Erratum

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On page 287, the first sentence of the Abstract was published as:

"Species richness in relation to area of habitat is extremely high in many freshwater groups, with an estimated 12 000 fish, 5000 amphibians and 2000 mollusc species dependant on freshwater habitats"

The correct text is:

"Species richness in relation to area of habitat is extremely high in many freshwater groups, with an estimated 12 000 fish, 5000 amphibians and 4500 mollusc species dependant on freshwater habitats"

We apologise for this error.

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Identifying important sites for conservation of freshwater biodiversity: extending the species-based approach

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Abstract Species richness in relation to area of habitat is extremely high in many freshwater groups, with an estimated 12 000 fish, 5000 amphibians and 2000 mollusc species dependent on freshwater habitats. Other major groups dependent upon fresh waters include, reptiles, insects, plants and mammals. The IUCN Redlist and The Nature Conservancy assessments both indicate the serious vulnerability and degradation of inland water habitats world-wide. It is evident that there are neither the resources nor the time to protect all areas where species are under threat. Clearly a method is needed for prioritising inland water sites for conservation at both local and regional scales. IUCN held a workshop in June 2002 to develop a method for prioritising important inland water sites for biodiversity conservation. The goal of the workshop was to develop a method which would help to focus on conservation efforts and funds at the regional scale and would serve as a tool for active conservation efforts at the local scale. The method was developed on the foundations of a review of the existing site prioritisation schemes for terrestrial, marine and freshwater ecosystems. Expert representatives for a broad range of priority taxa and for existing schemes provided input to the development of the site prioritisation method. This paper describes the development of the method, the selection criteria adopted, guidelines for their use and the site selection procedure.

KEYWORDS: biodiversity, conservation, freshwater, priority sites, species.

Introduction

Species-based criteria are employed in the majority of methods used to identify important sites for conservation of biodiversity (Table 1), yet basic information on species distributions and threatened status is frequently cited as being highly deficient for conservation planning purposes, particularly in inland waters (e.g. Abell, Thieme, Dinnerstein & Olson 2002). Despite this lack of species information, there is widespread agreement that biodiversity in inland waters is highly threatened; many believe at a greater level than in any other ecosystem (Allan & Flecker 1993; Kay 1995; McAllister, Hamilton & Harvey 1997; Master, Flack & Stein 1998; Ricciardi & Rasmussen 1999). Of those species considered in the 2002 IUCN Red List (IUCN 2002), 20% of amphibians, 30% of fishes (mostly freshwater species), 27% of molluscs (mostly freshwater species) and 20% of crustaceans are classed as threatened. The most detailed studies, such as those conducted in North America (Ricciardi & Rasmussen 1999), suggest that these figures markedly underestimate the true scale of the problem.

In recognition of the need to fill the gap in species knowledge, IUCN (The World Conservation Union) initiated a Freshwater Biodiversity Assessment Programme to address the loss of biological diversity in inland waters. Through its Species Survival Commission (SSC), with over 50 years of experience in species conservation and a global network of over 7000 expert members, it developed *The Red List of Threatened Species*™, which is widely used as a tool in the site prioritisation processes and provides the international benchmark to guide effective biodiversity conserva-

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Table 1. Site selection criteria and frequency of use in 13 site prioritisation schemes

Selection criterion	Number of schemes
Species endemism	11
Species richness	9
Species threatened status	9
Rare, outstanding, representative habitat types	7
Rare species	5
Threatened habitats	4
Species biodisparity	3
Biome restricted species assemblages	3
Habitats important as refugia/ migration routes/food sources	3
Species aggregations, particularly during migrations	2
Significant population numbers (often as breeding pairs)	2
Taxonomic distinctiveness	2
Beta diversity (species turnover along spatial gradients)	2
Keystone species	1
Representative species assemblages	1
Genetic value	1

The schemes assessed were: BirdLife International's Important Bird Areas; BirdLife International's Endemic Bird Areas; Centres of Plant Diversity; PlantLife's European Important Plant Areas; Ramsar Wetlands of International Importance; WWF-US Global 200 Ecoregions; WWF-US Freshwater Ecoregions; Conservation International's Terrestrial Biodiversity Hotspots; Conservation International's Coral Reef Biodiversity Hotspots; The Nature Conservancy's Critical Watersheds; UNEP-WCMC's Priority sites for Freshwater Conservation; The European 'Special Areas Of Conservation' and; the OSPAR Convention criteria for selection of species and habitats for protection.

tion. SSC intends to expand the taxonomic coverage of the Red List, in particular for freshwater taxonomic groups, through a series of global and regional assessments.

It is widely acknowledged that limitations in available finance, manpower and time require conservation planners to prioritise those areas that will, if protected, conserve the greatest level of biodiversity. Prioritisation of areas in inland waters is, however, a task for which robust methodologies have to be developed, particularly for species-based data. For maximum use of the species data generated through SSC assessments, a widely accepted method is needed to prioritise important sites of biodiversity in inland waters. Although a number of site prioritisation methodologies have been developed for terrestrial and marine ecosystems, only a few are specific to inland waters (e.g. the criteria used to identify Wetlands of International Importance under the Ramsar Convention). In general, terrestrial methods are not suitable for direct transfer to aquatic systems where the high connectivity of the aquatic medium has to be considered (Abell *et al.* 2002). In response to this need, the IUCN/SSC Freshwater Biodiversity Assessment Programme initiated a project to review existing site prioritisation methodologies and to adopt, modify or build upon those methods thought to be most suitable to inland waters. The site selection tool should be simple to use, transparent in its rationale, meet the needs of a diverse range of potential end users, and have the flexibility to operate on any geographical scale. This paper reports on the decision-making process and proposed actions for taking the project forward. The framework methodology is presented along with a preliminary discussion of the guidelines that must now be developed for application of the species-based selection criteria.

The framework methodology

A draft methodology was elaborated and agreed upon by representatives from a number of major conservation organisations and a range of taxonomic experts. The methodology is biodiversity based, consequently any recommendations made will require further integration with other considerations, such as economic and social reviews by freshwater managers and decision makers. The methodology can be broken down into seven steps (Box 1). Priority sites are selected primarily through assessments of species status and distributions, to reflect the focus and experience of IUCN's work on species assessments, but with full representation of habitats.

The conservation goal must be clearly defined at the outset of the prioritisation exercise. For example, the goal may be to develop a national action plan for inland waters biodiversity conservation, or it may be to identify important areas for biodiversity conservation within a single water catchment. Once this goal has been

Box 1. The seven step site prioritisation method

Step 1. Define the geographical boundaries within which to identify important sites.
Step 2. Define the wider ecological context of the designated assessment area.
Step 3. Identify and map the distribution of inland water habitat types.
Step 4. Catalogue the distribution and conservation status of priority aquatic taxa.
Step 5. Apply species-based selection criteria to identify sites.
Step 6. Ensure full representation of inland water habitats among those sites selected.
Step 7. Ensure inclusion of keystone species.

set, the assessment team should implement the following series of steps to achieve their conservation goal.

Step 1 – define the geographical boundaries within which to identify important sites

The extent and boundary of the area will depend on the task at hand. For example, the assessment area may include a number of countries if the goal has regional priorities for targeting conservation funds and activities. Alternatively, the area may be defined by a national boundary, should a country wish to develop a national conservation strategy. At the local scale, the assessment area may be a river sub-basin if the goal is to identify important sites for consideration when planning site developments, such as for aquaculture or hydropower.

Step 2 – define the wider ecological context of the designated assessment area

It is important to recognise the connected nature of aquatic systems and that protection of sites of importance for aquatic biodiversity often requires consideration of areas far beyond the borders of the target site and core assessment area. The maintenance of a natural flow regime within a river or stream, for example, may be much more important to the biodiversity of a site than directed protection of the site itself. In the case of a core assessment area intersected by a river, selection of conservation targets within that river must be made with consideration for ecological links with those parts of the river catchment that extend outside the core assessment area. In many cases it may be necessary to consider areas within neighbouring countries. In addition, species conservation status will often be assessed relative to populations outside the immediate area of assessment.

Freshwater ecoregions and catchments may provide the appropriate boundaries and context within which the conservation targets in the core assessment area may be selected. The results of prioritisation exercises undertaken by other organisations, such as WWF-US, may prove particularly useful at this stage.

Step 3 – identify and map the distribution of inland water habitat types

Selection of conservation targets based on assessment of species may not provide full representation of inland water habitats types and their associated species. All inland water habitats within the core assessment area should be characterised and mapped to allow for later screening for full representation once conservation targets have been selected. The most widely applied classification of inland water habitats is that adopted by the Ramsar Convention (Ramsar Convention Bureau 2000). However, it is considered not to provide sufficient resolution to ensure effective habitat representation within the prioritisation process. For example, the Ramsar habitat category 'Permanent Rivers' combines a great variety of ecologically distinct habitat subcategories that remain undefined. IUCN/SSC is working with its partner organisations on the improvement of habitat classifications to be used in its Species Information Service; in the case of inland water habitats, it is recommended to draw upon other systems such those of The Nature Conservancy (Smith, Freeman, Higgins, Wheaton, FitzHugh, Ernstrom & Das 2002), the MedWet Mediterranean Wetland Classification (Costa, Farinha, Hecker & Tomàs Vives 1996), or the USA National Wetland Classification (Cowardin, Carter, Golet & LaRoe 1979), to name but a few.

Step 4 – assemble an inventory of the distribution and conservation status of priority aquatic taxa

Recognising that it is unrealistic to expect complete coverage of all freshwater taxa, a list of priority taxa was agreed upon. The selected priority taxonomic groups, which are thought to act as reliable biodiversity indicators and for which assessments are most feasible include: wetland birds, fishes, reptiles, amphibians, crustaceans (isopods and decapods), molluscs, odonates, mammals and selected groups of plants. The selected taxa for assessment may, however, vary depending on the ecological context of the assessment area, especially where the area is of limited size. Other groups might be included where data are available.

Step 5 – apply species-based selection criteria to identify sites

An important site is identified if it satisfies one or more of the following four 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', where:

1 globally threatened status is determined according to the IUCN Red List Categories and Criteria (IUCN 2001);

2 the term 'significant numbers' is taxon specific;

3 the assessment may be based on infra-specific taxa, such as for fish stocks specific to individual river systems;

4 'other species of conservation concern' allows for inclusion of species which may be of regional or national concern (e.g. as specified in national Red Lists) even if otherwise common in areas beyond the assessment area. Taxonomically distinct or phyletically rare species could be included within this category.

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', where:
1 'non-trivial numbers' is interpreted to exclude vagrant individuals (the threshold number will be taxon specific);
2 guidelines for defining a 'restricted range' will be taxon specific.

Criterion 3: 'A site is known or thought to hold a significant component of the group of species that are confined to an appropriate biogeographical unit, or units', where:
1 non-native species are excluded from analyses;
2 the biogeographical unit is taxon specific – freshwater ecoregions (as defined by other conservation organisations) may be the appropriate biogeographical units for many taxa;
3 species rich areas are identified, not as areas rich in the total number of species, but as areas rich in species restricted to that biome. This kind of species richness is termed 'contextual species richness' by BirdLife International (Heath & Evans 2000).

Criterion 4a: 'A site is known or thought to be critical for any life history stage of a species'. Examples of such sites may include: feeding grounds or stopover sites for migratory birds; migration routes for diadromous fishes; spawning, nursery and feeding areas; and refugia from adverse environmental conditions such as drought or pollution.

Criterion 4b: 'A site is known or thought to hold more than a threshold number of individuals of a congregatory species', where the threshold number is taxon specific. BirdLife International and partners have determined these thresholds for birds, as adopted by the Ramsar Convention on Wetlands, but quantitative thresholds for other taxa are yet to be determined.

Step 6 – ensure full representation of inland water habitats among those sites selected

Where there have been no important sites identified throughout the full extent of a particular habitat type, the selection process is run again to identify the most important sites specific to that particular habitat. These additional sites are added to the portfolio of important sites, thus ensuring representation of all habitat types found within the full assessment area. The final portfolio of sites should then be checked for ecological integrity when viewed as a network of connected areas. WWF-US (Abell *et al*. 2002) and The Nature Conservancy (TNC) (Smith *et al*. 2002) have developed suitable approaches for this part of the process. Finally, the network of sites should be screened to ensure inclusion of all representative geological, hydrological and topographical land forms (a suitable classification of land forms is yet to be selected).

Step 7 – inclusion of keystone species

In the final step of the process, the network of selected sites is assessed to ensure representation of any potential, abundant, widespread keystone species that may have been omitted in the earlier steps.

Post-prioritisation activities

Once biodiversity conservation targets and their associated sites have been identified the following steps are recommended for the next stage of the conservation planning process.
1 Sites of socio-economic and cultural importance are identified.
2 Existing protected areas are mapped so that the network of selected sites may take account of any duplication with sites already protected. It may also be pragmatic to locate aquatic reserves adjacent to existing terrestrial protected areas where the management infrastructure is already in place and where the terrestrial impact on aquatic habitats can be better managed.
3 A threat analysis of site locations is undertaken. For example, potential impacts of climate change that may render sites selected as suitable today being unsuitable for target species in the future should be taken into account.
4 Additional sites are assessed for their restoration or rehabilitation potential.
5 Sites are ranked according to their priority for time-dependent conservation action. It is often the case that, because of financial and other considerations, conservation actions may have to be implemented over extended time periods. The potential for prioritisation based on use of mathematical selection algorithms should be evaluated.

The final product is a map of the most important sites for freshwater biodiversity within that country.

A worked example is given in Box 2 to demonstrate the procedure.

Box 2. Example procedure to identify important sites for inland water biodiversity for developing a national biodiversity strategy.

Step 1. The assessment area is defined as the national boundaries.
Step 2. The wider ecological context of the assessment area is defined to include the full extent of all water catchments, or freshwater ecoregions, within national boundaries and those shared with neighbouring countries. Transboundary areas are included in the assessment as they have potential to impact on biodiversity within the country being assessed.
Step 3. All inland water habitats within the country are classified and their distributions mapped.
Step 4. Species range distributions are mapped and threatened status assessed (IUCN Red List) for all selected priority taxa occurring with national boundaries (choice of priority taxa is a national decision). Species ranges are mapped throughout the full ecological context of the assessment area, as defined in Step 2, to account for potential transboundary migrations. Species threatened status may be assessed in either the national or global context, this is a national decision.
Step 5. The collated species information is used to identify all those sites within the full ecological context of the assessment area which qualify as important under the five selection criteria for inclusion of: (i) threatened species; (ii) restricted range species; (iii) a significant component of a species assemblage within any single freshwater ecoregion; and (iv) any site of importance for congregatory species or that is critical for any single life-history stage of a species. Any site that includes a species meeting one or more of the selection criteria is designated as an important site for inland water biodiversity within the country. Sites outside national boundaries may be included as their conservation status may have a direct impact on the biodiversity of the neighbouring country which is the focus of the assessment.
Step 6. If any of the habitat types mapped in step 3 is found to have no important sites then the site within that habitat which most closely qualifies under the criteria in step 5 would be added to the list of important sites, thus ensuring full representation of habitat types.
Step 7. A list of all species classified as 'Keystone' is compiled. Should any keystone species not be included in at least one important site then the site containing that species that most closely qualified under the criteria in step 5 would be added to the list of important sites.

Definitions and guidelines: a preliminary discussion

The principles and framework of this methodology are largely consistent with those employed by other organisations, such as WWF-US (Abell *et al*. 2002), TNC (Smith *et al*. 2002), and BirdLife International (Heath & Evans 2000). The general lack of species data for identification of key biotic targets has, however, left existing methodologies for species-based site selection poorly developed. The exception is for water birds, for which Bird Life International and partners have developed precise guidelines as employed in the identification of their 'Important Bird Areas' (Heath & Evans 2000). The species-based criteria incorporated in step 5 of this methodology are based on those developed for birds, but guidelines for their application need to be adapted to suit the full range of priority freshwater taxa. This is the area of development where the IUCN Freshwater Biodiversity Programme will focus its efforts.

Development of taxon-specific guidelines for species-based selection criteria

It is considered that guidelines for application of the selection criteria need to be taxon specific, thus important sites of biodiversity will be identified for each taxonomic group. If a site meets the selection criteria for any species, regardless of taxonomic grouping, it will be identified as an important site. The aquatic equivalent of terrestrial 'hotspots' (Myers *et al*. 2000) will be those sites that meet the selection criteria for a maximum number of different taxonomic groups.

The main species-based site selection criteria are generally defined (Table 1) and consistent with those proposed for the current methodology. However, guidelines for their application are not well developed, habitats often being employed as species surrogates. For example, with exception of birds (Ramsar Convention Bureau 2000), a set of taxon-specific guidelines to determine 'how many species are required to qualify an area as species rich', or 'how many individuals of an endangered species should be included within an area to qualify it as an important site' does not yet exist. The species data required to employ quantitative selection thresholds are currently limited, but it is intended that significantly more data will be made available through ongoing and planned biodiversity assessments. For example, information on total global or national population sizes, as required to determine 'significant numbers' of individuals of a threatened species, are not often available. In these cases, until those data are made available, possibilities are being investigated for basing threshold numbers of individuals on calculated values for minimum viable population size.

The development of taxon-specific guidelines is expected to take time and will involve consultations with taxonomic experts, discussion workshops and field testing. To date the following issues have been discussed by taxonomic experts at workshops focused on freshwater molluscs and freshwater fish.

Taxonomic distinctiveness

An appropriate definition and a method for quantifying the taxonomic distinctiveness, or phyletic rarity of a species (step 5, criterion 1) are required in selecting the appropriate methodology for measuring this parameter, and for setting a quantitative threshold that identifies a species as sufficiently distinct to qualify the associated site for selection. IUCN/SSC considers the main aim of biodiversity conservation as maximising the number of different characters or genes that persist within the world's flora and fauna. The problem is that the value of different genes or characters in a species will depend upon the other species with which it is compared. As species will have different distinctiveness values depending on whether they are assessed within the global, regional or local context taxonomic distinctiveness values will need to be determined for each geographical scale. Measures of taxonomic distinctiveness or phyletic rarity are often based on cladograms as: (i) the number of nodes separating two species; or (ii) where data are available on internode distances, as the internode distance between species. As available information is rarely available to calculate internode distance it is suggested that option (i) is used.

Once taxonomic distinctiveness has been quantified, a number of alternative approaches may be employed to designate important sites on the basis of this parameter.

1 The taxonomic distinctiveness of a site (measured as the mean value of all species in the site) may be used to weight the selection of the site when combined with other criteria, but it does not normally qualify the site for selection in its own right. For use of this option the weighting value applied to taxonomic distinctiveness needs to be determined.

2 The taxonomic distinctiveness of a site may be sufficient in its own right to qualify that site for selection. In this case a qualifying threshold value of distinctiveness needs to be determined.

3 Taxonomic distinctiveness is evaluated at the level of individual species. In this case a site may qualify as important if it includes one or more species that exhibit a pre-selected threshold of distinctiveness, which is measured in relation to all other species in the assessment area within the same taxon. Option (3) is the favoured approach.

Restricted range species

Step 5, criterion 2, requires a quantitative definition of non-trivial numbers of individuals of restricted range species. The term non-trivial is intended to exclude vagrant individuals. Knowledge of the normal range for each taxonomic group is required to set this threshold number and to provide guidance on the threshold range sizes that would qualify a species as having a restricted range. In many cases this information will be available within the documentation accompanying IUCN Red List assessments of threatened status, which are often based on threshold values for extent of occurrence or area of occupancy. Bird Life International has set a threshold global distribution of 50 000 km^2 to qualify a bird species as restricted range, or endemic (Stattersfield, Crosby, Long & Wege 1998).

Species associations of biogeographical units

Step 5, criterion 3 states that a site known, or thought, to hold a significant component of the group of species that are confined to an appropriate biogeographical unit, or units qualifies as important. The appropriate biogeographical unit needs to be determined for each taxon. For example, for water-restricted species this may be the water catchment or freshwater ecoregion whereas for taxa, such as amphibians, birds or odonates where terrestrial dispersal mechanisms are possible, an alternative unit may be defined. Guidance is also required to quantify what is considered to be a significant component of the species assemblage.

Congregatory species

The Ramsar Convention on Wetlands adopted thresholds of '$>1\%$ of a biogeographical population of a single species', and '$>20\,000$ individuals of one or more species' to qualify sites as important for birds (Ramsar Convention Bureau 2000). Similar guidelines are required for site selection based on other congregatory freshwater taxa. The Ramsar Convention has adopted preliminary criteria for congregatory fishes, but the selection criteria could still benefit from further development (Ramsar Convention Bureau 2000). Although migration routes should ideally have been captured as important areas under criterion 4a of step 5, the increased vulnerability associated with species congregations, such as migratory fish gathering to pass a river dam, should afford such sites priority status in their own right.

Keystone species

The proposed definition of a keystone species is: 'A species whose loss from an ecosystem would cause a

greater than average change in other species populations or ecosystem processes; whose continued well-being is vital for the functioning of a whole community.' The information required to determine whether a given species plays a keystone role is not easily obtained but when available it should be utilised.

Conclusions

In conclusion, this methodology has been developed with technical input from other conservation organisations experienced in site prioritisation, expert freshwater taxonomists and environmental impact assessors. It is highly compatible with existing methodologies and makes good use of the complementary work of IUCN's partners. IUCN's long-standing experience of species assessment and data management, combined with an ability to mobilise taxonomic expertise, puts it in a strong position to take the lead in development of species-based criteria and facilitation of the provision of appropriate knowledge to decision makers. The high level of compatibility of the methodology developed here with those employed by IUCN members and partners, such as WWF-US, TNC, BirdLife International, Conservation International and the Ramsar Convention Bureau, is encouraging in that it not only serves as a peer-reviewed endorsement of these approaches but also provides excellent opportunity for success in future collaborations between these organisations in their work towards conservation planning in inland waters.

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