EXECUTIVE SUMMARY

Introduction

Conservation planning and rivers

Freshwater ecosystems are the most threatened ecosystems globally experiencing the fastest loss of biodiversity and the greatest number of species extinctions. The last national appraisal of South African freshwater ecosystems estimates that over 80% of South African river ecosystems are threatened. The intimacy between catchment condition and river health is one reason why freshwater systems are amongst the most threatened systems globally.

One tool available to conservationists to staunch the current rate of loss to freshwater biodiversity and ecosystems is systematic conservation planning, which provides a structured approach in identifying biologically significant areas for conservation action. A necessary component of conservation planning is to set targets for how much of each biodiversity feature (i.e. element of biodiversity which can be quantified and spatially represented) needs to be protected, and additionally for rivers, to maintain connection between different biodiversity patches.

Target-setting follows either participatory or empirical approaches. Participatory approaches are typically based on expert opinion, and done on a case-by-case basis. Empirical approaches use statistical relationships, and can be applied nationally using more automated approaches. This means that the latter approach is more appropriate for national conservation planning initiatives. Because rivers are characterized by length and not by area, and because species persistence at one site is very often a function of upstream and downstream ecological processes, current statistical methods for setting river targets are not suitable. The current South African approach in freshwater planning makes use of a 20% target value, while a target value of 17% for inland water areas was recently proposed at the 10th meeting of the Conference of the Parties to the Convention on Biological Diversity. This approach is inadequate because it assumes that all rivers have similar diversity patterns down their lengths and between systems, which is not the case.

Setting river targets

The focus of conservation is moving from single-species conservation to communities of species and how these change in space. Consequently, targets should be based on established measures of species diversity and river ecology theory: The river continuum concept, which makes predictions of species diversity patterns with downstream distance based on ecosystem processes; and the hierarchical understanding of river systems. Much is already known about species diversity and rivers too: at the habitat scale, aquatic macroinvertebrates show strong associations with different hydraulic biotopes and geomorphological types. At a larger scale, there have been a number of studies which show that aquatic fauna correlate strongly with different longitudinal river zones and between river basins based on changes in geology. Interpreting patterns of species diversity can, however, be confounded by the effects of organic pollution and changes in flow.

In this conceptual framework, these measures provide a powerful approach for setting species targets, because a combination of these indices incorporates scale issues, which are critical to understanding river systems. The location of highest alpha-diversity, as related to the river continuum concept, and species turnover along a river's longitudinal axis (beta-diversity), determine where and how much of a river should be targeted to conserve maximum species diversity. Between-river diversity (gammadiversity) determines how many river systems should be conserved in each ecoregion, and this relies on a suitable river classification system. Within this approach, hypotheses of drivers of species diversity are implicitly provided (for example, disturbance and degree of connectivity between habitat components). Such an approach encompasses spatio-temporal variability and incorporates ecological processes operating at different scales along environmental gradients. At the spatial scale of this study, this approach means that:

- Species targets are set based on good biological data along a species axis.
- For alpha diversity to be maintained, upstream and downstream processes that conserve the diversity (or pattern) within a segment need to be conserved.
- Low beta diversity (i.e. low disparity between sites) implies that a relatively short section of river needs to be conserved. However, if beta diversity is large, then more of the river needs conservation measures.
- The more variable the system, the higher the beta diversity, and the longer the length needed

to protect diversity, i.e. segment length depends on predictability. Conversely, more stable predictable systems are more resilient, beta diversity is lower, and the length of river requiring protection is relatively shorter.

- River systems in similar ecoregions should have lower gamma-diversity than rivers in different ecoregions.

This study proposes a new direction for setting river targets, based on established measures of species diversity. The **aim** of this research was to develop a scientific methodology, equivalent to the species-area curve used for terrestrial systems, to set conservation targets for river lengths. Achieving this provides a transparent, objective approach for setting river conservation targets, such that the target represents a value based on biodiversity patterns and processes rather than a 20% “societal agreement” value. While recognising that the 20% value has served a useful function in entrenching the concept of river targets, it was also recognised by the aquatic scientists in South Africa that this target should be revised over time, as suggested by the cross-sector policy objectives for conserving South Africa’s freshwater biodiversity. This research successfully achieved this aim.

Methods
Aquatic macroinvertebrates and fish species data were assessed from nine rivers in South Africa (Western, Eastern Cape and KwaZulu-Natal provinces), using longitudinally located sites from surveyed and historical data. Data from previous studies (Great Fish, Berg, Thukela, Sabie-Sand, Mzimkhulu, Mkuze and Mvoti Rivers) were used together with data collected between November 2009 and June 2010 for the Mvoti, Mzimkhulu, Mkuze and Keurbooms Rivers. Species diversity patterns and rates of turnover were calculated and interpreted using river profiles and site characteristics (flows, water temperatures and geomorphology). Statistical analyses and a probability model were developed to predict specific sites where river conservation should focus, and river lengths upstream and downstream of these focal sites which should be conserved. Initial estimates of gamma diversity between rivers were estimated based on total numbers of species per river excluding common species.

Summary of results

Alpha diversity
Numbers of fish species showed no pattern with downstream distance for the Mkuze, Mvoti and Mzimkhulu Rivers, while a weak increase in numbers of species with downstream distance occurred in the Sabie River. Conversely, for aquatic macroinvertebrates, observed and expected alpha diversities were highest in the upper third and in the mid-order reaches of rivers sampled.

Beta diversity
Fish community patterns changed on an annual basis, with some sites changing more than others. Species turnover of aquatic macroinvertebrates was greater between different geomorphological zones, while being more similar within the same geomorphological zones. This turnover followed a sequential downstream pattern with a number of interesting trends. Firstly, the Berg River (Western Cape Province) had no species in common with the rivers in KwaZulu-Natal. Secondly, while the Berg River showed a constant rate of turnover with downstream distance, the KwaZulu-Natal Rivers showed a low turnover between the three river systems (i.e. common set of core species). Lastly, there was relatively little turnover in the upper-mid river reaches, and then more rapid turnover for the lowland sites in the case of all three rivers
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Beta diversity for aquatic macroinvertebrates generally showed exponential decay, with half-turnovers (50% change) being achieved at 20-50% downstream distance from source. Median rates of decay were *ca*. $X^{-0.3}$, although each river system exhibited its own decay function. Successive removal of rare species (“very” rare as single site, single abundance species, and rare as single site species) had the effect of decreasing the rate of turnover, while retaining the shape of the turnover signature for each river system. Beta diversities for fish showed no significant trends with downstream distance, and fish were not included in further analyses.

Average species turnover model
The three rivers showing the best statistical relationships of turnover with downstream distance (Berg, Mkuze and Mzimkhulu Rivers) were used to develop a model to estimate the probability of a downstream site not being representative (i.e. site pair similarity ≤50%) of an upstream source site as

a function of downstream distance. This model predicts that on average, there is complete turnover 20% of a river's length away from a source zone.

Drivers of turnover

Environmental gradients

Analyses based on physical, water temperature and flow metrics revealed that each river assessed was unique. Based on physical habitat and water quality, sites separated out into clear, high altitude rivers versus turbid, low altitude rivers with a secondary contribution of narrow, shallow, sandybottomed rivers to wider, deeper and rockier rivers. Sites followed a progressive downstream trend when characterised by water temperatures, with site groups defined warm versus cool temperatures, range of seasonal temperatures, water temperature predictability and timing of maximum water temperatures (early vs. later summer). Finally, flow predictability and how often rivers dried up were key variables when classifying sites by flow regimes.

River profiles

River profiles for four rivers in KwaZulu-Natal and the Berg River all showed clear inflection points, separating the rivers into upper and lowland zones. When profiles were plotted in conjunction with measures of alpha diversity and community similarity (from uppermost site and downstream paired sites), the sites of highest diversity and zones of highest turnover coincide with the profile inflection points.

Gamma diversity

Total river species similarities between paired river systems were 40-50% for rivers in KwaZulu-Natal, and 5% on average between the Berg River in the Western Cape and the KwaZulu-Natal rivers. Gamma diversity was highest for the Mzimkhulu-Berg and Mkuze-Mzimkhulu Rivers, and lowest between the adjacent Mkuze-Mvoti Rivers.

Discussion

Alpha diversities – selection of focal river reaches

Highest species diversity occurred in mid-order streams and at an intermediate distance down a river's longitudinal axis. Within this diversity gradient, community structure is complicated by the relative contributions of rare, abundant, and very abundant species. Site-specific alpha diversity is typically made up of few very common or very rare species, with many "middling" common ("abundant") ones.

Common species provide a better approximation of overall species patterns as opposed to rare ones. However, what should guide the selection of target river zones are the conservation planning goals: are the goals for rarity or maximum species number (pattern), or process (which would target the more common species which are driving system energy dynamics).

Beta diversity – how much river should be conserved?

In this study, fish were not a useful measure of determining river conservation targets, while aquatic macroinvertebrate species patterns exhibited predictable patterns of turnover with downstream distance, and are valuable in setting conservation targets. Average species turnover happened at predictable rates, and these rates could be decomposed into turnover of common ("core") species, which are further accelerated by rare species (single occurrences) and narrow range species (single site occurrences). Moreover what drives this turnover with downstream distance are break-points and river geomorphology. Sharp environmental change occurs as a result of geomorphology and topography, while gradual environmental change is driven by geography and climate. Understanding turnover patterns thus requires a spatially hierarchical understanding of river systems before targets should be set.

To understand the sharper ecotones requires knowledge of geological history and how this translates into different river profiles. The clear differences in turnover patterns between the Berg and Mzimkhulu Rivers, for example, can be partially explained through their different geological histories. The more subtle environmental changes driven by geography and climate were a combination of physical habitat, water temperature (magnitude and timing) and flows (predictability, magnitude of high flow events and perenniality).

Disruptions to the river continuum impact on the rate of turnover. The amount of natural vegetation at the catchment scale is a good predictor of river habitat integrity. The turnover pattern may thus be clouded by both catchment and river disturbance, where taxa sensitive to pollution and disturbance decline and generalist, opportunistic species increase.

Consistent with other research on South African rivers, aquatic macroinvertebrate communities in this study could be grouped into upland versus lowland assemblages, and also defined by geomorphological zones. The rate of species turnover in the rivers assessed was related to environmental gradients and breakpoints, where the more variable upper sites have more rapid turnover than reaches further downstream, i.e. upper reaches require more representative conservation zones than the reaches further downstream. Using a blanket 20% target per river type is thus probably a simplistic approach to setting targets, particularly for the upper river zones with higher species turnover.

Gamma diversity – how many basins should be targeted?

As only four rivers were assessed in this study, it was difficult to draw definite conclusions on gamma diversity. The basic gamma diversity estimates showed that to achieve riverscape-level conservation of aquatic biodiversity, it is necessary to explicitly target as many different primary catchments as possible. Under resource-limited conditions, it is more pragmatic to choose primary catchments further apart than closer together within the conservation planning region.

Key Conclusions

- A blanket 20% target for river types is not adequate;
- Upper river zones are the key sections of river length driving species patterns, and consequently upper river zones should be weighted more heavily in conservation planning than lowland zones;
- River types assume boundaries and ecotones, and the obvious ecotonal boundary to advocate more than a single generalized target value per river type is the clear distinction in turnovers between the steeper upper river zone and the less steep lowland zone;
- The 20% target should be adjusted to cater for upland and lowland targets as an initial refinement to the existing 20% targets, with at least a 20% target in lowland zones and a 40% target in the upper zones;
- Secure upper catchments in identified river systems, to maintain natural rates of species turnover in river sections where species richness is highest, and secure ecosystem services for downstream users;
- Link ecosystem services to level of river health, where catchment stakeholders decide on the level of services they would require or like (a desired state), which is then related back to ecosystem integrity by freshwater ecologists.

Recommendations for future research

- Refine differential targets for different geomorphological zones, using as a basis the hydraulic biotope heterogeneity per zone as the dialectic, as these are one of the key drivers in species turnover.
- Quantify the effects of seasonality on alpha diversity; the contributions of alpha and beta diversity to gamma diversity, and patterns of common and rare species as a function of downstream distance and biotope types.
- Refine river type classifications for upper river zones (upstream of profile inflections), and focus on selected whole systems rather than a percentage target of types.
- Refinement of a river classification of river types for South Africa. This should be hierarchical, beginning at the level of a river system (defined here as the mainstem in a secondary catchment), and sub-quaternary, focussing on biotope heterogeneity, geomorphology, and intra-annual flow patterns.
- Automating the process of setting river targets in a spatial conservation planning system.