Biological Conservation 148 (2012) 167–179

Contents lists available at SciVerse ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

# Conservation priorities for freshwater biodiversity: The Key Biodiversity Area approach refined and tested for continental Africa

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ARTICLE INFO

*Article history:*
Received 21 January 2011
Received in revised form 4 January 2012
Accepted 10 January 2012
Available online 17 February 2012

*Keywords:*
Key Biodiversity Areas
Protected Areas
Freshwaters
Africa
Red List
Conservation
Conservation planning

ABSTRACT

Freshwater ecosystems represent one of the most threatened broad habitat types globally. Despite containing around a third of all vertebrates, area-based approaches to conservation planning rarely include freshwater species as an explicit target for conservation. Here we describe and apply a globally applicable methodology comparable to those for other groups (i.e. Important Bird Areas) to identify river and lake catchments that represent, or contain, freshwater Key Biodiversity Areas. We discuss the rationale behind the methodology and propose appropriate definitions and quantitative threshold values for the selection criteria. Thresholds are developed through spatial analysis of species information for four comprehensively assessed freshwater taxonomic groups in continental Africa, comprising 4203 species, as recently assessed for the IUCN Red List of Threatened Species™. To illustrate application of the methodology freshwater Key Biodiversity Areas are identified across continental Africa, and conservation planning software used to prioritise a network of catchments that captures 99% of the total species complement within catchments covering ca. 20% of the total land area. Within these prioritised catchments only 19% of river length falls within existing Protected Areas suggesting that, given the high connectivity within freshwater ecosystems and their dependence upon catchment management for effective conservation, modification or expansion of the protected area network is required to increase effective conservation of freshwater species. By applying this methodology, gaps in the coverage of freshwater species by existing Protected Areas can be identified and used to inform conservation policy and investment to ensure it is inclusive of, and effective for, freshwater biodiversity.



## 1. Introduction

Although occupying less that one per cent of the earth's surface, freshwater ecosystems contribute disproportionately to global biodiversity, containing around one third of all vertebrates (Dudgeon et al., 2006; Strayer and Dudgeon, 2010), and providing ecosystem goods and services estimated to be worth trillions of dollars annually (Postel and Carpenter, 1997; Millennium Ecosystem Assessment, 2005). Growth of the human population and increased socio-economic development have led to severe pressures being placed on freshwater systems globally (Vörösmarty et al., 2010), leading to an estimated extinction risk amongst freshwater species that is significantly higher than found terrestrially (Dudgeon et al., 2006; Darwall et al., 2009; WWF, 2010). For example Ricciardi and Rasmussen (1999) estimate that extinction rates of freshwater animals in North America may be fives times higher than that found in terrestrial habitats. Across Europe, assessments for the IUCN Red List (IUCN, 2010) indicate significantly higher numbers of threatened freshwater molluscs (44%) and fish (37%) than mammals (15%), reptiles (19%), and amphibians (17%). Historically fresh water has been viewed as a human resource to be exploited (Palmer, 2010), such that over 50% of available water is now captured by humans, and the natural morphology, flow regime and biogeochemical cycles of many freshwater systems are disrupted (Jackson et al., 2001; Nilsson et al., 2005; Strayer and Dudgeon, 2010). In order to halt the decline in biodiversity and the associated loss of services there is a need to legitimise freshwater species as users of water (Naiman et al., 2002) and to identify and prioritise areas for conservation of freshwater biodiversity (Moilanen, 2007; Nel et al., 2009a; Linke et al., 2011).

The establishment of Protected Areas (PAs) has become an important mechanism for the conservation of biodiversity (Langhammer et al., 2007; Gaston et al., 2008) as habitat loss and degradation are acknowledged as being amongst the principle threats to biodiversity globally (Vié et al., 2009). With a new global target for coverage by PAs set at 17% for terrestrial habitats and inland water following the 10th meeting of the Conference of the Parties to the Convention on Biological Diversity there is a need to expand the network in a strategic way (Margules and Pressey, 2000; Eken et al., 2004; Rodrigues et al., 2004a). Locations of new PAs have been identified either for pragmatic reasons (Margules

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doi:10.1016/j.biocon.2012.01.016

and Pressey, 2000; Joppa and Pfaff, 2009) or on the basis of our understanding of better known groups, predominantly mammals, birds and amphibians (Brooks et al., 2004; Rodrigues et al., 2004b; Ricketts et al., 2005; Rondinini et al., 2005) in the belief that these will act as surrogates for lesser known groups. However, surrogacy between taxonomic groups from differing realms (i.e. freshwater vs. terrestrial) is low (Rodrigues and Brooks, 2007; Darwall et al., 2011) with studies in the United States (Herbert et al., 2010; Lawrence et al., 2011) and Brazil (Nogueira et al., 2010) demonstrating that existing PAs provide significantly less coverage for inland aquatic species and habitats than for terrestrial ones (Roux et al., 2008; Darwall et al., 2011).

Here we present a framework for identifying Global Key Biodiversity Areas (KBAs) for freshwater species (termed freshwater KBA subsequently). The rationale and criteria for identification of freshwater KBAs are extensions of the original concept of Important Bird Areas (e.g. Grimmett and Jones, 1989) adapted and applied to other taxonomic groups (Eken et al., 2004; Langhammer et al., 2007), with a preliminary framework methodology for identification of freshwater KBAs proposed by Darwall and Vie (2005). KBAs are sites of global significance for conservation of species, derived from a set of criteria based on vulnerability and irreplaceability, standardized globally and applicable across taxonomic groups (Eken et al., 2004; Langhammer et al., 2007). Within this definition, vulnerability refers to the likelihood that species within a site will be lost over time, and irreplaceability refers to the spatial options available for conservation of particular species (Langhammer et al., 2007). The aim of the KBA methodology presented here is identification of all globally significant sites that contain species requiring conservation action. Once sites qualifying as KBAs have been identified, gap analysis (e.g. Rodrigues et al., 2004a; Burgess et al., 2005) can be employed to examine the shortfall in representation of species within the existing PA network. The development of a methodology for the identification of freshwater KBAs can be seen as critical to inform the strategic expansion of the existing PA network for freshwater species as it provides a focus on those sites of the highest global significance.

Given the limited resources available for conservation, having identified KBAs, approaches based on expert knowledge and systematic conservation planning (e.g. Amis et al., 2009; Nel et al., 2009a,b; Beger et al., 2010; Esselman and Allan, 2011; Rivers-Moore et al., 2011 Roux et al., 2008; Turak and Linke, 2011) can then be used to prioritise investment. Recent years have seen a growing interest in the application of conservation planning techniques, developed primarily for terrestrial and marine systems, for setting freshwaters conservation targets (Linke et al., 2011). The application of existing techniques to freshwater systems presents new challenges, primarily relating to connectivity within the wider landscape (Hermoso et al., 2011; Nel et al., 2011). The identification of KBAs and the application of conservation planning approaches can be seen as having a synergistic relationship where the former identifies sites that are important for the conservation of species diversity and the latter prioritises amongst sites to identify a practical and effective network of protected or managed areas.

We consider catchments identified using the framework presented here as "potential" freshwater KBAs for a number of reasons. If a species meets any of the criteria that would trigger KBA qualification, expert knowledge must be used to refine information about the species, prioritising the most important catchments, or areas within those catchments, across its range. To shift status from a potential to confirmed freshwater KBA site designation should ideally be approved through workshops involving stakeholders (e.g. national, regional and local government, NGOs, local users, community groups). Through this engagement conservation planning principles may be used to design a national or regional reserve network that considers biodiversity targets within the social, economic and political context (Margules and Pressey, 2000) thus ensuring local engagement and approval of the process (Barmuta et al., 2011). While KBAs are identified using a set of global standards their protection/management depends on local implementation. Often they exist outside the formal Protected Area network and so such engagement is key. The process for registration of confirmed KBAs is currently being examined by the World Commission on Protected Areas and the IUCN Species Survival Commission leading to the development of a global database of formally approved KBAs.

The aim of the current study is to propose criteria to identify freshwater KBAs and to demonstrate their application by identifying a network of potential freshwater KBAs across continental Africa. In doing so, a primary consideration is to align our work with criteria for the identification of KBAs for other taxa, so that the conservation community can present a clear rationale across taxonomic groups for the identification of these sites to decision makers. Building on the work of Darwall and Vie (2005), we propose and test quantitative thresholds and examine whether threshold values based on the knowledge of other groups are appropriate for a range of freshwater taxa. We apply these criteria to data for all known species of freshwater crabs, fish, molluscs and odonates (dragonflies and damselflies) recorded from continental Africa for each group individually, and identify potential freshwater KBAs based on data for all four groups. Finally, we use optimization software commonly used in conservation planning to identify a set of potential freshwater KBAs that would collectively achieve species targets in an efficient manner.

## 2. Materials and methods

### 2.1. General methods

Data were collected based on a method developed by the IUCN Global Species Programme's Freshwater Biodiversity Unit to assess the conservation status of freshwater species. The Red Listing process is based on regional workshops that are highly participatory, involving local experts and stakeholders and as such represents a model for local engagement that could be used in the identification of freshwater KBAs. We describe a 7 step process first outlined by Darwall and Vie (2005) and focus on the development and testing of criteria for Step 5. Of the seven steps described, five have been incorporated into this analysis with Steps 3 and 6 omitted due to data limitations.

Step 1: Define the geographic boundaries within which to identify important sites.

The extent of our study is defined as continental Africa. This continent represents the first for which IUCN has assessed the distribution and conservation status of all known freshwater crabs, fish, molluscs and odonates. These four taxonomic groups were identified as priorities for assessment due to the availability of reliable information, their role in the maintenance of healthy freshwater systems, and the important contribution that they make for the provision of ecosystem goods and services and maintenance of livelihoods.

Step 2: Define the wider ecological context of the designated assessment area.

Defining the wider context is important in determining the scale at which conservation action should take place. Rivers and lakes cannot be evaluated in isolation from the surrounding landscape. In some instances action can be focussed on specific areas, whereas in other instances action must be at broader scales to consider the entirety of the catchment and connectivity in the broader landscape (i.e. river basins), often extending across national boundaries, to address ecosystem processes, threats, and management issues arising beyond the assessment area. Species were mapped to 7079 catchments comprising continental Africa, as delineated by a cleaned version of Hydro1k Elevation Derivative Database at level 6 (Appendix Fig. A1). These represent an appropriate management unit for freshwater systems that incorporate connectivity with the surrounding landscape both within and between catchments (Luck et al., 2009a). Use of catchment units captures smaller freshwater habitats (e.g. ponds, small streams) that are within the landscape but are difficult to capture in GIS.

Step 3: Identify and map the distribution of inland water habitat types.

The aim of step 3 is to ensure that all habitat types are represented in the final KBA network. For freshwater systems a consistent habitat classification has not been developed at the continental scale and so this step was not applied in the current study (see Step 6 below).

Step 4: Assemble an inventory of the distribution and conservation status of priority aquatic taxa.

Data on the distribution and conservation status of all known species of freshwater fish, molluscs, odonates and crabs across continental Africa were collated and assessed at 6 regional workshops held between 2003 and 2008. In total, 4318 freshwater species were assessed composing 106 crabs, 2946 fish, 562 mollusc and 704 odonates. The conservation status of each species was assessed using the IUCN Red List Categories and Criteria: Version 3.1 (IUCN, 2010). For each species, presence within a catchment was based on both records from sampling (known distribution), and expert knowledge (inferred distribution). Using these data for each species, ranges were constructed that represented the likely distribution of the species based on their presence within catchments.

Step 5: Apply species based site selection criteria.

**Criterion 1.** *A site is known or thought to hold a significant number of one or more globally threatened species or other species of conservation concern*

This criterion is based on vulnerability and targets species with the highest risk of extinction. In the current study we use globally threatened species according to the IUCN Red List of Threatened Species™ that classifies species into three categories (Critically Endangered, Endangered, or Vulnerable) based on a globally accepted set of quantitative criteria (IUCN, 2010). For this criterion ''other species of conservation concern'' can be included, for example, species that are evolutionary distinct (e.g. EDGE species (Isaac et al., 2007)). The two principle questions that arise for the application of this criterion are: (i) what is the threshold number of individuals of a particular species that are to be present for a KBA to be triggered, and; (ii) how many species of each category should be present for a KBA to be triggered?

Species distribution data in the current study are recorded as present within catchments and no information about population sizes is provided. Data on the numbers of individuals is rarely available for freshwater species so questions relating to threshold numbers of individuals (step (i) above) cannot be addressed, although Langhammer et al. (2007) provide provisional thresholds where population data are available. One method to address this data shortfall is through the use of expert knowledge where local experts identify the most important sites for specific species in terms of likely abundance.

For each taxonomic group, catchments were selected as potential freshwater KBAs based on three alternative scenarios; (1) Critically Endangered species present; (2) Critically Endangered or Endangered species present and; (3) Critically Endangered, Endangered or Vulnerable species present. We consider that the presence of a single species classified as Critically Endangered or Endangered is sufficient to trigger qualification as a potential freshwater KBA as these species are at extremely high risk and very high risk of extinction in the wild respectively (IUCN, 2010). Our analysis was therefore limited to testing differing threshold values for the number of species classified as Vulnerable.

To examine whether targeting threatened species provides co-benefits for other taxa within the taxonomic group, random species accumulation curves were generated for each of the four taxonomic groups using the ''specaccum'' function in the R Vegan package (Oksanen et al., 2010). The percentage of the total species inventory captured based on the three scenarios was compared with the percentage of the total species inventory captured by random selection.

**Criterion 2.** *A site is known or thought to hold non-trivial numbers of one or more species (or infraspecific taxa as appropriate) of restricted range*

The importance of this criterion arises from the relationship between the size of a species range and its extinction risk (Purvis et al., 2000) with species with small (restricted) ranges more likely to go extinct than those that are widespread. In the criterion definition the term non-trivial is used to specifically exclude areas where species occur as vagrants as these sites will not be priority conservation targets for that species and will artificially increase the species range. The current study focuses on globally assessed species from the IUCN Red List however as discussed by Darwall and Vie (2005) this criteria could equally be applied to infraspecific taxa, such as sub-species, or fish stocks specific to individual freshwater systems.

The principle challenge for applying this criterion is in defining the area threshold for a species to be classified as restricted range. To define restricted range species two approaches have been suggested. Firstly, the use of a percentile approach, for example the 25% of species (from each taxonomic group) with the smallest ranges qualify as restricted range (Langhammer et al., 2007). Secondly, the use of an absolute threshold approach where any species with a distribution range area below a specified value qualifies (Langhammer et al., 2007). Based on knowledge of mammals, birds and amphibians a value of 50,000 $km^2$ has been suggested as a robust limit (Eken et al., 2004). Research suggests that for mammals and birds the two approaches yield similar results with around 25% of species being captured based on a threshold of 50,000 $km^2$. However for amphibians the 50,000 $km^2$ threshold captures around 60% of species.

To examine application of this criterion to freshwater species the range of each species was calculated based on the total area of catchments with known or inferred presence of the species. The percentage of species meeting the threshold for restricted range was examined iteratively using species range areas between 1000 $km^2$ and 100,000 $km^2$ using incremental steps of 1000 $km^2$. To assess the appropriateness of thresholds developed for other taxonomic groups we examined outputs when applying (1) the 25 percentile of smallest species ranges, and (2) the percentage of species captured based on a threshold value of 50,000 $km^2$.

**Criterion 3.** *A site is known or thought to hold a significant component of the group of species that are confined to an appropriate biogeographic unit or units*

Criterion 3 puts species into an ecological context that cannot be represented by looking at species individually. Heterogeneity of environmental conditions across the globe has led to the development of assemblages of species endemic to individual biogeographic units (e.g. ecoregions Langhammer et al., 2007). These unique species assemblages represent valuable units of biodiversity that should be conserved. The rationale behind this criterion is to identify where groups of species restricted in this manner occur as they might not be captured through individual species based criteria. Criterion 3 provides a mechanism to identify priority areas where there are few threatened species (e.g. due to inaccessibility) but high endemism. The principle challenge under Criterion 3 is identifying catchments that contain areas of "contextual species richness" defined as areas rich in species restricted to an individual biogeographic unit (Langhammer et al., 2007).

While thresholds tested for Criterion 1 and 2 are based on the approaches previously developed for the better known taxonomic groups (e.g. birds, mammals and amphibians), Criterion 3 is the least developed of the KBA criteria. Langhammer et al. (2007) detail a number of differing methodologies, for example some Important Bird Areas (IBAs) have been identified based on the selection of a network of sites that capture all species restricted to a particular biogeographic region. In Turkey, sites qualified as KBAs under this criterion if 25% of species restricted to a biogeographic unit occur there (Langhammer et al., 2007). Two principle questions arise when developing this criterion for freshwater ecosystems; (i) how should a biogeographic unit be defined and, (ii) how is "a significant component of a group of species" defined.

Freshwater ecoregions of the world developed by Abell et al. (2008) are used as the biogeographic units in the current study. For each taxonomic group we identified all species that occur in a single freshwater ecoregion. The proportion of ecoregion restricted species present within each catchment was then calculated. To establish an appropriate threshold for the proportion of species restricted to a ecoregion we tested values between 1 and 100%. The proportion of ecoregions that would include potential freshwater KBAs and the proportion of catchments per ecoregion that would qualify as potential freshwater KBAs were examined.

**Criterion 4a.** *A site is known or thought to be critical for any life history stage of a species*

Criterion 4a identifies sites that are essential for the completion of the life cycle of the species. Sites identified under this criterion could include migration routes, spawning or feeding grounds. During the Red List assessment process information on such sites is collated and coded for each species. Experts can draw upon this information source during the KBA review procedure and will bring their own knowledge to workshops during the prioritisation exercise to identify key areas for management.

**Criterion 4b.** *A site is known or thought to hold more than a threshold number of individuals of a congregatory species*

In Criterion 4b the aim is to identify sites that hold, at some time, a large proportion of the global population of an individual species and so are irreplaceable as their loss could have a significant impact on the species. For freshwater species it is most likely that this criterion would apply to species congregations along migration routes, such as at the mouths of rivers, or at breeding grounds. Within the literature there is a general consensus that between 1% and 5% of the global population is an appropriate threshold for a site to qualify under this criterion (Langhammer et al., 2007) so this threshold may also be appropriate for catchments. For freshwater species, population data are most commonly only available for species with a restricted range or for those classified as threatened, although even for these species information may not be spatially explicit. Due to this lack of data, expert knowledge is an important resource for the identification of sites of importance, stressing the importance of engagement with stakeholders in the KBA process.

As both Criterion 4a and 4b largely rely on expert knowledge yet to be obtained through workshops they are not considered in further detail within the current study.

Step 6: Ensure full representation of inland water habitats among those sites selected.

This step represents a "coarse filter" approach to be added as a precautionary measure (Groves et al., 2002), as protecting sites within all habitat types is intended to capture species in poorly surveyed areas where existing information is insufficient for application of Step 5. Several freshwater classification approaches have been applied at regional scales using selection criteria that include condition and connectivity in achieving representation targets (e.g. Thieme et al., 2007; Khoury et al., 2011). Areas with insufficient information for application of Step 5 represent priorities for research. Due to the lack of a consistent habitat classification across continental Africa Step 6 was not used in the current study.

Step 7: Ensure inclusion of keystone species.

After identifying a network of potential freshwater KBAs, an inventory of all known species was compiled to identify catchments with ecologically important species. The full Red List was used to identify ecologically important species – those which play important roles in the life histories of other species – such as intermediate fish hosts for molluc larvae, or that are critical for habitat creation, maintenance, or nutrient cycling.

### 2.2. Prioritisation of catchments

The aim of the freshwater KBA methodology presented here is to identify all catchments of global conservation significance. Given that there are limited funds for conservation investment it is necessary to prioritise amongst KBAs to produce an efficient reserve network. In the current study the conservation planning software MARXAN (Ball et al., 2009) was utilized to prioritise amongst triggered catchments using a simple set of rules (scenarios) to examine the efficiency with which species can be represented and overlap with the existing PA network. We stress that this was a simple exercise to examine efficiency of representation and we discuss the limitations in detail in the discussion.

As the Red List category indicates the vulnerability of the species MARXAN was set up to represent 100% of catchments containing Critically Endangered (CR) species in the final network together with 75% of catchments containing Endangered (EN) and 50% of catchments containing Vulnerable (VU) species. Targets for other species were for representation in at least two disjunct catchments for redundancy to lower extirpation risk. The area ($km^2$) of the catchment (min 7.3 $km^2$, max 80,318.7 $km^2$, median 2634.0 $km^2$) was used as the unit of cost for selection within the prioritised network (Moilanen et al., 2008) to minimize total area for efficiency.

Based on these settings MARXAN was run using three scenarios relating to the existing PA network and the efficiency of implementation. While few PAs are designed specifically for freshwater species we considered that the presence of a PA within a catchment provides an indication of management potential. The World

Database on Protected Areas (IUCN and UNEP-WCMC, 2010) was used to identify catchments containing PAs. Of the 7079 catchments 2790 contain land designated as a PA under the IUCN categories (Dudley, 2008). The total area covered by PAs in these catchments was often low (i.e. 27% of PAs incorporate an area of less than 5% of the catchment) and not congruent with freshwater habitats (i.e. 24% of catchments have less than 5% of their total river length within a PA). Although dependent on a number of factors such as intensity and type of anthropogenic impact (Paul and Meyer, 2001), once disturbance within a catchment crosses a threshold of ca. 30% there is often a marked decline in the quality of a river system (Allan, 2004). Therefore in the first scenario, if 70% or more of a catchment intersected within PA boundaries, it was fixed into the MARXAN solution and could not be removed. Catchments where the PA incorporated between 25% and 70% of the total area were initially included within the reserve network but the algorithm was allowed to remove them if a more efficient solution was identified.

In the second scenario the constraint imposed by existing PAs was removed. In the final scenario the cost criterion was also removed to examine the network of catchments that would be selected if the sole aim was to prioritise based on the presence of species and species assemblages of conservation concern. In each scenario MARXAN was run with 1000 iterations to select an optimal reserve network.

## 3. Results and recommendations

### 3.1. Definition and thresholds for criteria

#### 3.1.1. Criterion 1

For crabs, molluscs, and odonates the inclusion of species classified as threatened according to the IUCN Red List triggers selection of catchments representing less than 10% of the total land area (Table 1). For fish, the corresponding figure is 21.64% of the total land area. Although the number of threatened taxa is higher for fish than for other taxonomic groups this is not the principle driver of this difference, as many VU fish species are concentrated within a few catchments (i.e. Lake Victoria). The pattern is driven primarily by a small number of wide ranging but VU species for example *Oreochromis machochir*, a common and widespread species from southern Africa classified as VU due to risk of hybridisation with the alien invasive *Oreochromis niloticus*.

In testing Criterion 1 the principle aim was to examine the implications of applying a threshold for the number of VU species that must be present for a catchment to qualify as a potential freshwater KBA. As demonstrated in Fig. 1, for fish and odonates there is a decrease in the total land area captured within potential freshwater KBAs up to a threshold value of five VU species. All catchments containing more than five VU species also contain either a CR or EN species and would therefore already qualify as a potential freshwater KBA under this criterion. Although the proportion of species captured remains consistent with increasing threshold values (Fig. 1) a threshold set at more than one VU species could lead to serious omissions in identifying potential freshwater KBAs. For example, 27 fish classified as VU would not be represented within any potential freshwater KBA if a threshold value for VU species was applied as they occur in isolation within catchments with no other qualifying species. A precautionary approach is taken where the presence of any threatened species triggers qualification as a potential freshwater KBA. For the limited number of wide ranging VU species expert opinion can be used to identify key areas for conservation action. For example, for *O. machochir* (VU) conservation action could focus on those catchments where barriers to the spread of invasive species exist or might be imposed, creating strongholds for the remaining populations. For such wide-ranging species, the possibility of triggering freshwater KBA qualification based on the presence of a single VU species maintains the maximum number of conservation planning options.

Based on catchments that would qualify as potential freshwater KBAs, this criterion would represent >85% of the total species inventory of fish, molluscs and odonates across Africa at some point in their range (Table 1). For mollusc and odonate species despite less than 10% of the total area of continental Africa qualifying as a potential freshwater KBA, a high proportion of the total species inventory for each of these groups is represented. As discussed previously the relatively large area qualifying under this criterion for fish is due to inclusion of a number of widespread VU species. However, based solely on the presence of CR or EN species 81% of the species inventory would be captured in catchments covering just 9% of continental Africa. This result suggests that there is the potential to prioritise a reserve network that can represent a high proportion of species that do not qualify under the freshwater KBA criteria.

It is possible that this pattern is driven by chance, and that selecting a comparable number of catchments across continental Africa at random would result in a similar proportion of the total species inventory being represented. As can be seen in Fig. 2 for fish and molluscs prioritising based on threatened species is a significantly better strategy than selecting sites at random. For crabs and odonates the relationship is more equivocal, while more species are captured than would be expected on average the number of species falls within the band representing the standard deviation. For these taxonomic groups we conclude that random selection and selection based on threatened species are equally effective at repre-

**Table 1**
Percentage of land area and, number of threatened taxa qualifying and the percentage of the total species inventory captured within potential KBAs.

| Group | Threat status | Qualifying taxa based on the Red List status | Total taxa in group in Africa | % of African land area | % of total taxa captured in qualifying area |
|---|---|---|---|---|---|
| Crabs | CR | 2 | 106 | 0.05 | 5.66 |
| | CR, EN | 12 | | 0.78 | 35.85 |
| | CR, EN, VU | 25 | | 1.93 | 53.77 |
| Fish | CR | 113 | 2946 | 3.45 | 48.30 |
| | CR, EN | 257 | | 9.12 | 81.23 |
| | CR, EN, VU | 606 | | 21.64 | 94.67 |
| Molluscs | CR | 49 | 562 | 1.53 | 53.56 |
| | CR, EN | 112 | | 4.00 | 82.56 |
| | CR, EN, VU | 145 | | 8.19 | 85.59 |
| Odonates | CR | 13 | 704 | 0.56 | 55.40 |
| | CR, EN | 25 | | 3.21 | 73.72 |
| | CR, EN, VU | 58 | | 7.36 | 84.66 |

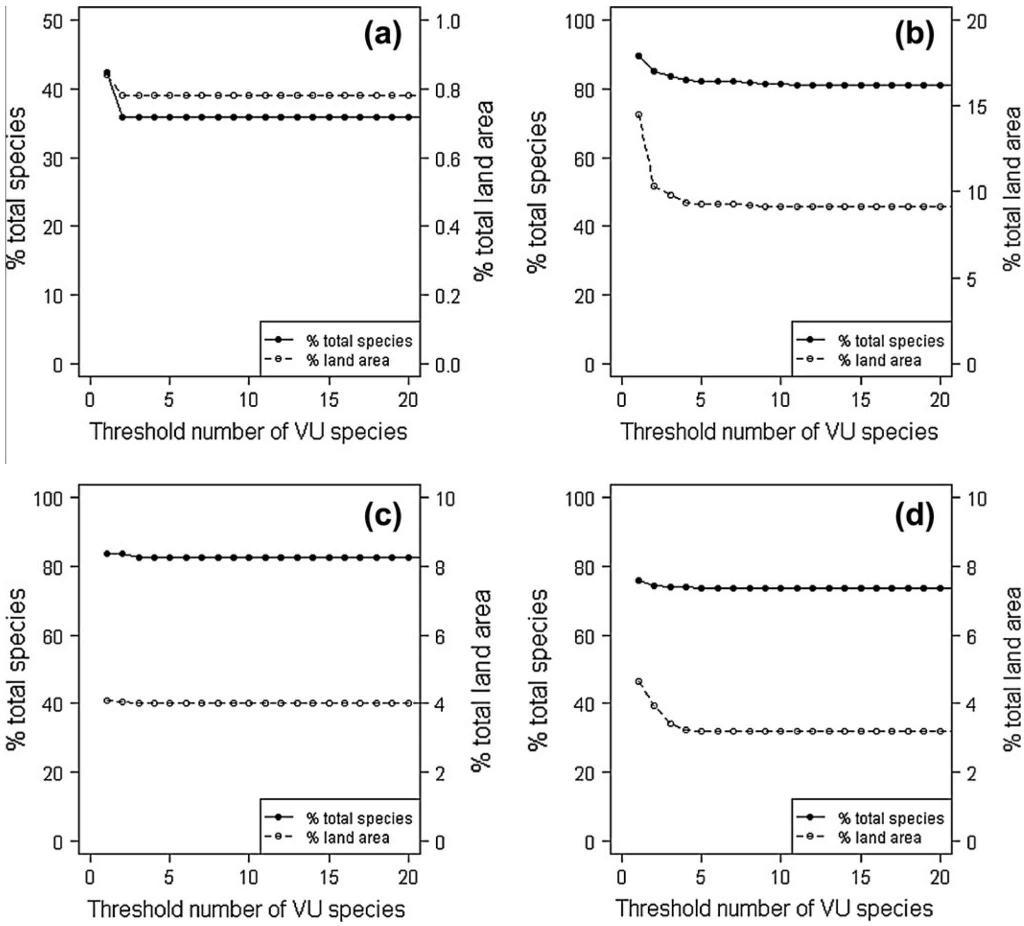


**Fig. 1.** Thresholds for number of Vulnerable (VU) species of (a) crabs, (b) fish, (c) molluscs, and (d) odonates within a catchment for qualification under Criterion 1. Illustrated are the total percentage of species captured for each threshold value (left hand axis; solid black points and line) and the percentage of total land area qualifying for each threshold value (right hand axis; hollow point and dashed line).

senting the total species inventory. However, explicitly targeting threatened species is clearly preferable than a random approach where purely by chance important areas may be missed.

*3.1.2. Criterion 2*

The principle challenge for Criterion 2 is in defining threshold values for "restricted range". Results indicate that there are similarities between taxonomic groups in values obtained for crabs, fish and molluscs based on both a percentile and absolute threshold value. Using a percentile approach where the 25% of species with the smallest ranges are considered as restricted range would result in a threshold value of between 17,000 and 24,000 km$^2$. Conversely an absolute threshold of 50,000 km$^2$ captures around 50–60% of species (see Fig. 3). An absolute threshold value is preferable to a percentile approach since, when the species inventory changes due to continued assessment work or changes in taxonomy, thresholds based on a percentile approach would have to be continually recalculated. It is clear that the absolute threshold of 50,000 km$^2$ established for birds and mammals is not appropriate for crabs, fish and molluscs as it would include more than 50% of species within each group failing to sufficiently highlight species upon which to focus future conservation efforts. With the current dataset representing all known species of crabs, fish and molluscs in continental Africa it is suggested that an absolute threshold of 20,000 km$^2$ is applied. This would capture between 20% and 30% of all species within each species group.

Odonates show a different pattern. Based on a percentile approach a threshold of 25% of species would include those with a range of up to 87,000 km$^2$. Conversely setting an absolute threshold of 50,000 km$^2$ captures 18% of species. For odonates we conclude that setting 50,000 km$^2$ as an absolute threshold may be appropriate. Compared with other freshwater taxa, odonates are not restricted by barriers imposed by catchment boundaries as they possess an aerial stage with strong dispersal abilities. Thresholds similar to mammals and birds, taxonomic groups similarly unconstrained by these barriers, are therefore considered to be appropriate.

*3.1.3. Criterion 3*

Based on differing thresholds values for the proportion of ecoregion restricted species Fig. 4 illustrates both the proportion of ecoregions that contain qualifying catchments, and the proportion of qualifying catchments within these ecoregions. A threshold of <5% is needed for all ecoregions and catchments that contain ecoregion restricted species to qualify under this criterion. In contrast, above a threshold value of ca. 50% a low number of ecoregions and catchment qualify across the groups.

Two problems arise when trying to determine a threshold. First, wide-ranging species that occur in a number of ecoregions will often comprise a significant proportion of the overall species inventory within each catchment. As a result too high a threshold value will result in a large proportion of catchments being excluded. Second, there is considerable variation in both the size of ecoregions and the number of species that are found within them. Ecoregions such as the Dry Sahal in the north of the continent contain generally low numbers of species across a large area,

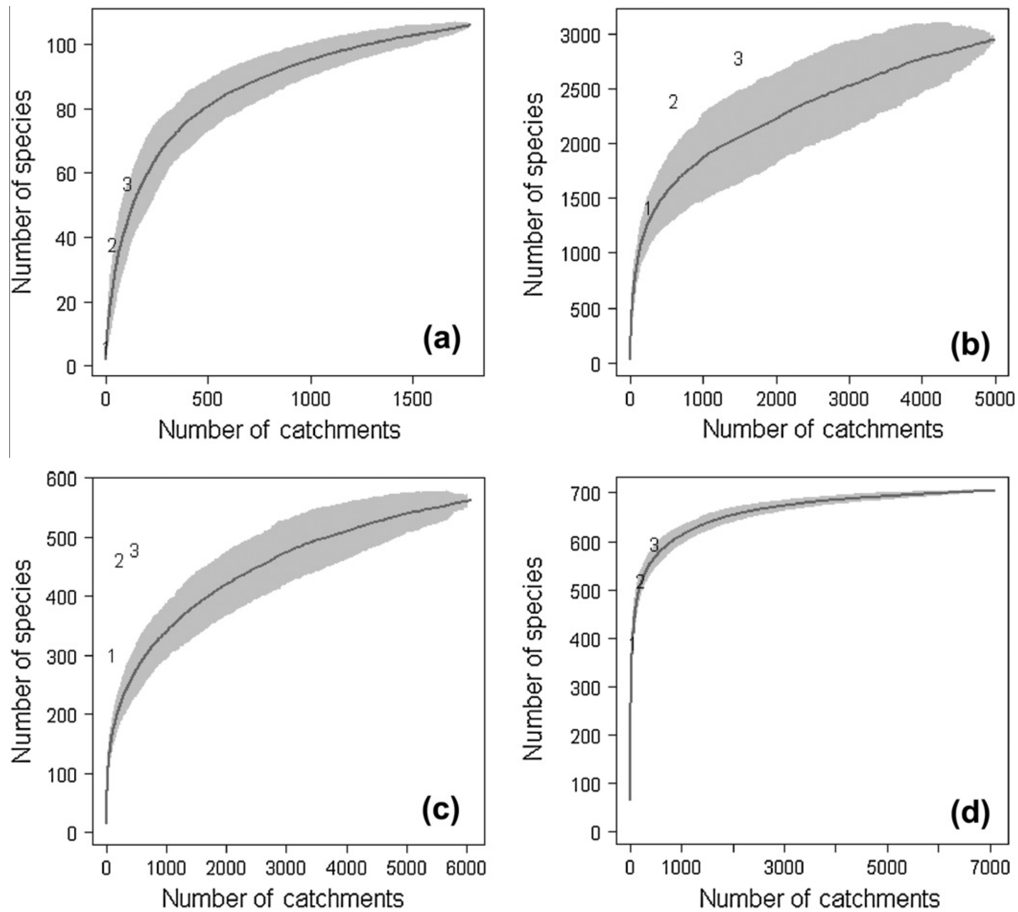


**Fig. 2.** Random species accumulation curves for (a) crabs, (b) fish, (c) molluscs, and (d) odonates. The gray band represents the standard deviation based on 1000 runs. The number of species from the total species inventory captured based on Criterion 1 is indicated based on (1) presence of one Critically Endangered species, (2) presence of one Critically Endangered or Endangered species or (3) presence of one Critically Endangered or Endangered or Vulnerable species.

whereas the Lake Tanganyika ecoregion contains high numbers of endemic species within an comparatively small area. The threshold value must be set to not only capture ecoregions such as Tanganyika where there are clearly unique assemblages of taxa, but also to pick up those catchments that capture more cryptic assemblages of species that may not already receive global attention.

We suggest a threshold of 25% of species being restricted to the ecoregion to trigger qualification of a catchment. This represents a compromise that (i) reduces the number of qualifying catchments, focussing on those with a species assemblage representative of the ecoregion and, (ii) still provides a range of catchment within ecoregions allowing spatial options for subsequent prioritisation.

### *3.2. Summary of criteria and thresholds*

Box 1 summarizes the criteria and proposed thresholds for the identification of potential freshwater KBAs examined in the current study. Fig. 5 spatially summarizes for each of the four taxonomic groups the catchments that are triggered as potential freshwater KBAs. In total, for the four combined taxa, 2309 catchments qualify covering 34.28% of the total land area of continental Africa and capturing 99% of all the taxa at some point in their range (Fig. 6a). Of these priority catchments a total of 21.30% of the land area and 15.11% of the river length are within an existing PA.

Box 1. Summary of KBA criteria and thresholds for freshwater taxa.

Criterion 1: *A site is known or thought to hold a significant number of one or more globally threatened species or other species of conservation concern*.
*Threshold*: The presence of one or more CR, EN or VU species will trigger the site as a potential freshwater KBA.
Criterion 2: *A site is known or thought to hold non-trivial numbers of one or more species (or infraspecific taxa as appropriate) of restricted range*.
*Threshold*: A threshold value of 20,000 $km^2$ should be applied for crabs, fish and molluscs and a threshold value of 50,000 $km^2$ applied for odonates.
Criterion 3: *A site is known or thought to hold a significant component of the group of species that are confined to an appropriate biogeographic unit or units*.
*Threshold*: To trigger qualification at least 25% of the total species from a specific taxonomic group must be restricted to the freshwater ecoregion in which the catchment is located.

### *3.3. Coverage*

Within the qualifying catchments 100% of crab, 99.2% of fish, 99.1% of mollusc and 99.7% of odonate species across continental

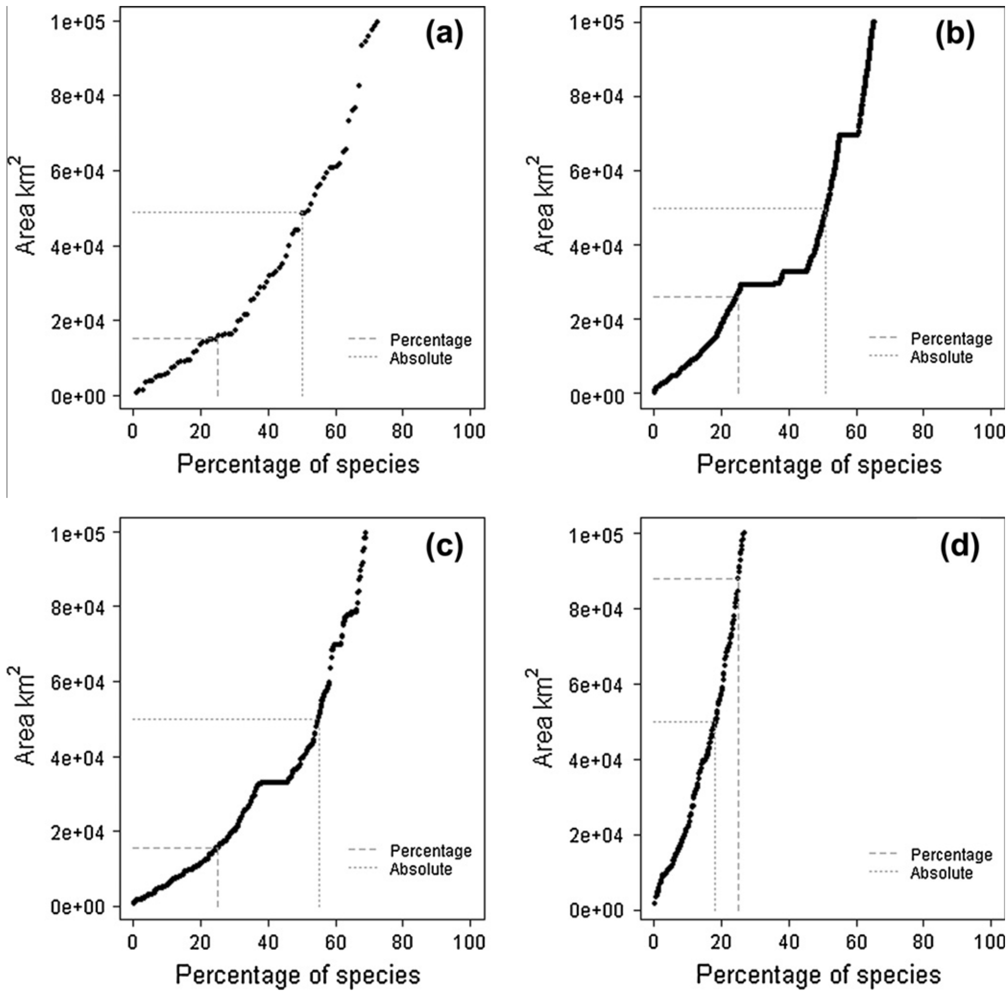


**Fig. 3.** Percentile and absolute thresholds for the identification of range restricted species for: (a) crabs, (b) fish, (c) molluscs and (d) odonates.

Africa were represented to some degree. Based on data recorded for the IUCN Red List there was no significant omission of species of known ecological importance (Step 7).

Species restricted to a single freshwater ecoregion were identified and none were found to fall outside the network of potential freshwater KBAs. The importance of this check is that within some ecoregions species may not have been picked up, despite being restricted to a single ecoregion, as they do not co-occur with large numbers of other ecoregion restricted species (Langhammer et al., 2007). However, in all cases such species were found to already qualify under either Criterion 1 or 2.

### *3.4. Prioritisation within the network*

MARXAN prioritised between 1287 and 1343 catchments, covering between 17.14% and 21.46% of the total land area (Fig. 6) depending on the simple scenarios considered. The resulting network based on any of the three scenarios captures identical numbers of the total species inventory with a substantial reduction in total land area covered (from 34.28%) indicating that it is possible to design a more efficient (with respect to area) reserve network within the qualifying freshwater KBAs.

In the first scenario, which was based on coverage by existing PAs, 30.99% of the total area of catchments prioritised for freshwater biodiversity fell within a PA. Based on the intersect between the river network and existing PAs 19.33% of the total river length for these prioritised catchments falls within a PA, although this will include rivers that act as boundaries of existing PAs so may be an overestimation.

## 4. Discussion

The main driver for development of the methodology presented is a commitment by the World Commission on Protected Areas and the IUCN Species Survival Commission to produce, by 2012, a consistent and defensible methodology to allow the identification of sites of importance for conservation of species, under the umbrella terminology Key Biodiversity Areas. The thresholds and criteria presented here are the first for identifying global KBAs for freshwater species within this KBA framework.

This methodology can now be applied to ensure that important conservation sites in inland waters are identified as part of general development and conservation actions. With the greatly increasing availability of spatial data sets on freshwater species (Darwall et al., 2009) it should now be possible to apply this approach widely across many parts of the world. As well as identifying new areas, the method can aid gap analysis in regions where the process of identifying important sites for freshwater is already ongoing (e.g. Nel et al., 2011). The method can also form the basis for establishing thresholds for other freshwater species as new data become available. The framework of the methodology could be adapted for use at national scale, for example by using data from sub-global assessments of the conservation status of species (IUCN,

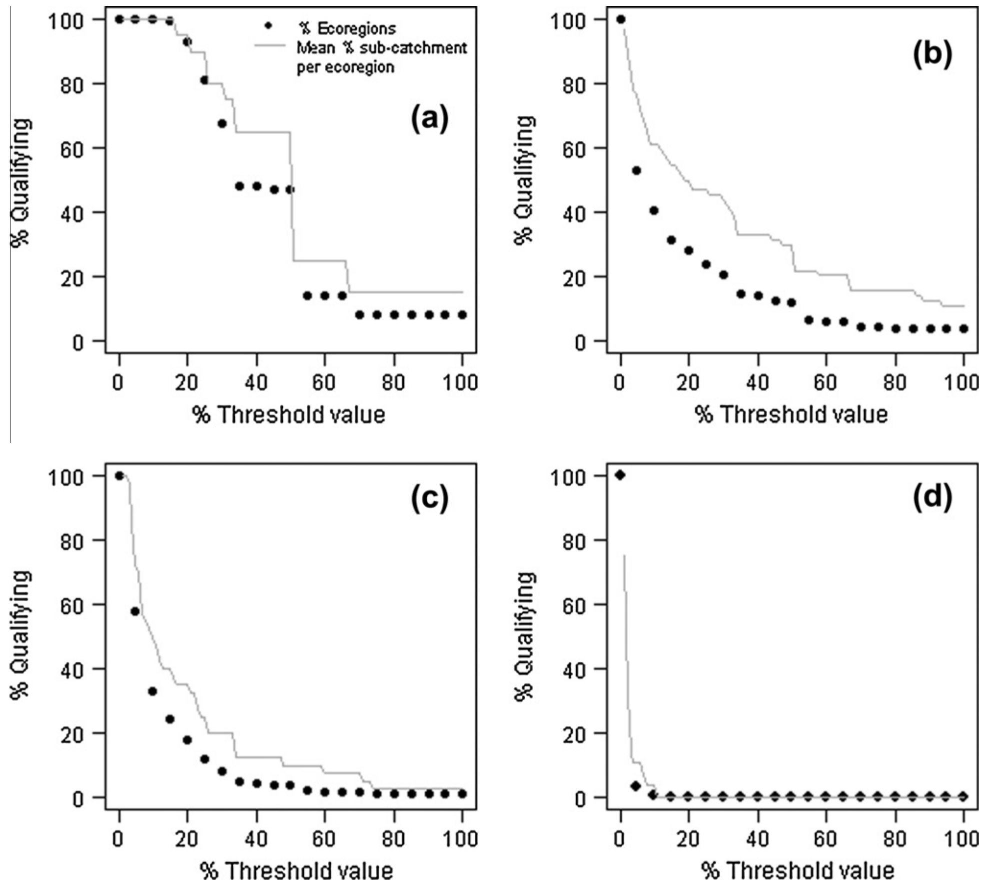


**Fig. 4.** The proportion of ecoregions and mean proportion of catchments per ecoregion qualifying based on differing threshold values for the proportion of (a) crabs, (b) fish, (c) molluscs and (d) odonates restricted to a single ecoregion. Proportions area calculated based on total number of catchments and ecoregions that could qualify as they contain 1 or more ecoregion restricted species.

2003), although these should not be considered Global KBAs as there are often difference between regional and global assessments of the conservation status of species. More specifically, the method can help Ramsar country focal points to identify potential areas for future designation as Wetlands of International Importance. This allows for broadening the scope of Ramsar sites which are currently often designated on the presence of birds. Similarly, the KBA methodology has been suggested as one process with which to identify World Heritage sites based on natural criteria (Foster et al., 2010). KBAs are also incorporated within tools such as the Integrated Biodiversity Assessment Tool for Business (www.ibatforbusiness.org) that is specifically aimed at ensuring decisions affecting critical natural habitats are informed by the best scientific information. The KBA approach is aimed at identifying those sites that are global priorities for the conservation of vulnerable and/or irreplaceable species, and species assemblages that best represent individual ecoregions. The approach is not aimed at conservation of those many other widespread and/or common species although in many, but not all, cases they will also benefit.

Having identified potential freshwater KBAs at the catchment scale, conservation of species can be achieved through a continuum of actions ranging from total exclusion zones at the site scale within a catchment, through to multiple use management at the catchment scale and beyond. This methodology defines catchments that contain critical species and species assemblages, and does not infer the scales or places where conservation and management actions should take place. KBAs are coarse-scale areas that contain species and species assemblages of conservation concern. Finer-scale and more comprehensive information can be used subsequently to define areas for conservation and management activities. Abell et al. (2007) present a scheme based on three nested levels of protection where (i) “Freshwater Focal Areas” describe the specific feature requiring protection and can be quite restrictive about activities that can take place within them, (ii) “Critical Management Zones” are those places where management is essential to maintain functionality of the focal area, and (iii) the “Catchment Management zone” includes all upstream catchments of the critical management zone where basic catchment management principles are applied. By ensuring that there is an appropriate combination of management practices, such that the quality and quantity of water is sufficient to meet the requirements of species, freshwater systems can be managed for both the maintenance of biodiversity in its own right and also as a natural resource (Dugan et al., 2006; Dodds and Oakes, 2008; Luck et al., 2009b; Rebelo et al., 2009).

Linear features such as rivers are often used as boundaries for delineating PAs (Abell et al., 2007) with freshwater features rarely identified as conservation targets in their own right. In South Africa Nel et al. (2007) demonstrated that only 50% of rivers within the PA network could be considered to be intact. It may therefore be necessary to refine the extent of KBAs identified for other taxonomic groups (e.g. IBAs) or alter boundaries of existing PAs for the targeted protection of freshwater species, and to examine management practices within existing PAs to ensure protection of freshwater species. Based on the freshwater criteria outlined here, 2309 catchments representing 34.28% of the total land area of continental Africa qualify as potential freshwater KBAs. Subsequent prioritisation by MARXAN resulted in selection of ca. 1300 catchments covering

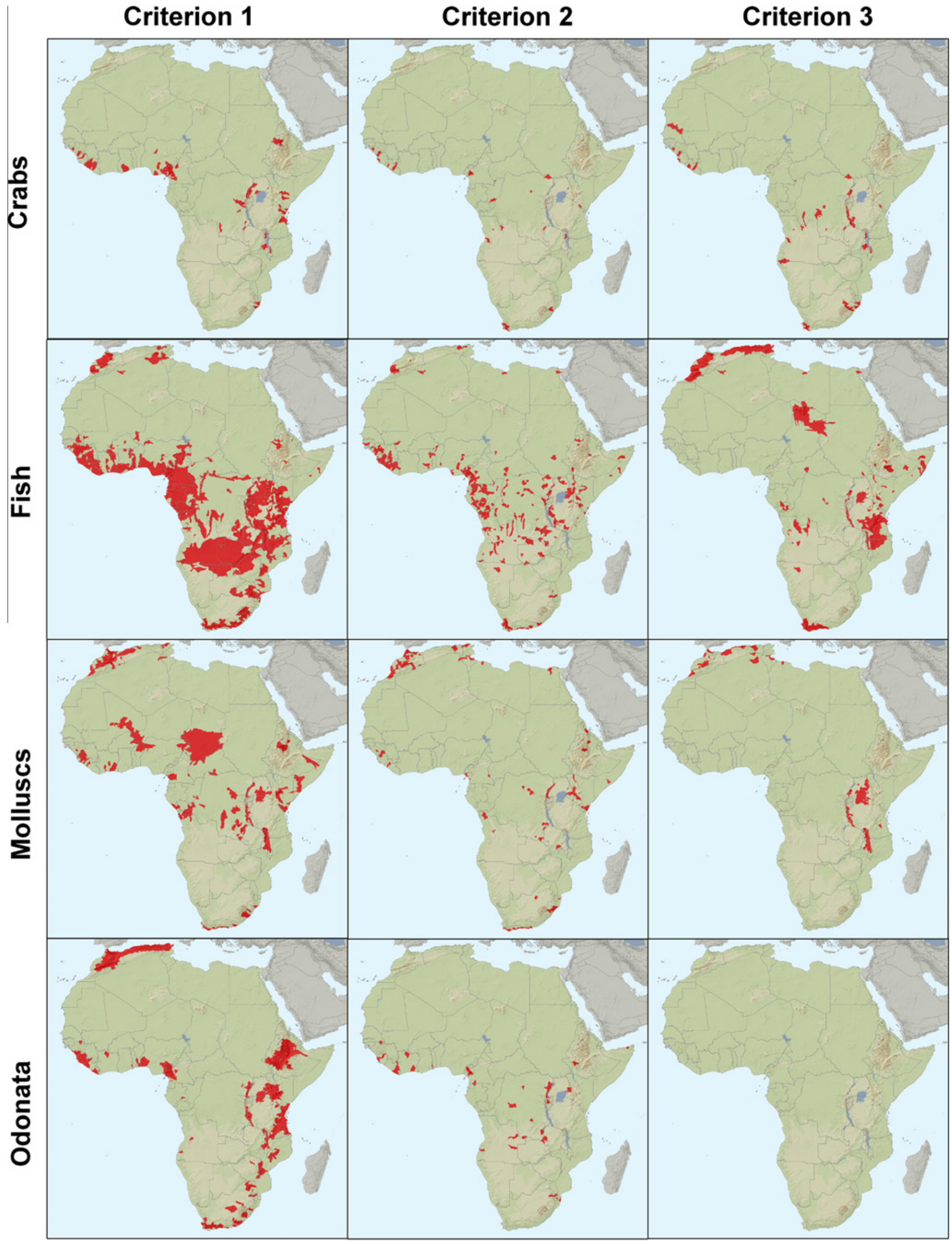


**Fig. 5.** Spatial distribution of catchments qualifying under each criterion.

a total area of around 20% of continental Africa (depending on the scenario applied). Congruence between these prioritised freshwater KBAs and the existing PA network was found to be low suggesting that considerable investment must be made in freshwater conservation to close this gap. The prioritisation carried out in the current study was simplistic as the aim was to examine how efficiently the potential freshwater KBAs can represent species based on existing PAs. To be effective for freshwater species, prioritisation of sites must take into consideration many other factors, such as longitudinal, lateral, and temporal connectivity, condition, the capacity for ecological processes to function, and the potential for conservation and management to be successful (Roux et al., 2008; Hermoso et al., 2011; Khoury et al., 2011; Nel et al., 2011). We justify our approach in that (i) it highlights the considerable gaps that exist in the existing PA network for freshwater species, and (ii) despite recent developments (see Turak and Linke (2011) and references within) the methodology for prioritisation of freshwater sites still lags behind that for terrestrial and marine systems (Barmuta et al., 2011; Beger et al., 2010). Ultimately while conservation planning tools provide useful guidance, stakeholder engagement is key to the development of a realistic and practical network of sites that will be effective for conservation.

Freshwater biodiversity in its own right has largely been ignored in the conservation community due in part to a lack of robust data on which to make decisions (Revenga and Kura, 2003). For example Abell et al. (2010) state that the resource allocation framework used by the Global Environment Facility to target spending of $1 billion annually incorporates data on terrestrial but not freshwater biodiversity. Here we have presented for the first time a methodology, aligned with other taxonomic groups, for the identification of Key Biodiversity Areas using data focused on species. Given the significant threats to freshwater species

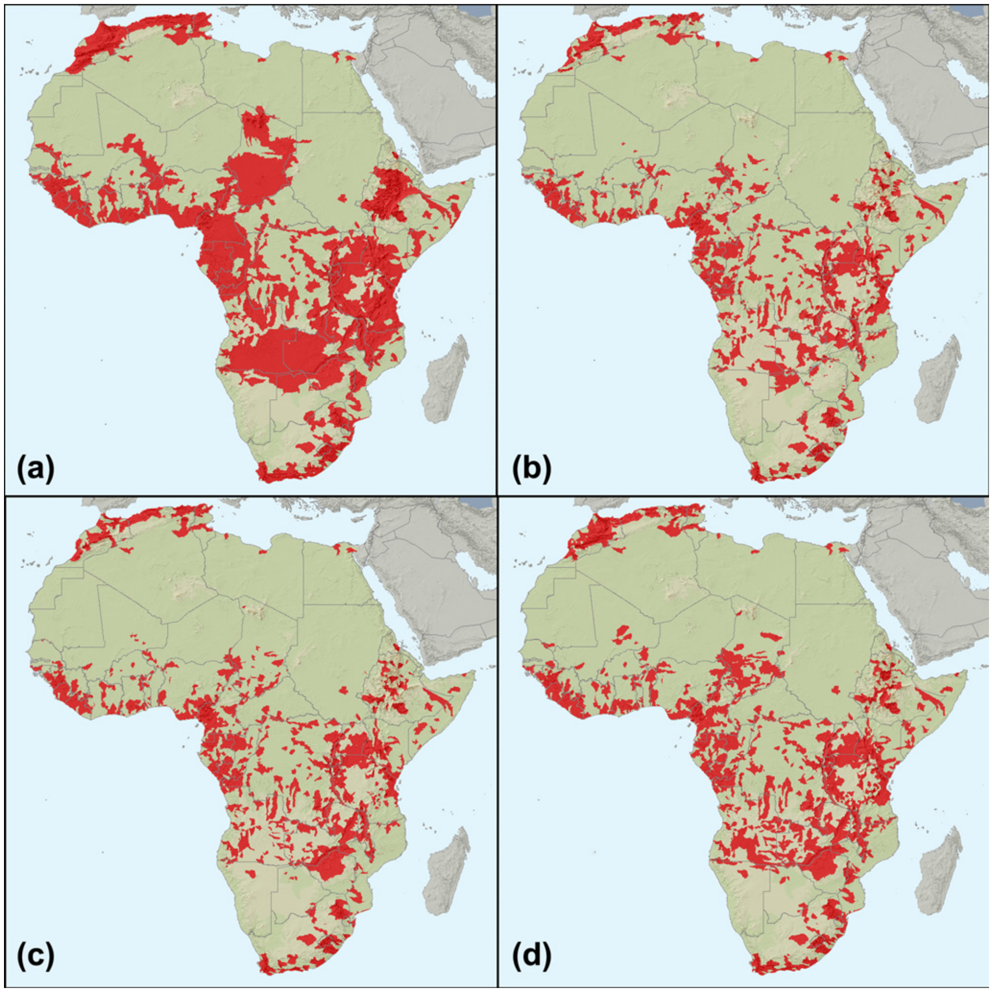


**Fig. 6.** Where (a) indicates catchments qualifying as potential freshwater KBAs based on all criteria for all four taxonomic groups, and then based on prioritisation using Marxan where (b) existing PAs are locked into the solution, (c) no PAs are locked into the solution, (d) a uniform cost is applied to all sites.

and the disproportionate contribution that they make to overall biodiversity, the management of freshwater ecosystems should be prioritised if we are to meet ambitious targets such as those set by the Convention on Biological Diversity for 2020. We hope the development of this new methodology for identifying freshwater KBAs will contribute to a globally standard approach that is applied to help achieve these objectives.

## Acknowledgements

The authors would like to extend their thanks to Matthew N. Foster and Lincoln Fishpool for helpful comments during the development of this manuscript and the anonymous referees whose comments improved the manuscript considerably. We would also like to thank representatives from Birdlife International, Conservation International, WWF, Wetland International and UNEP-WCMC who attended a workshop in Cambridge to develop the criteria.

Species level data used in this analysis are freely available to download from the IUCN Red List website at http://www.iucnredlist.org/initiatives/freshwater.

This work was made possible through financial assistance from Conservational International and the European Commission funded project "Biodiversity of Freshwater Ecosystems: Trends, Pressures and Conservation Priorities (BioFresh)". This publication reflects the views of the authors alone, and the European Commission cannot be held responsible for any use which may be made of the information contained therein.

## Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.biocon.2012.01.016.

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