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Rivers in peril inside and outside protected areas: a systematic approach to conservation assessment of river ecosystems

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ABSTRACT

This paper establishes a framework within which a rapid and pragmatic assessment of river ecosystems can be undertaken at a broad, subcontinental scale, highlighting some implications for achieving conservation of river biodiversity in water-limited countries. The status of river ecosystems associated with main rivers in South Africa was assessed based on the extent to which each ecosystem had been altered from its natural condition. This requires consistent data on river integrity for the entire country, which was only available for main rivers; tributaries were thus excluded from the analyses. The state of main river ecosystems in South Africa is dire: 84% of the ecosystems are threatened, with a disturbing 54% critically endangered, 18% endangered, and 12% vulnerable. Protection levels were measured as the proportion of conservation target achieved within protected areas, where the conservation target was set as 20% of the total length of each river ecosystem. Sixteen of the 112 main river ecosystems are moderately to well represented within protected areas; the majority of the ecosystems have very low levels of representation, or are not represented at all within protected areas. Only 50% of rivers within protected areas are intact, but this is a higher proportion compared to rivers outside (28%), providing some of the first quantitative data on the positive role protected areas can play in conserving river ecosystems. This is also the first assessment of river ecosystems in South Africa to apply a similar approach to parallel assessments of terrestrial, marine, and estuarine ecosystems, and it revealed that main river ecosystems are in a critical state, far worse than terrestrial ecosystems. Ecosystem status is likely to differ with the inclusion of tributaries, since options may well exist for conserving critically endangered ecosystems in intact tributaries, which are generally less regulated than main rivers. This study highlights the importance of healthy tributaries for achieving river conservation targets, and the need for managing main rivers as conduits across the landscape to support ecological processes that depend on connectivity. We also highlight the need for a paradigm shift in the way protected areas are designated, as well as the need for integrated river basin management plans to include explicit conservation visions, targets, and strategies to ensure the conservation of freshwater ecosystems and the services they provide.

Keywords

Conservation assessment, conservation biogeography, protected area gap analysis, conservation status, freshwater biodiversity, freshwater conservation planning, integrated river basin management.

INTRODUCTION

Conserving river ecosystems depends on whole-catchment management, where land and water are managed in an integrated manner to achieve ecological and socioeconomic sustainability (O'Keeffe, 1989; Ward, 1998; Saunders *et al*., 2002). This requires the development of integrative assessment and planning approaches that proactively consider the needs of both terrestrial and freshwater ecosystems. Systematic conservation assessment and planning methodologies are relatively well advanced for

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terrestrial ecosystems, both globally and in South Africa (Margules & Pressey, 2000; Balmford, 2003; Cowling & Pressey, 2003; Driver *et al.*, 2003; Groves, 2003). However, rivers have generally been poorly dealt with in most assessments of terrestrial ecosystems unless they are considered important for terrestrial biodiversity pattern and process, and their conservation status is usually ignored. In an effort to correct this, systematic conservation assessments and plans specifically targeting freshwater ecosystems have begun to emerge (e.g. Roux *et al.*, 2002; Higgins, 2003; Weitzell *et al.*, 2003), applying the basic concepts that have been developed for terrestrial ecosystems as well as recognizing the need for some refinements to make the plans more suitable to the freshwater realm (Dunn, 2003). However, the majority of these assessments and plans are done in isolation to terrestrial ecosystem assessments and there is a need to combine these to develop assessments, plans, strategies, and policies that are inclusive of both terrestrial and freshwater realms (Abell, 2002), to begin meeting the needs of integrated river basin management.

Thieme *et al.* (2005) recently completed a continental scale assessment of freshwater ecoregions of Africa and Madagascar that complements a terrestrial assessment of the same region (Burgess *et al.*, 2004). Together, these shed light on a means of integrating assessments in that they both classify the respective freshwater and terrestrial ecoregions according to five levels of endangerment that are based on a similar logic as that used for threatened species in the IUCN Red Data Books (Mace & Lande, 1991; Hilton-Taylor, 2000). The advantage of using these endangerment categories for assessing both terrestrial and aquatic ecosystems are twofold: (1) they provide a familiar political terminology around which much species conservation policy has been developed (e.g. Mace & Lande, 1991; IUCN, 1994; IUCN, 2001), which may therefore facilitate incorporation into existing policy mechanisms; and (2) they provide a common currency for assessing ecosystems, thus enabling comparisons across terrestrial and aquatic realms, and the development of appropriate integrated strategies. Similar endangerment categories were used to assess freshwater ecosystems in this study, in an attempt to develop a common terminology for comparisons with assessments of terrestrial (B. Reyers *et al.*, unpubl. data), marine (Lombard *et al.*, 2004), and estuarine (Turpie, 2004) ecosystems. An additional advantage of applying these endangerment categories in the context of this study is that South African biodiversity policy (National Environmental Management: Biodiversity Act no. 10 of 2004) provides for the listing of threatened ecosystems and our approach offers a means of identifying such ecosystems.

This study presents a nationwide subcontinental assessment of ecosystems associated with main rivers of South Africa. It was undertaken as part of the country's National Spatial Biodiversity Assessment (Driver *et al.*, 2005) and is the first nationwide assessment to apply similar approaches to concurrent assessments of terrestrial, marine, and estuarine ecosystems, therefore facilitating comparisons across all four realms. There have been relatively few studies in South Africa dealing with systematic identification of rivers for conservation. Noble (1974) examined the representation of 'aquatic biotopes' and habitats for threatened species in South Africa and on this basis derived an expert-based set of 23 aquatic sites for conservation. O'Keeffe *et al.* (1987) examined the conservation status of selected rivers based on expert opinion of the relative importance of the river for conservation and the extent to which it had been disturbed from its natural state. These studies laid a good foundation for the criteria deemed important for conserving freshwater ecosystems. However, the study by Noble (1974) was not based on a systematic and spatially explicit classification of all freshwater ecosystems across the country; and the study by O'Keeffe *et al.* (1987) was a weighted scoring approach that ran the risk of undermining representation of ecosystems with a low conservation status, as is common for many scoring approaches (Pressey *et al.*, 1994). It was only a decade later that the use of techniques based on principles of systematic conservation planning (Margules & Pressey, 2000) was applied in South Africa to identify landscape-level conservation priorities for rivers in the Cape Floristic Region (Van Niewenhuizen & Day, 1999) and the Greater Addo Elephant National Park (Roux *et al.*, 2002). Although these two studies were both systematic, focusing on achieving conservation targets for river biodiversity, as well as attending to important ecological and evolutionary processes that support and maintain this biodiversity in the long term, they were undertaken at a subnational scale. There remained a need for a nationwide systematic assessment of river conservation priorities, to provide context to water resource management and conservation activities in the country as a whole.

The results presented here are an initial step towards identifying systematic conservation priorities for rivers at a nationwide scale. The short time-frame within which this assessment had to be completed (less than 8 months) necessitated the development of a relatively rapid, pragmatic, and inexpensive framework within which main river ecosystems were assessed. Both ecosystem status and protection levels of main river ecosystems were assessed. Ecosystem status is defined as a measure of the proportion of the river ecosystem still in its natural, intact state. Protection level of each river ecosystem is defined as the proportion of its minimum conservation target achieved in protected areas, where the minimum conservation target of each river ecosystem was set quantitatively as 20% of its total length, and only intact river lengths contributed towards the target. This approach offers a new and relatively rapid framework for assessing river ecosystems. Species data, frequently a limiting factor in conservation assessments of river ecosystems, are not required. River integrity data are required; however, surrogates of river integrity can be applied where these data are limited (e.g. Stein *et al.*, 2002). Endangerment categories thus generated allowed comparisons between terrestrial, river, and marine ecosystems, while assessing protection levels in conjunction with river integrity offered a more meaningful method of measuring protected area gaps for river ecosystems.

METHODS

Defining main rivers

The 1 : 500,000 river data layer (DWAF, 2004a) was used in these analyses. Although this is based on 1 : 500,000 topographical maps, it has been refined to include alignment of the rivers to

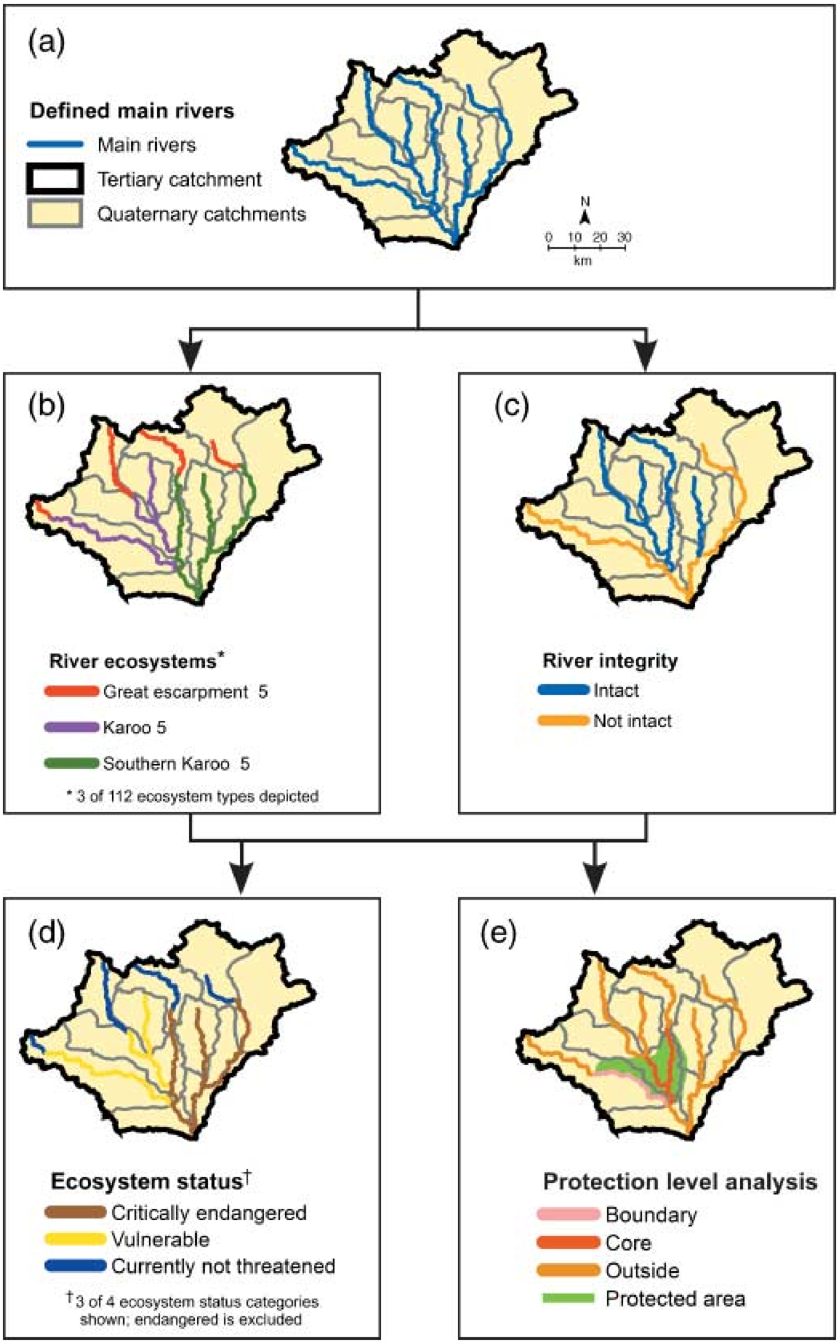

Figure 1 A schematic example of the steps used to derive ecosystem status and protection levels. Main rivers were defined using quaternary catchments (a). These main rivers were coded according to their ecosystem type (b) and river integrity (c). For each ecosystem type, the extent still intact (i.e. considered suitable for contributing towards quantitative conservation targets) was calculated, and ecosystem status was assigned using thresholds (d). Rivers were coded according to whether they fell outside protected areas (outside), formed the boundary of a protected area (boundary), or fell within a protected area (core). Intact core river lengths within statutory Type 1 protected areas were calculated for each ecosystem type (e), which was then assigned to an appropriate protection level category.

within 50 m of 1 : 50,000 topographical maps. We defined the main rivers using the South African Department of Water Affairs and Forestry quaternary catchments (Midgley *et al*., 1994). These catchments are part of a national hierarchical drainage subdivision system, which divides drainage regions into successively smaller hydrological units: from primary catchments, through to secondary and tertiary catchments, and finally to quaternary catchments. This system is similar to the system used to delineate the US Geological Survey (USGS) hydrological units (Seaber *et al*., 1987), where quaternary catchments are comparable to the USGS cataloguing units. Main rivers were defined as the rivers that pass through a quaternary catchment into a neighbouring quaternary catchment (Fig. 1). In instances where no river passed through the quaternary catchment (e.g. in coastal quaternary catchments that often encompass relatively short, whole river systems, or in quaternary catchments containing only endorheic rivers), the longest river system was chosen as the main river.

Mapping river ecosystems

River ecosystems were defined based on a hierarchical classification framework by Dollar *et al.* (2006). The framework characterizes rivers according to geomorphological and hydrological descriptors, to derive components of rivers which, under natural conditions,

Table 1 Eight statistical classes of hydrological index derived using the hydrological indices of Hannart & Hughes (2003) for all 1986 quaternary catchments in South Africa, Lesotho and Swaziland. For South African rivers, regions of low variability (commonly containing the perennial-type rivers) have a hydrological index class close to 1, whilst semiarid regions of high variability (commonly containing periodic- or ephemeral-type rivers) would be assigned to classes 6–8

Hydrological index	Class
0–5	1
5.1–8	2
8.1–17	3
17.1–37	4
37.1–53	5
53.1–65	6
65.1–95	7
95.1–110	8

Table 2 State of main river integrity within South Africa, according to the desktop estimates of present ecological status categories (Kleynhans, 2000). Percentage of main river length was calculated by summating the length of river reaches in each present ecological status category and expressing this as a percentage of the total length of main rivers in South Africa. For the purposes of this study, rivers with a present ecological status of natural or largely natural (categories A or B, respectively) was considered 'intact', and suitable for contributing towards quantitative conservation targets; categories C–F were considered unsuitable for contributing towards quantitative conservation targets

Present ecological status category	Description as per Kleynhans (2000)	% Main river length
A	Natural, unmodified	4
B	Largely natural	25
C	Moderately modified	47
D	Largely modified	21
E to F	Seriously to critically modified	2

are likely to share similar biological response potential, and can therefore be used as coarse-filter surrogates of river biodiversity (*sensu* Higgins *et al*., 2005). These components, hereafter 'river ecosystems', were derived for this national scale assessment by combining two spatial layers: geomorphic provinces (Partridge *et al*., 2006) as a freshwater-specific refinement of the provinces developed by King (1951), and hydrological index (Hannart & Hughes, 2003).

The 1 : 500,000 river layer was spatially overlaid with the layer for geomorphic provinces to classify rivers according to the nature of the landscape through which it flows. Next, rivers were assigned a hydrological index class, broadly describing the amount and variability of water flow in a river. The hydrological index class for each river was derived by grouping hydrological indices at the quaternary catchment scale (Hannart & Hughes, 2003) into eight statistically derived classes (Dollar *et al*., 2006), where regions of low flow variability (commonly containing the perennial-type rivers) have a hydrological index class close to 1, and the semiarid regions of high flow variability (commonly containing periodic- or ephemeral-type rivers) would be assigned to classes 6–8 (Table 1). Distinct combinations of geomorphic provinces and hydrological index classes assigned to rivers were used to depict river ecosystems at a national scale (Fig. 1).

Mapping river integrity

We used the desktop estimate of present ecological status developed for the national Water Situation Assessment Model to depict river integrity in South Africa (Kleynhans, 2000), where river integrity describes the extent to which the river has been modified by human activity (Kleynhans, 1996; Kleynhans, 1999). Estimates of river integrity were collected for the main rivers of all quaternary catchments through a series of local expert workshops throughout the country between 1998 and 1999. Six attributes (flow, inundation, water quality, stream bed condition, introduced instream biota, and riparian or stream bank condition) were evaluated according to present ecological status categories ranging from A (natural) to F (critically modified). The six attributes were amalgamated into an overall estimate of instream and riparian habitat integrity by calculating the median present ecological status category. For the purposes of this assessment, rivers with an overall present ecological status category of natural or largely natural (Class A or B, respectively; see Table 2) were considered 'intact' and suitable for contributing towards achievement of quantitative conservation targets. Targeting intact rivers for conservation maximizes the benefits already in place within these naturally functioning ecosystems. The median present ecological status category for each quaternary catchment main river was joined to the 1 : 500,000 main rivers GIS layer to provide a measure of integrity for each main river (Fig. 1). An overview of the state of main river integrity in the country was calculated by summing the length of river reaches in each present ecological status category and expressing this as a percentage of the total length of main rivers in South Africa.

Ecosystem status

The main river ecosystems were combined spatially with the layer of river integrity to calculate the total intact length of each of the ecosystems associated with main rivers. The proportion of intact length to total length of each river ecosystem was measured to derive its ecosystem status (Fig. 1). Ecosystem status was assessed based on thresholds that recognize minimum quantitative conservation targets for biodiversity pattern (below which an ecosystem becomes *critically endangered*); and thresholds that recognize conservation targets for maintaining ecological and evolutionary processes that sustain biodiversity pattern and allow it to evolve naturally over time (which in turn determine whether an ecosystem is *endangered*, *vulnerable*, or *currently not threatened*). Setting thresholds is a potentially valuable concept to use as a basis for developing tools to conserve and manage biodiversity. We acknowledge, however, that there are a range of uncertainties in the application of thresholds (Hugget, 2005), and that future empirical studies are required to support the thresholds used in this study.

The minimum conservation target, as described in Margules & Pressey (2000), was set for each river ecosystem as 20% of its total river length. This value was taken from a recommendation by the World Conservation Union's Caring for the Earth strategy (IUCN, 1989), which stipulates that a minimum of 20% of a country's natural aquatic assets require protection. Critically endangered river ecosystems have an intact length of < 20% of their total original extent (i.e. their minimum conservation target). Dropping below this threshold implies that the ecosystem is inadequately represented in the country, and has become critically endangered. Endangered river ecosystems have an intact length of < 40% and ≥ 20% of their total length; these ecosystems have lost significant amounts of their natural habitat, and their ability to support ecological and evolutionary processes is likely to be compromised. Vulnerable river ecosystems have an intact length of < 60% and ≥ 40% of their total length; these ecosystems have lost some of their original natural habitat, and their ability to support ecological and evolutionary processes is likely to be compromised if they continue to lose natural habitat. River ecosystems classified as currently not threatened have an intact length ≥ 60% of their total length; these systems have lost a smaller proportion of original habitat. Ecosystems with a status of critically endangered, endangered, and vulnerable were considered threatened ecosystems in this assessment.

The spatial distribution of ecosystem status was examined within the context of flow predictability by comparing the ecosystem status in more permanently flowing main rivers (defined as those with a hydrological index class of 1–5, Table 1) with those main rivers that have a more variable flow (defined as those with a hydrological index class of 6–8, Table 1).

Protection levels

River ecosystems were spatially combined with a layer of protected areas compiled for the terrestrial national spatial biodiversity assessment (B. Reyers *et al*., unpubl. data) to calculate the proportion of each river ecosystem currently under formal protection. Only statutory Type 1 protected areas were used in these analyses, which include national parks, provincial nature reserves, local authority nature reserves, and Department of Water Affairs and Forestry Nature Reserves. The legislation governing other types of protected areas (Types 2 and 3) is less certain (Driver *et al*., 2005). Since many rivers form boundaries of protected areas, we distinguished between boundary rivers that are protected on one side only and core rivers that are protected on both sides of their river bank. Boundary rivers, defined as those rivers that fell within a buffer of 500 m on either side of the protected area boundary, were excluded from these analyses. We also excluded any core rivers that were not intact, i.e. only intact core river lengths within statutory Type 1 protected areas were used in these analyses (Fig. 1).

River ecosystems were assigned a protection level based on the percentage of their minimum conservation target (20% of their total length) achieved by intact core river lengths within statutory Type 1 protected areas, as follows: not protected (0%), hardly protected (< 5%), poorly protected (5–50%), moderately protected (50–99.9%), and well protected (≥ 100%).

RESULTS

Main river ecosystems and their integrity

Main rivers, as defined in this assessment, constitute less than 45% of the rivers analysed at the 1 : 500,000 scale; the remainder is considered tributaries. There are 112 river ecosystems associated with main rivers, defined using distinct combinations of geomorphic provinces and hydrological index classes (Fig. 2, see Appendix S1 in Supplementary Material). Four of these river ecosystems occur only in main rivers, i.e. there are no examples of these river ecosystems contained in tributaries.

According to the estimates of present ecological status (Kleynhans, 2000), less than a third of main rivers in South Africa are still intact and suitable for contributing towards minimum conservation targets (Table 2). The majority of main rivers (47%) are moderately modified, while 23% of them can be considered irreversibly transformed in terms of their ability to support biodiversity, and are deemed unsuitable for conservation (those rivers that fall into the D, E, or F present ecological status categories, Table 2).

Ecosystem status

An alarming 84% of South Africa's 112 main river ecosystems are threatened (Fig. 3a, see Appendix S1), with 54% critically endangered, 18% endangered, and 12% vulnerable. Only 16% of main river ecosystems are currently not threatened. The more permanently flowing main rivers have a higher proportion of threatened ecosystems than those main rivers with variable flow (Fig. 3b). The semiarid interior of the country, characterized by rivers with variable flow, is therefore the only area in South Africa that still contains a large proportion of main river ecosystems that are currently not threatened (Fig. 4). Main rivers in the rest of the country contain mostly threatened ecosystems, except in the vicinity of the larger protected areas (Fig. 4).

Two of the four river ecosystems that are unique to main rivers are critically endangered (Lower Vaal and Orange valleys-5 and Swartland-5; see Appendix S1). For these ecosystems, there are no tributaries that could contribute towards their conservation. However, for the rest of the critically endangered main river ecosystems, options may exist for their conservation in intact tributaries, which, in general are less impacted than main rivers.

Protection levels

Over 90% of all main rivers in South Africa fall completely outside statutory Type 1 protected areas (Table 3). Half of the remaining rivers form boundaries of protected areas; thus less

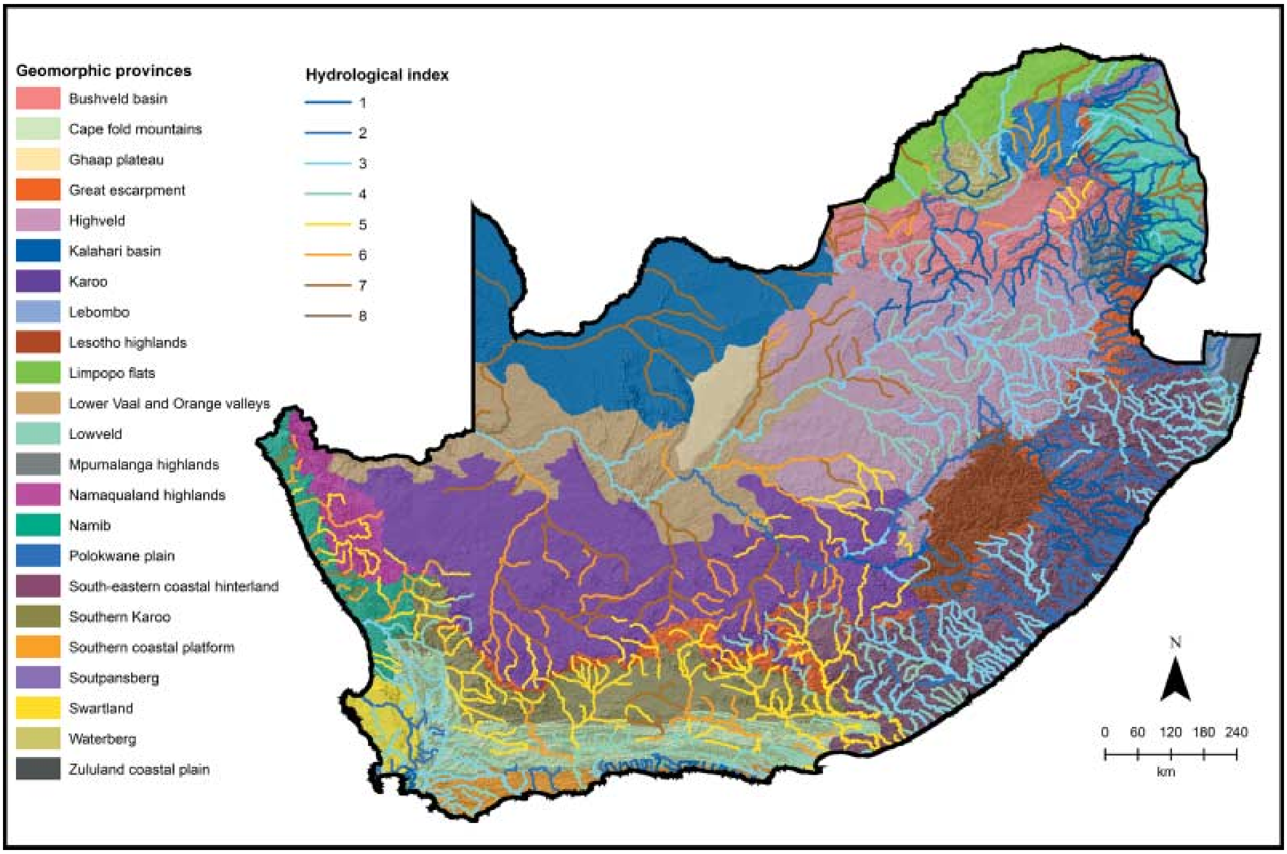

Figure 2 Main river ecosystems in South Africa ($n = 112$). River ecosystems were defined using unique combinations of geomorphic province (shaded areas) and hydrological index class (shaded lines).

Table 3 Proportion of main rivers in South Africa falling outside protected areas (Outside), on boundaries of protected areas (Boundary) or within protected areas (Core, i.e. > 500 m from boundary). Proportion of river length still intact is also given

Location of river	Total length in South Africa (%)	Length intact (%)
Outside	92	28
Boundary	4	36
Core	4	51

than 5% of main rivers in the country are core rivers within protected areas, receiving protection on both sides of their river bank. Just over 50% of the core river length are still intact, showing an improvement in overall condition compared to rivers falling completely outside of protected areas, which have only 28% of their river length still intact. As could be expected, rivers forming the boundaries of protected areas have an overall condition that is lower than core rivers, but better than rivers completely outside protected areas (Table 3).

Sixty-five of the 112 (58%) main river ecosystems are either not protected or have no remaining intact length (Fig. 5). A further 31 main river ecosystems receive low levels of protection. Only 16 (14%) main river ecosystems are moderately to well protected, having achieved over half of their minimum conservation target (i.e. > 10% of their total length) in statutory Type 1 protected areas.

DISCUSSION

Ecosystem status

This assessment applied a similar approach to parallel assessments of terrestrial, marine, and estuarine ecosystems, and it revealed that main river ecosystems are in a critical state, far worse than terrestrial ecosystems: 54% of main river ecosystems are critically endangered, compared to the 5% of critically endangered terrestrial ecosystems (Driver *et al*., 2005; B. Reyers *et al*., unpubl. data). These results mimic published literature on global trends of the state of freshwater and terrestrial biodiversity (McAllister *et al*., 1997; Ricciardi & Rasmussen, 1999; Abell, 2002; Higgins, 2003; Gleick, 2004; WWF, 2004). The alarming state of main river ecosystems has important implications in developing strategic government direction and policy concerning biodiversity conservation in the country. Freshwater needs to be placed at the forefront of biodiversity planning and implementation (e.g. in the National Biodiversity Strategy and Action Plan), to ensure conservation of freshwater ecosystems and the important services they provide.

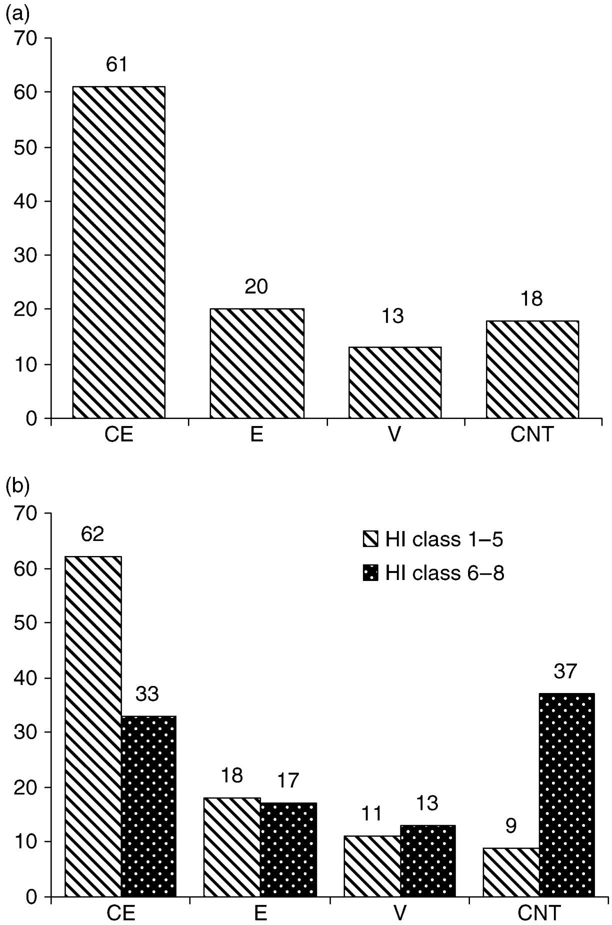

Figure 3 (a) The number of main river ecosystems ($n = 112$) that are critically endangered (CE; < 20% intact), endangered (E; 20–40% intact), vulnerable (V; 40–60%), and currently not threatened (CNT; > 60% intact); and (b) ecosystem status of the more permanently flowing main rivers compared to that of rivers whose flows are more variable, where rivers with a hydrological index (HI) class of 1–5 are considered more permanent and those with a HI class of 6–8 more variable. Proportion of ecosystems is calculated as the number of ecosystems expressed as a percentage of the total number of ecosystems in each group.

Main rivers in South Africa are heavily utilized and regulated to improve water security for socioeconomic use, and there are widespread water transfer schemes across the country to cater for areas where water requirements exceed the natural water availability (Braune, 1985; O'Keeffe, 1989; DWAF, 2004b). This places a great deal of stress on natural ecosystems, as demonstrated by the ecosystem status assessment that shows that 84% of main rivers have become degraded to the point at which they are now threatened (Fig. 3a). Furthermore, the more permanently flowing main rivers, which tend to lend themselves better to utilization and regulation than those rivers with more variable flow, have a higher proportion of threatened ecosystems (Fig. 3b). Modifications to perennial rivers are often associated with significant investments in infrastructure and development (e.g. construction of large dams and irrigation schemes), which make remedial action difficult from political and socioeconomic perspectives.

This assessment is based on main rivers only, and ignores the conservation potential of the numerous major tributaries feeding the main rivers, which are often representative of the same types of ecosystems and in better condition. Had tributaries been included in this assessment, some river ecosystems shared between main rivers and tributaries may well have been classified as less threatened. This highlights the importance of tributaries for conserving biodiversity, in which conserved tributaries could be viewed as refugia for river biodiversity, replenishing other parts of the river system from time to time. For this replenishment to occur, however, it is important that the longitudinal connectivity between the tributaries and its main river be maintained.

In management terms, we propose a multiple-use landscape that seeks to balance the needs of resource utilization and biodiversity conservation. In this management scenario, intact tributaries would play a crucial role in meeting conservation targets, and these would need to be maintained in a relatively natural state with no discharges or impoundments. Main rivers of tributaries selected for conservation could be moderately utilized but would need to be maintained in a healthy enough state to facilitate longitudinal connectivity; this requires understanding ecological needs and designing dam releases accordingly (Postel & Richter, 2003). This supports the global findings that conserving biodiversity and meeting human needs do not have to be mutually exclusive (Richter *et al.*, 2003; Gilman *et al.*, 2004).

As an initial step towards prioritizing conservation action, we therefore recommend focusing conservation attention on conserving intact tributaries containing critically endangered main river ecosystems, while maintaining main rivers in a state healthy enough to facilitate longitudinal connectivity between conserved tributaries. Conservation of the two critically endangered river ecosystems that are unique to main rivers (the Lower Vaal and Orange valleys-5 and the Swartland-5; see Appendix S1) cannot be supported by tributaries. If we are to meet their minimum conservation target, then portions of suitable main river will need to be rehabilitated. If this is not possible (e.g. owing to socioeconomic constraints), this assessment at least makes explicit exactly which ecosystems we have lost or would lose, thus enabling an examination of the subsequent consequences.

Protection levels

Globally, as in South Africa, there has been very little emphasis on proclaiming protected areas for the primary purpose of conserving freshwater ecosystems (Saunders *et al.*, 2002). It is therefore not surprising that most main river ecosystems are not represented in protected areas (Fig. 5). Moreover, inclusion in protected areas does not guarantee conservation: only 50% of the core rivers within protected areas are intact (Table 3). In extreme cases, rivers within protected areas are considerably degraded because they are designed around dams; in most cases, rivers are inadequately conserved because they are not fully contained within protected areas, and are negatively impacted by activities outside the protected area, such as dam construction and agriculture. Despite these deficiencies, the higher proportion of intact rivers inside protected areas, compared to outside (Table 3),

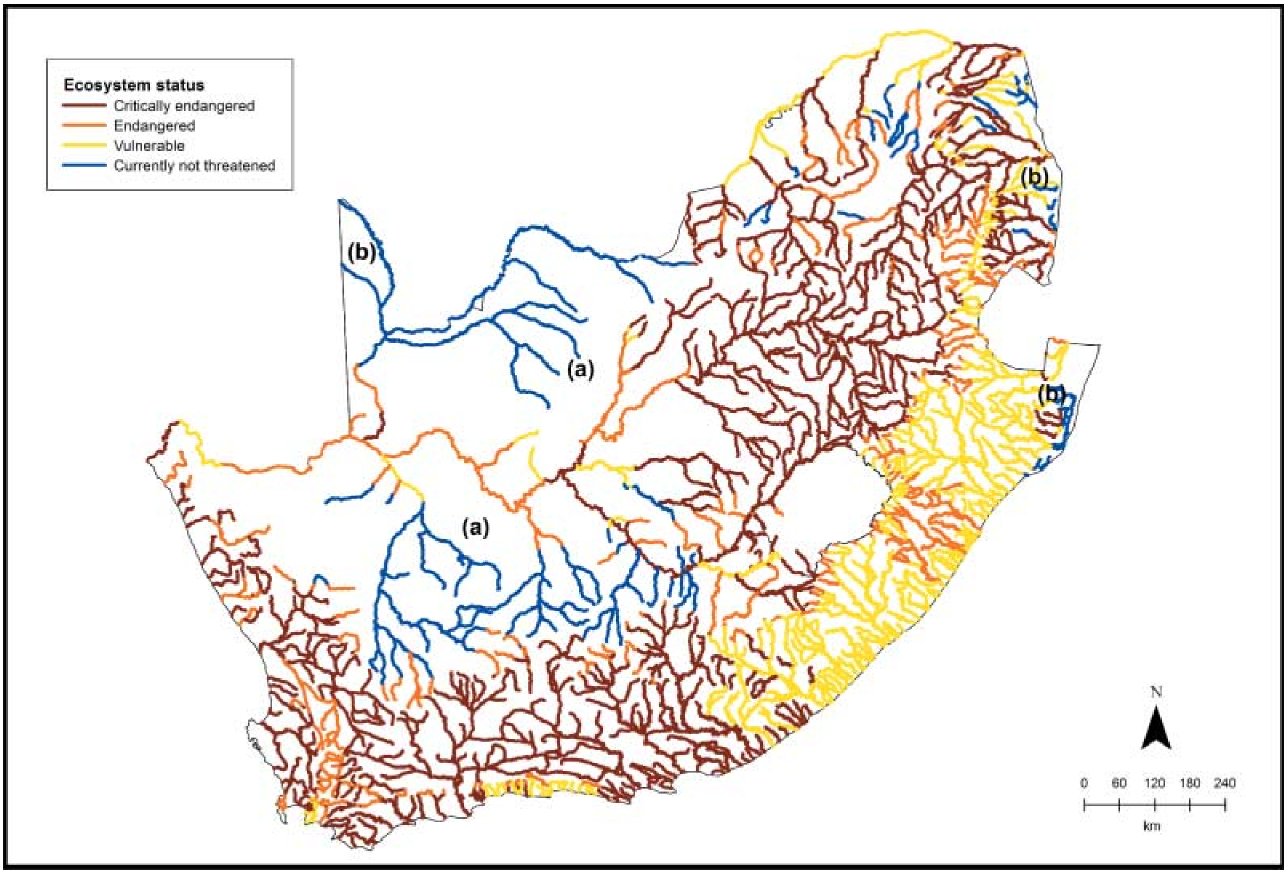

Figure 4 Ecosystem status of main rivers in South Africa, based on the extent of ecosystem still intact. All main rivers are depicted according to their ecosystem status at a national scale, i.e. if a river contains a critically endangered ecosystem, that portion of the river is depicted as critically endangered, regardless of its integrity. The approximate vicinities of the arid interior and larger protected areas, referred to in the text, are denoted by (a) and (b), respectively.

emphasizes the positive role protected areas can have, through appropriate land management strategies.

Saunders *et al.* (2002) provide a few examples where protected areas have been designed with the conservation of freshwater in mind. However, they recognize that whole catchment protection is often difficult to attain, and put forward alternative freshwater protected area design and management strategies, including application of multiple-use zones, use of vegetated buffer strips, attention to ecological flow requirements, and eradication of exotic species. While we recognize that conserving the whole river systems in protected areas is seldom a practical management option, we believe that changing the way in which future protected areas are designated or expanded could help improve the representation of freshwater ecosystems within the protected area systems. These include (1) giving explicit consideration to representing freshwater ecosystems in protected areas; (2) understanding the relative contribution different land makes to freshwater conservation in consolidating land around existing protected areas (e.g. see Roux *et al.*, 2002); (3) avoiding the use of rivers to delineate boundaries of protected areas; and (4) using alternative design and management strategies (e.g. those from Saunders *et al.*, 2002), in combination with existing protected areas, to protect rivers before they enter the protected area.

Although more attention needs to be given to conserving freshwater biodiversity in formal protected areas, this management option alone is not feasible for meeting conservation targets of all ecosystems (currently only 14% of main river ecosystems are moderately to well protected). The most feasible management solution is one of integrated river basin management (IRBM) within catchments, which takes into account the interrelationships between water, the biophysical environment, and socioeconomic and political factors. However, Gilman *et al.* (2004) have found that systematic conservation planning for freshwater biodiversity is underrepresented in most IRBM plans, particularly in developing countries. There is thus an urgent need for promoting the systematic and purposeful conservation of freshwater biodiversity within the context of most IRBM programmes. IRBM plans need to develop clear and explicit conservation visions, targets, and guidelines to ensure the sustainability of freshwater ecosystems and their services, even as stakeholder interests in the area develop. In South Africa, the national Department of Water Affairs and Forestry, custodians of the country's water resources, has acknowledged this need through a project aimed to develop cross-sectoral policy objectives for inclusion of systematic conservation of freshwater ecosystems in their strategic planning processes (Roux *et al.*, 2006).

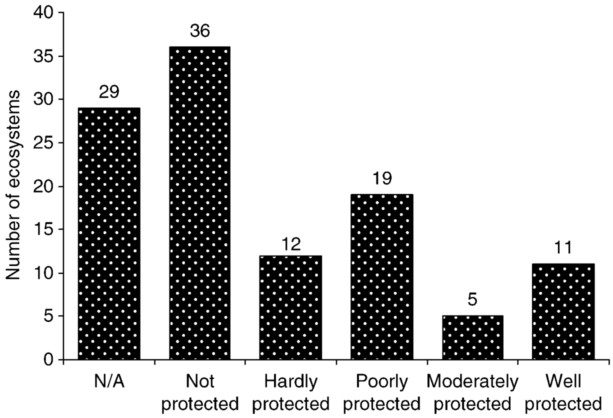

Figure 5 The number of river ecosystems ($n = 112$) that are not protected (0%), hardly protected (< 5%), poorly protected (5–50%), moderately protected (50–99.9%), and well protected (≥ 100%) within statutory Type 1 protected areas. Protection levels are based on the proportion of quantitative conservation target met within protected areas, where the conservation target was taken as 20% of the total length of each main river ecosystem in South Africa. N/A represents those river ecosystems that were not applicable to this analysis because they had no intact main river remaining. Only intact rivers falling within protected areas and > 500 m from boundary, as opposed to forming the boundary, were considered as contributing towards this conservation target.

Limitations and future improvements

Distinguishing between main rivers and tributaries was useful in highlighting the dire state of main rivers and their ecosystems in the country. However, an assessment of both main rivers and tributaries will give a more complete picture of overall ecosystem status of rivers in the country, and the ability to achieve longitudinal connectivity across the landscape. This is currently not possible owing to the lack of data on ecological integrity of tributaries at a national scale. The main river integrity data are also outdated, with transformation having proceeded at alarming rates since the derivation of these data. There is thus a need to update the national scale river integrity data to include both main rivers and major tributaries. This updating should take cognizance of the numerous subnational river health surveys (e.g. River Health Programme, 2001a,b).

Lack of available data on river ecological integrity in Lesotho, Swaziland, and Mozambique also prevented an assessment of ecosystems associated with rivers shared by neighbouring countries. Assessing river basins that are not split by political boundaries would provide a more complete regional assessment of ecosystem status, highlighting ecosystems whose conservation requires the cooperation of more than one country. Nevertheless, this assessment was useful for informing national policy-makers of the status of freshwater ecosystems at a countrywide scale.

River ecosystems used in these analyses are in the process of refinement, and should therefore be viewed as preliminary. Once the ecosystems have been refined, they need to be reviewed by experts to assess whether they provide a true reflection of river ecosystem types at a national scale. The adequacy of these river ecosystems as biodiversity surrogates in conservation planning should also be tested.

There is a range of uncertainty in the setting of thresholds used for devising the different ecosystem status categories. These include issues such as the ability to identify ecological thresholds, the variation in the response of different species or ecosystems to the same disturbances, and the variation in response to thresholds at different scales (Huggett, 2005). We acknowledge the need for empirical data to support the thresholds between ecosystem status categories (20%, 40%, and 60%); these studies should improve our scientific understanding of river ecology, ecosystem functioning, and the response of ecological variables to disturbances. We also recognize that uniform thresholds undermine the relative responses of different ecosystems to the same disturbances. Thresholds used in this assessment should therefore be refined as new research becomes available.

We were considerably limited in drawing conclusions about the prioritization of rivers for conservation action in this assessment because we could not include an assessment of tributaries, and were unable to examine the vulnerability of different rivers to future threats. As a first step in prioritization, we suggest that conservation action should focus on healthy tributaries containing critically endangered main river ecosystems. Future refinements of this study should focus on developing a more robust priority layer that includes both an analysis of the contribution tributaries make to conservation targets and an analysis of vulnerability to future threats. Apart from extending this assessment to include tributaries, there is an additional need to consider wetlands and ground water, as well as to include an assessment of key species or species groups (see, e.g. Master *et al.*, 1998).

CONCLUSIONS

This study assembled existing information to produce a nationwide assessment that examines endangerment and protection levels of rivers *within* large catchments, at a scale fine enough for conservation action (quaternary catchments). The results produced were systematic, defensible, and alarming, confirming general suspicions of the state of main river ecosystems. One of the main advantages of this assessment is that the results were used to guide the National Biodiversity Strategy and Action Plan, which has a strong focus on implementation (Driver *et al.*, 2005). Figures were therefore designed to create a visual impact for decision makers, and undertaking this assessment with concurrent assessments of terrestrial, marine, and estuarine ecosystems also drew attention to the strategic national need to pay more attention to the state of freshwater biodiversity (Driver *et al.*, 2005).

As demands on water increase, the impounding of main river flows to provide water security is likely to increase. This study highlights the importance of intact tributaries for achieving river conservation targets, since tributaries are generally less regulated than main rivers. However, this does not preclude the need for managing main rivers as conduits across the landscape to support ecological processes that depend on connectivity. In management terms, we propose that a moderately used main river connecting intact tributaries may be the best means of achieving a balance between resource utilization and resource protection, particularly in water-limited countries.

While protected areas do not adequately protect river ecosystems assessed in this study, there is a marked improvement in overall river integrity inside protected areas compared to outside. This provides a strong, quantitative argument for establishing protected areas that target freshwater ecosystems, species, and the functional processes that support these. This can be initiated by expanding existing protected areas where possible to include whole river systems, avoiding the use of rivers to delineate boundaries of protected areas and attempting to conserve entire catchments. Where inclusion of entire catchments is not feasible, an attempt should be made to protect rivers before they enter protected areas through the application of management strategies such as delineation of multiple-use zones, riparian zones, and partial water discharges in line with ecological flow requirements.

River conservation is entirely dependent on sound management of the entire catchment they drain. They therefore rely on effective IRBM and there is an urgent need for IRBM plans to include explicit conservation visions, conservation targets, and guidelines to ensure that the needs of freshwater biodiversity are met, even as stakeholder needs grow. This will also ensure the sustainable provisioning of ecosystem services derived from freshwater ecosystems.

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SUPPLEMENTARY MATERIAL

The following supplementary material is available for this article:

Appendix S1 Main river ecosystems in South Africa, with their associated ecosystem status and protected area category. The river ecosystem name is described in terms of the geomorphic province through which it flows, and a number that indicates the hydrological index class into which it falls. The hydrological index describes flow variability of the river, where regions of low flow variability (commonly containing perennial-type rivers) have a hydrological index class close to 1, and the semiarid regions of high flow variability (commonly containing periodic- or ephemeral-type rivers) would be assigned to classes 6–8. Ecosystems labelled 'N/A' under their protected area category have no remaining intact main river

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