expertise of the targeted survey respondents. An invitation was posted on both the list-server and in the society's newsletter for anyone to request a survey questionnaire and contribute to the study. The Reference Group believed that the survey should be targeted towards individuals with a wide knowledge and vision for rivers, so the survey was not extended to local river organizations, which, the Reference Group considered, were likely to focus on a limited range of local issues.

The survey was e-mailed to nominated respondents and followed by up to two reminders if no reply was received. The survey was conducted electronically using an Excel spreadsheet in an attachment. This strategy enabled the data to be readily transferred into a spreadsheet for processing and for matching with respondent details. The data from the survey were discussed with the Reference Group, particularly in determining the acceptance of new potential attributes contributed by respondents. The revised list of criteria and attributes was finalized with the experts in the Reference Group; time limitations for the study precluded a second iteration with the survey respondents.

The survey questions and their analysis

A covering letter to the survey explained that the purpose of the exercise was to identify those attributes considered by river experts to be important in assessing river ecology. The question posed to respondents was as follows:

> The following attributes could be used to define or describe a river of 'high ecological value'. How important do you consider each of these attributes in assessing the ecological value of a river? Please rate each attribute on a score of 1 to 10 where 1 is of very low value and 10 is of very high value. If you think an attribute is of no value, please enter 0, if you are unsure about an item, enter X.

Scores from all respondents were then averaged to summarize the level of importance attributed to each proposed attribute. Attribute scores within four of the five criteria were then averaged to provide a summary of the importance of these criteria.

Respondents were invited to suggest other attributes if they felt any had been overlooked. As a quick desk-top exercise to see whether the respondents could apply the criteria and attributes as defined, they were asked to nominate a single Australian river they considered to be of high ecological value and indicate the criteria and attributes they believed this river demonstrated.

RESULTS

The response to the survey

A total of 73 scientists and river managers in Australia returned the questionnaire. Of the 73 completed questionnaires, 52 were received as a result of targeted respondents or forwarded on from such individuals, and the remaining 21 resulted from requests in response to posting on the ASL list-server. From the e-mail distribution, 22 messages were returned unrecognized and no solutions were found to resolving these problematic addresses. Six individuals indicated that they were unable or unwilling to complete the questionnaire, of which two were 'unable to assist' (perhaps felt they had inadequate knowledge), two were 'too busy', one (incorrectly) thought the exercise was dealing only with 'wild rivers', which he considered inappropriate, and the sixth person felt the complexity of the topic merited the opportunity for more discussion of issues and interpretation. A further 36 people recorded as having been sent the questionnaire did not respond. It is not possible to calculate a true response rate because of the nature of the survey strategy, but a conservative estimate indicates at least 65% of those targeted did respond either directly or by advising another person to complete the task.

Tables 1 and 2 show the distribution of responses by location, role, and expertise. 'Managers' were classed by self-identification with this role (Table 1) and were either located within government agencies with general river management responsibilities or else employed within a catchment management authority. The category 'researchers' represents a range of experience, including people with high-profile leadership roles within the limnological community, university-based researchers, scientists working in river management agencies, and scientists working in specialized centres for limnology or related research. Other interests included: intermittent streams (one person from Victoria), inland aquatic systems (one,

Table 1. Distribution of respondents by state and primary role

	Researcher	Manager	Consultant	Community group	Other/Unknown	Total
Australian Capital Territory (ACT)	5	1				6
New South Wales (NSW)	8	4	3	1	1	17
Northern Territory (NT)	3	1				4
Queensland (Q)	7	8	1	1	2	19
South Australia (SA)	4	1	1			6
Tasmania (T)	3					3
Victoria (V)	9	2	2			13
Western Australia (WA)	3	2				5
Total	42	19	7	2	3	73

Table 2. Distribution of respondents by state and major interests

	Total	ACT	NSW	NT	Q	SA	T	V	WA
Macroinvertebrates	13	1	1	1	1	3	1	4	1
Aquatic ecology	25	5	2	2	2	2	2	8	2
Fish	8		3		3			2	
Floodplains/lowland rivers	3	1						2	
Hydrology	5	2	1		2				
Geomorphology, including sediment transport	5	1		3	1				
Instream and riparian flora	5			1	2	2			
Water quality/monitoring, bioassessment	11	1	6	1	2	1			
Water, stream or wetland management	14	1	3	1	7			2	
Ecological processes including nutrient cycling	4		2		1			1	
Birds	1		1						
Algal blooms	2	1	1						
Disturbance ecology	2	1	1						
Stream rehabilitation	2				2				
Stormwater/wastewater management	2		2						
Wetlands	9		2	1	2	2		1	1
Environmental flows	5		2		3				
Other	12								

Note: some respondents gave more than one interest.

WA), ecotoxicology (one, SA), environmental advocacy (one, NSW), environmental protection (one, NSW), conservation biology (one, NSW), microbial ecology (one, NSW), rainforest ecology (one, Q), irrigation (one, Q), palaeoecology (one, V), modelling biophysical systems (one, ACT), and statistics (one, V). Four respondents noted that they also had an interest in taxonomy of particular groups as well as their ecology.

Distribution of responses by State largely reflects distribution of the general population, with the exception of a larger than expected response from the State of Queensland. This may be attributable to the work under way at the time within the government agency, supported by local researchers, on developing flow models for water allocations and on evaluating river status. Relatively higher numbers of responses from the ACT and Northern Territory may be accounted for by the presence in those territories of centres for limnological research. It should be noted that many researchers deal with limnological issues well beyond the state in which they reside, and some managers are involved in issues across state boundaries. The opinions of 'researchers' and 'managers' and of viewpoints from different areas of expertise were considered equally valid and treated equally in the analysis.

Validation and rating of criteria and attributes of high ecological value

All 73 respondents completed ratings for all criteria and attributes. These are summarized in Table 3. The sequence of attributes is presented as in the questionnaire, grouped into five criteria. Responses within each criterion are sorted by mean score in descending order.

Respondents took different approaches to the rating task. Some used the full range from 0 (or 1) to 10, whereas others used only scores of 6 or 7 and above. A few respondents used mainly 10 or high scores with few or no low scores. Every attribute achieved at least some scores of 10.

No attribute had a notably low overall rating (Table 3). Every candidate attribute had at least one rating of 10, and 11 attributes had a least one rating of 0. Lower mean ratings (Table 4) tended to have higher variance than attributes with mean ratings of 8 or above, with the exception of 'undisturbed catchment' (Table 5).

Ratings of the importance of most attributes varied over the whole range of possible scores from 0, or 1, to 10. The only exceptions were 'intact riparian vegetation' (range 4 to 10, mean 8.58, SD 1.4), 'rare or threatened communities or ecosystems' (range 5 to 10, mean 8.63, SD 1.5) and 'rare or threatened habitats' (range 4 to 10, mean 8.27, SD 1.6). Four individuals rated all the attributes under the category of 'representativeness' as 'uncertain', suggesting that they may not be convinced of representativeness as a criterion of ecological value. Four respondents scored all attributes of 'naturalness' at a score of 10, whereas the majority of respondents used a range of scores within that criterion.

The overall mean scores suggest general support rather than support from small numbers of specialists only. Thus, for example, only five respondents indicated a particular interest in instream and riparian flora (Table 2), yet attributes relating to flora received widespread support. In a similar way, there was support for geomorphological values even though only five respondents indicated this as a special interest or expertise.

Even the attributes with the highest average scores overall such as 'natural ecological processes, including energy base and energy flow through food webs' were considered to be of minor importance by a few individuals (range 3 to 10, mean 8.6, SD 1.6; Table 5). Other 'naturalness' attributes with higher average scores displayed a similar pattern of a wide range of ratings by individuals. Seven of the top 10 scores were attributes of the 'naturalness' criterion.

The lowest mean scoring attributes (Table 4) not only attracted more 'uncertain' responses but also displayed more variance. Karst features and maintenance of karst processes attracted the greatest uncertainty of their significance, or possibly reflecting doubt about the appropriateness of inclusion or understanding of karst processes. Three of the four 'representativeness' attributes fell amongst the lowest

Table 3. Ratings by respondents of possible attributes of ecological value for rivers

		Mean	SD	Variance	Median	Lowest score	Uncertain
Criterion 1 Naturalness	Natural ecological processes, including energy base and energy flow through food webs	8.6	1.6	2.5	9	3	3
	Intact native riparian vegetation	8.6	1.4	2.1	9	4	
	Natural instream faunal community composition	8.3	1.6	2.7	9	1	1
	Undisturbed catchment	8.1	2.2	4.8	8	1	
	Unregulated flow	8.1	2.0	3.9	8	1	
	Natural nutrient cycling process	8.0	1.6	2.5	8	3	4
	Natural processing of organic matter	8.0	1.6	2.7	8	2	4
	Unmodified river/channel features	7.9	1.7	2.9	8	2	
	Intact and interconnected river elements	7.8	1.9	3.5	8	2	4
	Natural temperature regimes	7.6	1.8	3.1	8	2	2
	Natural water chemistry	7.5	1.8	3.4	8	1	1
	Absence of exotic flora or fauna	7.5	1.8	3.4	8	1	
	Absence of interbasin water transfer	7.1	2.3	5.3	8	0	2
	Habitat corridor	6.9	1.9	3.7	7	2	6
Criterion 2 Representative-ness	Representative aquatic or riparian communities	7.5	2.3	5.1	8	0	4
	Representative river processes	6.8	2.2	5.0	7	0	4
	Representative river system or section	6.8	2.4	5.6	7	0	5
	Representative river features	6.1	2.4	5.6	6	0	5
Criterion 3 Diversity or Richness	High diversity of endemic flora or fauna species	7.7	1.9	3.8	8	3	
	Diversity of instream habitats	7.4	2.2	4.9	8	0	1
	High diversity of native flora or fauna species	7.4	2.1	4.4	8	1	
	Diversity of channel, floodplain (including wetland) morphologies	7.3	2.2	4.7	8	1	1
	High diversity of ecological processes	7.2	2.2	4.9	7	2	5
	High diversity of floodplain and wetland communities	7.2	2.1	4.2	7	0	1
	High diversity of instream or riparian communities	7.2	2.2	4.8	7	0	1
	Important bird habitat	5.9	2.4	5.9	6	0	2
	Diversity of rock types or substrate size classes	5.7	2.3	5.1	6	0	3
Criterion 4 Rarity	Rare or threatened communities or ecosystems	8.6	1.5	2.2	9	4	
	Rare or threatened habitats	8.3	1.6	2.6	9	4	
	Rare or threatened ecological processes	7.9	1.8	3.2	8	3	3
	Rare or threatened fish or other vertebrates	7.9	1.8	3.3	8	1	1
	Rare or threatened flora	7.8	1.8	3.2	8	1	1

Table 3 *Continued*

		Mean	SD	Variance	Median	Lowest score	Uncertain
	Rare or threatened hydrological regimes	7.6	1.8	3.4	8	2	5
	Rare or threatened invertebrate fauna	7.6	1.9	3.6	8	1	1
	Rare or threatened instream hydrological processes	7.5	1.9	3.6	8	2	4
	Rare or threatened geomorphological features	7.3	1.9	3.5	7	1	1
Criterion 5 Special Features	Important for the maintenance of downstream or adjacent habitats	8.2	1.6	2.5	8	2	
	Significant ephemeral floodplain wetlands	7.9	1.7	3.0	8	2	3
	Drought refuge for terrestrial or migratory species	7.9	1.8	3.4	8	1	1
	Important for migratory species or dispersal of terrestrial species	7.6	2.0	4.0	8	1	1
	Habitat for important indicator or keystone taxa	7.2	2.0	3.9	8	1	2
	Dryland rivers with no opening to ocean	6.7	2.1	4.6	7	2	4
	Important for the maintenance of karst system or features	6.5	2.0	4.0	7	0	13
	Karst, including surface features	6.4	1.7	3.1	6	2	13
	Rivers with unusual water chemistry	6.3	1.9	3.6	7	2	4

Table 4. Attributes with the 10 lowest mean scores

Criterion	Attribute	Mean	SD	Variance	Lowest score	Uncertain
1	Habitat corridor	6.9	1.9	3.7	2	6
2	Representative river processes	6.8	2.2	5.0	0	4
2	Representative river system or section	6.8	2.4	5.6	0	5
5	Dryland rivers with no opening to ocean	6.7	2.1	4.6	2	4
5	Important for the maintenance of karst system or features	6.5	2.0	4.0	0	13
5	Karst, including surface features	6.4	1.7	3.1	2	13
5	Rivers with unusual water chemistry	6.3	1.9	3.6	2	4
2	Representative river features	6.1	2.4	5.6	0	5
3	Important bird habitat	5.9	2.4	5.9	0	2
3	Diversity of rock types or substrate size classes	5.7	2.3	5.1	0	3

scores. Even the lowest scoring attributes, i.e. 'diversity of rock types or substrate size classes' (5.68) and 'important bird habitat' (5.92), were considered very important by a few individuals who gave them high scores.

Table 5. Attributes with the ten highest mean scores

Criterion	Attribute	Mean	SD	Variance	Lowest score	Uncertain
4	Rare or threatened communities or ecosystems	8.6	1.5	2.2	4	
1	Natural ecological processes, including energy base and energy flow through food webs	8.6	1.6	2.5	3	3
1	Intact native riparian vegetation	8.6	1.4	2.1	4	
1	Natural instream faunal community composition	8.3	1.6	2.7	1	1
4	Rare or threatened habitats	8.3	1.6	2.6	4	
5	Important for the maintenance of downstream or adjacent habitats such as floodplain/estuary	8.2	1.6	2.5	2	
1	Undisturbed catchment	8.1	2.2	4.8	1	
1	Unregulated flow	8.1	2.0	3.9	1	
1	Natural nutrient cycling process	8.0	1.6	2.5	3	4
1	Natural processing of organic matter	8.0	1.6	2.7	2	4

Table 6. Summary ratings for four criteria

Criterion	Mean	SD	Variance
Naturalness	7.9	1.8	3.3
Representativeness	6.8	2.3	5.3
Diversity	7.0	2.2	4.7
Rarity	7.8	1.8	3.2

Overall, naturalness was considered to be the most important 'criterion, with a mean rating of 7.86, closely followed by rarity (Table 6). The criteria of 'representativeness' and 'diversity' showed the greatest variation in scores and somewhat lower mean (mean 6.79, SD 2.3 and mean 6.99, SD 2.3 respectively). Calculation of mean scores for a criterion assumes that each attribute is of equal value and, therefore, must be treated with caution. No mean score is presented for the criterion 'special features' because there is no common theme between the attributes.

Suggestions for Australian rivers of high ecological value and their attributes

Respondents were asked, 'Please give an example of a river, or section of a river system, in Australia which you regard as a river of high ecological value'. This was an exercise to test whether the notion of a river of 'high ecological value' was workable, and whether respondents could relate the value to attributes listed. A total of 53 different rivers or river sections were suggested from 71 survey respondents. The scale of rivers nominated ranged from upstream sections or tributaries to large rivers, including the entire Murray–Darling system. Using the list of attributes, the values perceived or known for the nominated river were listed by the respondents. Eighteen respondents nominated a river but did not suggest attributes for which they considered it to be of value. This may owe as much to the nature of the effort required to complete this part of the questionnaire and does not necessarily indicate ignorance of particular values.

Nominations of a river of high ecological value tended to be for rivers in the most natural condition, with naturalness attributes listed as important. Local or working knowledge was clearly a key factor in the nomination of particular rivers, since these were most frequently in the state in which the respondent resided.

Table 7. Attributes most frequently mentioned for nominated Australian rivers of high ecological value

Criterion	Attribute	Times recorded
1	Unregulated flow	42
1	Undisturbed catchment	33
1	Intact and interconnected river elements	30
1	Intact native riparian vegetation	30
1	Natural instream faunal community composition	30
1	Unmodified river/channel features	29
1	Natural ecological processes, including energy base and energy flow through food webs	28
1	Natural water chemistry	27
1	Natural temperature regimes	27
1	Absence of interbasin water transfer	25
1	Natural processing of organic matter	23
1	Habitat corridor	23
1	Natural nutrient cycling process	22
3	Diversity of instream habitats, e.g. pools, riffles, meanders, rapids	22
3	High diversity of native flora or fauna species	22
2	Representative river system or section	20
1	Absence of exotic flora or fauna	17
3	High diversity of endemic flora or fauna species	17
3	Diversity of channel, floodplain (including wetland) morphologies	16

Table 8. Additional attributes of high ecological value contributed by survey respondents

Criterion	Attribute
Criterion 1: Naturalness	Unmodified flow
Criterion 2: Representativeness	Representative aquatic macroinvertebrate community
	Representative instream flora community
	Representative riparian community
Criterion 3: Rarity	Rare or threatened geomorphological processes
	Unusual water chemistry

Fourteen of the 19 attributes most frequently suggested for nominated high-value rivers fall in the criterion ‘naturalness’ (Table 7). Diversity of instream habitats and biota were also considered important for many rivers nominated. Attributes least frequently mentioned tended to fall under the criterion of ‘special features’. These include dryland rivers, karstic rivers, ephemeral wetlands, and rivers important for migration, dispersal or as drought refuges. It is important to note that the criteria and attributes nominated relate only to a single river suggested by an individual and based on their immediate knowledge of the river, rather than through a systematic assessment process.

Refining the list of criteria and attributes

No attribute used in the survey attracted universally low scores, with even the lowest rating attribute assigned a mean score of 5.7. The proposed attributes were considered by the Reference Group, therefore, to be acceptable for describing the ecological values of Australian rivers. Additional attributes were suggested by 14 respondents (Table 8), and reviewed by the Reference Group. Some nominated attributes were considered to lie outside the scope of ‘ecological value’ as adopted in the study. A few of the proposed attributes met the requirement of contributing new or refined interpretations of a criterion. ‘Unmodified flow' distinguishes between 'unregulated flow' referring to the absence of significant infrastructure, such as dams, and flow that is unmodified by the abstraction of water for irrigation from the run of the river. Another new attribute suggested was 'rare or threatened geomorphological processes' which provides a geomorphological equivalent to 'rare or threatened ecological processes'. It was proposed that 'representative aquatic or riparian communities' should be separated into aquatic macroinvertebrate, instream flora, and riparian communities. It was also suggested that it was more appropriate to include 'unusual water chemistry' under the 'criterion rarity'.

The list of criteria and attributes displayed in Tables 3 and 8 together summarize the collected views on ecological value for rivers by respondents to the survey.

DISCUSSION

In the introduction to a volume providing a world-wide analysis of the state of river conservation, Boon *et al.* (2000) noted that there are marked differences in the concepts of river conservation across the globe, especially between developed and developing regions. For developing regions, 'conservation' often focuses on water quality and quantity rather than wider ecosystem values, and even in developed regions there are differences in approaches to conservation issues and in evaluation methodologies and concepts. Defining the values for river conservation is clearly a key step in developing methods for assessment, both at a national and regional levels. The results described here provide such a working list for Australian rivers, though it is important to note that other aspects, such as cultural or historic values, may well be incorporated in broader assessment processes for river conservation.

An Australian perspective on river conservation values

It may be argued that the range of expertise on which these results draw reflects Australian opinions in much the same way as for studies that form the basis for assessment protocols in other countries. O'Keeffe *et al.* (1987), Boon *et al.* (1994) and Collier (1993) targeted individuals to evaluate conservation criteria and attributes for particular approaches to river assessment. The distribution of limnological expertise in the present study shows a range not dissimilar to that reported by Boon *et al.* (1994) and Collier (1993), with interests dominated by aquatic ecology and invertebrates, followed by fish, macrophytes, and for the Boon *et al.* study, algae. The interests of almost half of the respondents in the New Zealand study (48%) are listed as general freshwater ecology, with invertebrates interest somewhere between 14 and 17% (Collier, 1993). In the Australian study, vertebrates other than fish were not specifically mentioned as the major field of interest, apart from one respondent's interest in bird ecology, and microbial organisms were generally absent from the list. River managers were not generally targeted in the overseas studies, although those with specialisms in catchment planning, environmental assessment and water quality (13 of 161 respondents) in the survey by Boon *et al.* (1994) might be included in this category.

The distinction between 'management' and 'ecological research' is not clear-cut in this Australian study. A major interest (Table 2) expressed as 'bioassessment', water quality, algal blooms, and wetland management could be oriented either towards basic research or management applications. Many of those presently in management positions (Table 1) are likely to have expertise in a particular aspect of river ecology. Conversely, among those respondents identifying themselves as researchers, some 35% are working in a river management organization, and some of those researchers based in research or academic institutions are likely to be involved in management-oriented research. Half of all respondents nominating management as their principal interest (seven individuals, Table 2) were based in Queensland, where an active group within a government agency was developing approaches to determining water allocation models and river assessment protocols. An interest in water quality and monitoring was highest amongst

New South Wales respondents (six out of a total of 11 respondents, Table 2). With these exceptions, the spread of expertise was more or less distributed across the Australian States and Territories, in line with general population distribution. The earlier international studies assumed equal value for all opinions in a similar way to the present study. An electronic survey strategy appeared to be effective in reaching a wide range of respondents and opening up the opportunity to participate.

The premise underpinning the study was that those with particular interest in river conservation would provide the richest source of informed opinion. Two phases were used in the development of a list of criteria and attributes for rivers of high ecological value. In a similar way, a two-stage process was adopted by Boon *et al.* (1994), who used the views of respondents to endorse and refine a draft framework developed by an expert panel. In the Australian study, the list of criteria and attributes proposed by the work of the expert Reference Group was re-evaluated by means of a survey. Using two standard qualitative research methods, expert panel and purposive survey sampling, permits confidence in the findings and cross-validates outcomes (Patten, 1990).

The use of non-probability sampling in the study limits the generalizations that may be made from the results, though arguably this is no less true for the surveys on which the work of Boon *et al.* (1994), Collier (1993) and O'Keeffe *et al.* (1987) are based. The profiles of respondents (Tables 1 and 2) suggest that these results may be used at least as a working basis for the definition of ecological values of Australian rivers that will receive endorsement from river scientists and managers. The inclusive approach to the survey method had another important agenda: to encourage consideration of river conservation issues and bring the matter to prominence in the limnological community.

What defines high ecological value for rivers in Australia?

Concepts of ecological value and significance change over time. Such changes or refinements are reflected in the changes to criteria for listing of wetlands of International Importance under the Ramsar Convention (www.ramsar.org (16 November 2001)) and modifications to criteria for World Heritage listing (http://who.unesco.org/n-criteria-changes.htm (13 February 2004)). Important international conventions (Biodiversity) and organisations (IUCN) adopt a wider definition of biodiversity than simply species diversity, though in Australia, at least, the legislation for protection of ecosystem and genetic diversity lags behind acceptance of this broader interpretation.

The criteria and attributes identified in this study are a snapshot in time of the definition of ecological value for Australian rivers. The results of other surveys (O'Keeffe *et al.*, 1987; Collier, 1993; Boon *et al.*, 1994) in the field of river conservation were used for a specific purpose — to devise an assessment protocol — but they may be compared with the Australian study as reflecting a national perspective on defining what is important to conserve (Boon, 2000). Concepts of conservation value for rivers have changed over the 18 years since the first attempts by O'Keeffe *et al.* (1987) to develop a system of river conservation assessment. The list used in their system identifies measurable indicators or attributes under three headings — the river, the catchment, and the biota. Core concepts such as diversity and naturalness form the framework adopted by Collier (1993) and Boon *et al.* (1997), with specific descriptors or attributes listed under each concept. Similar broad concepts emerge from each approach, although there are differences in particular attributes adopted for the assessment. Collier (1993) used only three criteria in his assessment trial: degree of modification; diversity and pattern; and rarity and unique features or species. In addition to these three criteria, the SERCON protocol includes representativeness and special features, as well as separating the criteria for naturalness from assessment of impacts (Boon *et al.*, 1997). The Australian survey showed greater primacy for geomorphological values compared with SERCON, which addresses geomorphological features largely as habitat components. However, in Britain, there are separate criteria and procedures for selecting rivers as SSSIs on the basis of geomorphology (Boon, personal communication).

Among the criteria and attributes emerging from this study, naturalness and rarity are universal conservation themes. Whereas rarity is a universal theme, it has expanded to incorporate communities, ecosystems, and structural features, as well as species. Some themes are becoming more refined or specific in interpretation, such as the criterion 'diversity'. Other elements may be considered emergent themes, notably identifying ecosystem processes and functions as important conservation values. Biogeographic themes are also of emerging importance, first noted by O'Keeffe *et al.* (1987) with attributes for numbers of endemic fish and invertebrate species. 'Diversity of endemic species' was noted as an attribute of high ecological value in the Australian survey, but other biogeographic themes did not arise. These might have included, for example, attributes demonstrating ancient distributions and affinities through outlying populations or communities characterized by species with Gondwanan affinities. Such attributes are acknowledged for their significance in biodiversity conservation (http://www.nhm.ac.uk/science/projects/worldmap/priority/method.htm#3methods (22 July 2003)) and encompassed within some terrestrial conservation assessment criteria (www.rfa.gov.au (22 July 2003); www.ea.gov.au/heritage/law/heritageact/criteria.html (21 July 2003)).

The Australian survey demonstrated an integrated and holistic view of river ecosystem values with the specific inclusion of aspects of river geomorphology and hydrology. Although elements of river structure are present in other river conservation assessments, they are more often interpreted as habitat components rather than as having intrinsic conservation value. Other important emergent conservation values are process-based, functional values reflecting the connectivity and dynamics of river systems. It is more difficult to select appropriate and valid descriptors or attributes for these conservation themes, and they are more difficult to measure.

'Naturalness' was the highest rated criterion, and among the 10 attributes with the highest overall ratings (Table 5), seven fell within the criterion of 'naturalness'. The value placed on naturalness is reflected in its nomination as a key attribute for the respondents' nominated Australian rivers (Table 7). The concept of river 'naturalness' is a difficult one to define in regions of the world where there has been a continuity of human impacts upon catchments and river systems for centuries (Boon, 2000; Boon *et al.*, 2002). By contrast, in Australia, major and widespread impact on rivers can be seen at a 100 year time scale, though some rivers in more remote areas have escaped significant change. A geographical information system-based assessment of Australian rivers (Stein *et al.*, undated) used a number of disturbance factors to arrive at a river disturbance index for all rivers and river sections (http://www.heritage.gov.au/anlr/code/arc.html (12 April 2003)). Hence, an objective measure of 'naturalness' is available for Australian rivers.

The identification and protection of wild rivers, or rivers that may be identified as having a high degree of naturalness, is considered a high priority in Australia (Georges and Cottingham, 2002; Barmuta, 2003). Knowledge of many types of rivers, river habitats, and ecosystems is limited, and protection of rivers in a natural condition is a critical conservation action. In Australia there is an opportunity, not shared with most nations, to protect some rivers and reaches in a near-pristine condition.

Despite the priority on wild rivers, some attributes of ecological value remain in disturbed rivers, a point emphasized by some survey respondents. The SERCON protocol (Boon *et al.*, 1994) and the assessment proposed by O'Keeffe *et al.* (1987) and Collier (1993) incorporate the condition of the river as an element of conservation status.

Under the 'rarity' criterion, rare and threatened communities, ecosystems, and habitats rated more highly overall than species, despite the emphasis of legislative action on species-level conservation (http://www.ea.gov.au/biodiversity/threatened/communities/index.html (17 July 2003)). The high priority given to rarity at community and ecosystem levels may be attributable to the vivid evidence of pressures and threats to whole river systems and continuing loss of habitat across the landscape (Ball *et al.*, 2001). A priority on protecting communities and ecosystems is consistent with the strategies for maintenance of ecosystem integrity advocated by the IUCN (www.biodiv.org/decisions (22 May 2001)), Ramsar Convention (www.ramsar.org (16 November 2001)) and Australia's biodiversity strategy (EA, 1998). In addition, in

Australia, a focus on systems rather than species may be a consequence of the poor level of knowledge of many taxa (Horwitz *et al*., 1999; Kitching, 1999).

'Diversity' has been a continuing emphasis of biodiversity conservation, as protecting hot spots can be an effective conservation measure for greater numbers of species (http://www.nhm.ac.uk/science/projects/worldmap/priority/method.htm#3methods (22 July 2003)). The diversity attribute receiving the highest rating in the survey related to high diversity of endemic species, suggesting the growing significance of such biogeographic values. Perhaps surprisingly, given the evolutionary interest of the Australian biota on a world scale (Wilson and Johnson, 1999; Whiting *et al*., 2000; Zwick, 2000), no other biogeographic attributes were offered by respondents. By comparison, terrestrial conservation strategies recognize biotic elements that demonstrate past and recent geological history through attributes such as distributional outliers or limits of range. Conserving these distributional attributes also contributes to biodiversity conservation at a genetic level (http://www.nhm.ac.uk/science/projects/worldmap/priority/method.htm#3-methods (22 July 2003)).

'Representativeness' has emerged as a more important biodiversity conservation theme in recent years, reflected in Ramsar criteria and in strategies in support of the Biodiversity Convention. The notion of representativeness (of a class of ecosystem or biotic community) forms the foundation of the Biodiversity Strategy (EA, 1998) and of the RFA (www.rfa.gov.au (22 July 2003)) in Australia. Use of representative examples is seen to be important for conserving values of whole ecosystems rather than single species. Representative examples can also be important as surrogates to protect species whose ecology is poorly known, a common situation for Australian biodiversity conservation. Representativeness requires a classification framework in order to locate particular examples. The absence of an agreed classification of rivers may have been a barrier to acceptance of representativeness as a criterion, since there is not an accepted national typology of Australian rivers, nor an agreed approach or scale for defining biotic communities. The pattern of means, standard deviations, zero and uncertain ratings (Table 3) for all the attributes of the criterion 'representativeness' suggests that this criterion will demand debate and further research before it can be applied in a national river assessment protocol for Australia.

The 'special features' criterion follows the grouping together of some disparate characteristics and follows the approach used in SERCON (Boon *et al*., 1994). Some attributes listed (Table 3) under this criterion, such as 'karst' or 'inland rivers', may more properly be considered as examples of particular river types and, therefore, might themselves be screened under other criteria or attributes. The attributes attracting most 'uncertain' ratings related to karst; this is possibly an expression of doubt as to whether such systems should be considered as rivers. This is a moot point: many extant karst systems not only originated by riverine processes but also retain river flow that can be a combination of surface and underground flows.

Dryland rivers had relatively lower ratings (mean score 6.71, Table 3) and were among the 10 lowest scoring attributes (Table 4) despite the importance of such systems in Australia (Walker *et al*., 1997) and their significance on a world scale (Comin and Williams, 1994). One explanation for this may lie in the lack of familiarity with inland systems amongst the majority of the Australian population, the greatest proportion of whom live in the urban areas fringing the coasts. It also reflects the focus of management intervention and R&D on the coastal and wetter areas with more intense rural and urban development. Karst and inland river systems pose special problems, and relevant geomorphologists and biologists were perhaps not included in the survey. Similarly, the low score for bird habitat (mean score 5.9) may reflect a specialized field of interest not covered by the limnological community.

The support demonstrated in the Australian survey for attributes associated with stream processes, connectivity, and landscape-scale river conservation issues is striking. Values such as 'natural ecological processes' (mean score 8.6), 'natural nutrient cycling' (mean score 8.0) and 'maintenance of downstream or adjacent habitats such as floodplains and estuaries' (mean score 8.2) are not identified as such in the SERCON methodology (Boon *et al*., 1994, 2002). SERCON includes floodplains in the criterion 'special features' (Boon *et al*., 2002) only recognizing explicitly their importance as habitats. Limited acknowledgement to such process-related ecological values is indicated by O'Keeffe *et al*. (1987) and Collier (1993), who respectively identify 'importance to adjacent ecosystems' for the South African approach and 'number of associated wetlands . . .' in New Zealand. Attributes that focus on ecological processes may be partially inferred in these assessment protocols by the choice of some indicator measures or attributes that demonstrate some healthy instream processes. The Australian survey suggests that such attributes may be elevated to more explicit process-related conservation criteria such as 'natural ecological processes', 'natural nutrient cycling processes', 'rare or threatened ecological processes' and 'important for the maintenance of downstream or adjacent habitats'. The high mean ratings for such attributes suggests widespread support amongst limnological researchers, not limited to those working in these specialized and complex fields of investigation. It also suggests that limnological researchers generally take a holistic view of the ecosystem they study, a proposition endorsed by the support for hydrogeomorphic values. In future, links between groundwater processes and surface water values are likely to emerge as another dimension of riverine ecological conservation (Boulton *et al*., 2003). These links are already being addressed in new European legislation (Eurpoean Commission, 2000).

Attributes related to river functions within the landscape were also supported as indicating high ecological value. 'Important for the maintenance of downstream or adjacent habitats such as floodplain/estuary' (mean 8.2, SD 1.6) was amongst the top 10 attributes (Table 5). The role of rivers in providing corridors for dispersal and migration, and refuges in times of drought, was also recognized. Landscape-scale functions of ecosystems are rarely identified in terrestrial conservation (Harris, 2002), although issues such as provision of corridors may be important in conservation planning.

Implications for conservation planning and assessment

The results of this survey support a claim for similar ecological values for freshwater as for terrestrial ecosystems, and, therefore, are a legitimate basis for pursuing similar conservation directions in Australia (Dunn, 2003). There are also additional attributes or values not addressed in terrestrial conservation, particularly related to processes that sustain instream ecosystems, as well as the connectivity of river environments. Assessing some of these attributes may be difficult, but this is not a reason to ignore their importance. Further, such process-related attributes are often fundamental to the protection of structural attributes, such as threatened communities or species, or diversity of channel and floodplain morphology (Moss, 2000).

The present exercise was not intended to develop a strategy for conservation assessment. It does not provide the basis for a numerical scoring or assessment system, nor should ratings be directly translated into a scoring or weighting system. Assessment of river values needs to take place at a number of levels: individual rivers; regional and national conservation planning; and regional river management. No single scheme for assessment is appropriate to meet these different needs, and river assessment protocols should be devised to meet particular purposes. Issues of scale and (if deemed necessary and appropriate) scoring, weighting and integrating attributes in an assessment protocol must also be appropriate to the purposes for which the protocol is designed, and the context in which the results will be applied. For example, SERCON 2 will eventually incorporate 'SERCON Applications' to enable it to be applied for specific purposes (Boon *et al*., 2002). O'Keeffe and Uys (2000) discuss the evolution in complexity of tools for assessment and point out that computerized applications offer new approaches to decision making. This could include the development of hierarchies of assessment tools tailored for different purposes.

River conservation in Australia is confounded by the complexity of levels of governance and inconsistencies of legislation between states. Concepts of river ecosystems and their implication for management are difficult to grasp and are politically confronting in a land of limited essential water resources. Conservation of terrestrial systems in Australia has several strands: representative systems through the RFAs and National Reserves Program, rare and threatened species and communities through Commonwealth and State legislation, and various special values through the Forest Agreements and the currently evolving National List. Individual states seek to protect many of these features in secure parks and reserves. A case can be argued that river ecosystems are also important components of Australia's biodiversity and, therefore, similar strategies and resources should be devoted to their conservation.

Protection of river systems in Australia, at present, occurs in an *ad hoc* fashion and is often historically based on scenic river values, river wildness, or coincidentally associated with landscapes or terrestrial protection in national parks or other reserves. At present, legislative protection and government policy has very limited reference to geomorphological or hydrological processes that are fundamental to river management. Provisions for the protection of water quality and quantity may have positive consequences for the conservation of river values, but they do not address all the processes that threaten river ecosystems.

A systematic approach to river conservation in Australia will demand a number of different strategies in a similar way to terrestrial conservation, an acknowledgement of the wider range of riverine attributes, innovative approaches to reserve design, and collaborative approaches among landowners and river users.

ACKNOWLEDGEMENTS

The study was funded by the Land and Water Resources Research and Development Corporation of Australia, project number UTC1. Peter McQuillan, School of Geography and Environmental Studies, two anonymous reviewers, and Phil Boon provided valuable comments on the draft. Julie Davidson reviewed the project methodology and comments on the final draft were provided by Peter Davies and Mick Brown.

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