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Identification of High Value Rivers and Streams in the Waikato Region: Final report

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Contents

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Executive Summary

A range of information and analyses were compiled to describe river and stream conservation value in the Waikato Region for Environment Waikato staff to use in the identification of Significant Natural Areas (SNAs). Specific components include:

1. Data describing the distributions of Freshwater Environments of New Zealand (FWENZ) classification groups were analysed using the site selection software, Zonation, to identify sets of sites that would provide maximum conservation outcomes at minimum cost. Rivers and streams were grouped into planning units, based around 3rd order catchments or sub-catchments. Rankings for each planning unit were calculated using an approach that takes account of the need for representative protection of a full range of ecosystem types, while allowing for both human impacts and requirements for upstream-downstream connectivity between planning units in larger rivers and streams. Rankings were also calculated taking account of current protected areas to identify those planning units that would best complement areas that are already formally protected.

2. A parallel set of analyses using Zonation were performed on data describing the expected probability of capture of seventeen native fish species, as predicted from species distribution models.

3. Results from a separate analysis of national conservation rankings performed for the Department of Conservation at a national scale using FWENZ data and Zonation were summarised for each planning unit occurring within the Waikato Region.

4. Information describing the distributions of rare or threatened freshwater species (longfin eel, giant kokopu, shortjaw kokopu, lamprey, koura, blue duck, Hochstetter’s frog) within the Waikato Region were assembled from a variety of sources and summarised. This information was used to identify those planning units likely to support rare or threatened species.

Results are provided as spatial data for use by Environment Waikato staff in the identification of Significant Natural Areas.

1. Introduction

The desire to make efficient decisions when setting aside land for conservation has led to the development of both new conceptual understanding and practical tools that are collectively referred to as “systematic conservation planning” (e.g., Margules & Pressey 2000). The general objective of most of these approaches is to identify areas for protection that provide habitat for as wide a range of species and communities as possible, at minimum cost. While many of the tools developed in this new discipline have been applied mostly in terrestrial settings, several approaches are now emerging that are more specifically targeted to the robust identification of optimal sets of sites for the conservation of freshwater biodiversity. The challenges that are specific to conservation in freshwater ecosystems are explored by Abell et al. (2007), who argue that terrestrial conservation concepts and tools often fail to cater adequately for river and stream features such as their inherent longitudinal connectivity. They draw particular attention to the need for consideration of the way in which protection of values at one location may require management actions to be undertaken in other locations, e.g., in the headwater catchment of a high-value lowland wetland.

One of the first approaches that specifically addressed these considerations was described by Linke et al. (2007), who developed an approach in which protection was required for the headwaters of any high value down-stream site. A more computationally sophisticated approach has been developed by Moilanen et al. (2008), who adapted the terrestrially developed site prioritisation tool Zonation (Moilanen et al. 2005) by allowing the specification of connectivity constraints that could be applied in either upstream or downstream directions. This encourages not only the protection of headwater catchments for downstream sites, but also the maintenance of upstream movement for mobile species, e.g., by diadromous fish species occurring in mid- to upper-catchment habitats.

In this project, we apply the technique described by Moilanen et al. (2008) to rivers and streams of the Waikato Region. Our aim was to assemble a set of tools that could be used to identify Significant Natural Areas (SNA) for streams and rivers in the Region, using several sources of information. The main body of our research was designed to estimate conservation rankings for 3rd order catchment-based planning units throughout the region. These were calculated using Zonation to identify sets of planning units providing the most efficient protection of freshwater habitats, while taking account of both existing protection and the need for protection of a full range of ecosystem types, i.e., representativeness as stated in New Zealand’s Biodiversity Strategy. These analyses were repeated using two sets of data describing the biological character of Waikato rivers and streams. The first was a biologically-tuned environmental classification developed for the Department of Conservation (Freshwater Environments of New Zealand — FWENZ, Leathwick et al. 2008), while the second was a set of predicted distributions for native freshwater fish occurring in the Waikato Region (Leathwick & Julian 2008a). These results have been supplemented by additional information describing national conservation rankings from an analysis performed for the Department of Conservation, estimated species richness for native fish and aquatic macro-invertebrates, and the distributions of seven rare or threatened taxa.

2. Methods

2.1 Data

The rankings of conservation value presented in this report are based on a diverse range of data describing the distribution of rivers and streams in the Waikato Region, their ecological character, degree of protection and physical condition. The main analyses we present are based on a set of catchment/sub-catchment planning units (Leathwick & Julian 2007) in which streams of first, second or third-order were treated as discrete individual units, while streams of fourth or greater order were split into separate planning units consisting of their third-order sub-catchments and their higher-order main stems (Fig. 1). For example, the Waikato River, a seventh-order catchment, is split into a large number of third-order headwater sub-catchments, a small number of fourth to sixth-order units formed by the progressive combining of the flow from the initial third order units, and a large seventh-order unit consisting of the main stem of the Waikato River from Lake Taupo to its mouth. Splitting the latter unit into a number of sub-units would have been desirable, but this would have required complex editing of the underlying spatial data to a level beyond the scope of this project. A range of attributes was used to describe the character of each planning unit as follows:

Ecological character—descriptions of the ecological character of each planning unit were based on two sets of data as follows:

Environmental classification data were derived from the biologically-tuned FWENZ classification of New Zealand's rivers and streams produced for the Department of Conservation (Leathwick et al. 2008). This classification used a range of environmental attributes stored in the "REC" database, a network-based GIS database that describes New Zealand's river and stream network. Attributes described various aspects of the character of each river or stream segment, including the annual flow and its variability, the slope both in the segment and downstream to the sea, the distance to the coast, and the character (climate, rock-type, slope, vegetation cover) of the upstream catchment. An advanced modelling method (Generalised Dissimilarity Modelling – GDM – Ferrier et al. 2004; Ferrier et al. 2007) was used to select variables from this database to maximise the prediction of species turnover in two biological datasets describing the distributions of native fish and aquatic macro-invertebrates respectively. The classification was then created by taking the selected environmental variables and using them to define a multivariate classification that grouped together rivers and streams having similar environmental attributes. Because this process specifically relies on biological data to guide the selection of environmental variables, we expect these groups to provide a strong summary of patterns of variation in biological character. Each river and stream segment in the

Waikato Region was allocated to a FWENZ classification group at a 200-group level nationally (Fig. 2). Seventy-eight of the classification groups occurred in the Region, i.e., 122 of the groups occur elsewhere in New Zealand, but are not found in the Waikato.

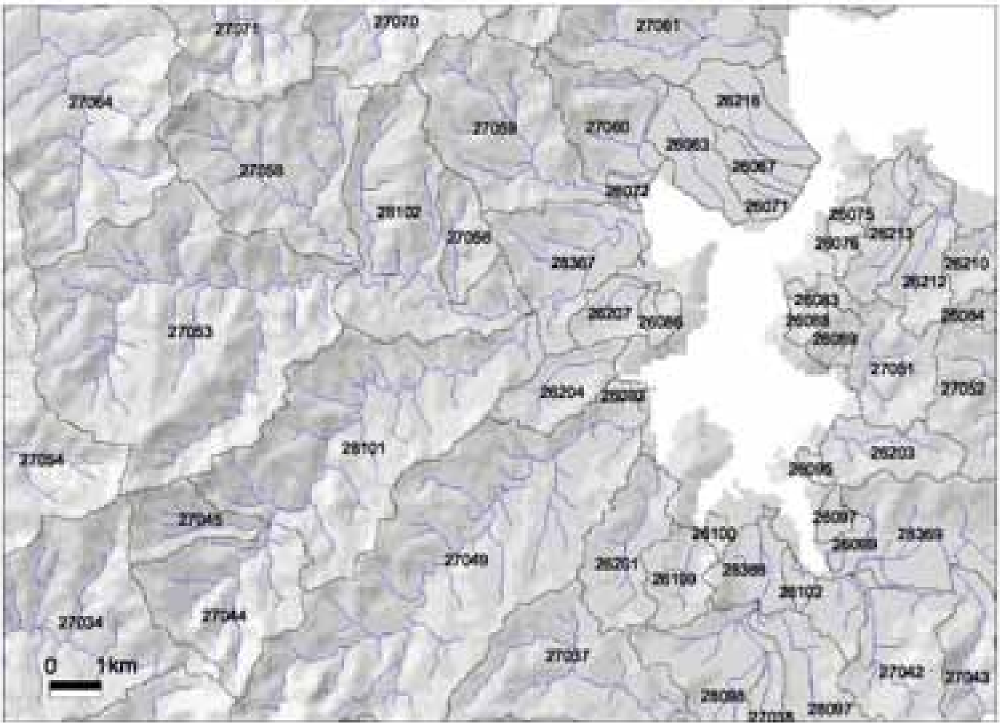

Figure 1: Planning units for catchments flowing into Whitianga Harbour. Planning units 27044 and 27045 are 3rd order headwater catchments that flow into the 4th order planning unit 28101. This in turn flows into the 5th order planning unit 28367. First order planning units flowing directly into the sea occur around the coast, e.g., 26216 towards the top right.

Predicted fish distribution data were drawn from a set of national predictions of the distributions of widespread native fish species produced for the Department of Conservation (Leathwick & Julian 2008a). Predictions for each species were derived from a statistical model that related records of catches from the New Zealand Freshwater Fish Database to a set of environmental predictors chosen for their functional relevance. Predictions for 17 species were available for each river or stream segment as listed in Table 1. These include the fifteen widespread diadromous species listed in Leathwick & Julian (2008a), the locally important diadromous species grey mullet, and the non-diadromous Cran’s bully. All values were continuous, varying between zero and one.

Table 1: Fish species used in the Zonation analysis.

Scientific name	Common name
Anguilla australis	Shortfin eel
Anguilla dieffenbachii	Longfin eel
Cheimarrichthys fosteri	Torrentfish
Galaxias argenteus	Giant kokopu
Galaxias brevipinnis	Koaro
Galaxias fasciatus	Banded kokopu
Galaxias maculatus	Inanga
Galaxias postvectis	Shortjaw kokopu
Geotria australis	Lamprey
Gobiomorphus basalis	Cran's bully
Gobiomorphus cotidianus	Common bully
Gobiomorphus gobioides	Giant bully
Gobiomorphus hubbsi	Bluegill bully
Gobiomorphus huttoni	Redfin bully
Mugil cephalus	Grey mullet
Retropinna retropinna	Common smelt
Rhombosolea retiaria	Black flounder

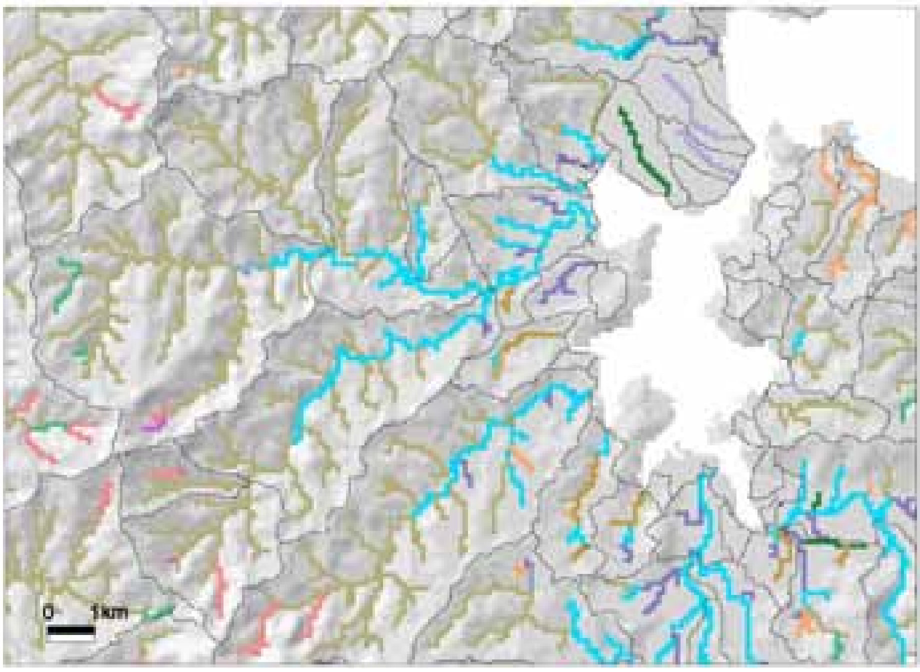

Figure 2: Environmental group membership for rivers and streams flowing into Whitianga Harbour. Note the clear separation between lowland low-gradient streams (mostly pale mauve or dark green), lowland hill-fed streams (sky-blue), hill-country streams (pale brown), and steep headwater streams (pink or mid-green).

Current condition—estimates of the current condition of each river and stream segment were described by an index of pressure derived from a set of factors describing various human impacts on catchments (Fig. 3) as described in Leathwick & Julian (2007). Factors contributing to this index describe spatial variation in modelled in-stream nitrogen concentrations, the predicted occurrence of introduced fish, the extent of both natural vegetation and impervious surfaces (roads, buildings, etc.) in the upstream catchment, disruption of natural flow variability and fish passage by dams, and point discharges from mines and industrial sites. Values for the final index in theory range between 0 (completely degraded) and 1 (pristine), but in practice ranged from 0 to 0.91 with a mean of 0.30 for the Waikato Region.

Current protection—spatial data provided by Environment Waikato GIS staff were used to create a layer indicating the distribution of land set aside primarily for conservation purposes. This included land administered by the Department of Conservation, land covenanted either under Nga Whenua Rahui or the QEII trust, or land set aside for conservation purposes by district councils. The latter included areas set aside by the Otorohanga, Waipa, Franklin, Matamata-Piako and Hauraki Plains District Councils.

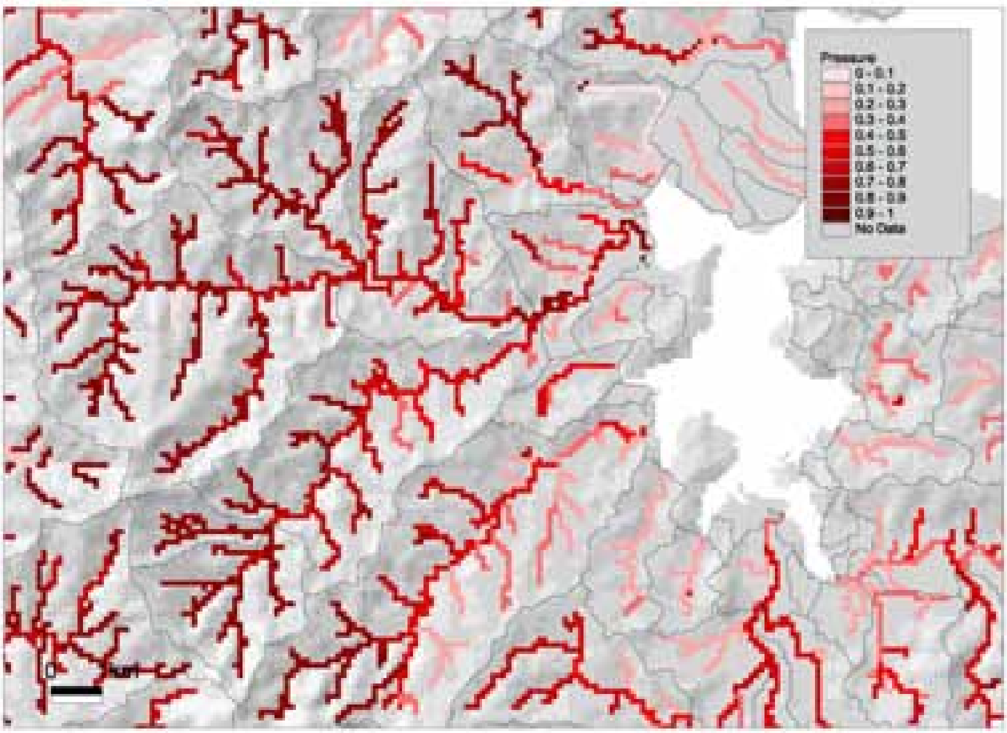

Figure 3: Variation in current condition for rivers and streams flowing into the Whitianga Harbour. Note the generally lower condition of lowland and coastal streams.

No spatial data describing the distribution of such land was available for the remaining district councils within the Waikato Region, but any omitted areas are likely to be very minor in extent relative to protected areas already identified. Once the layer describing the distribution of conservation lands had been constructed, it was combined with the planning unit layer to calculate the proportion of each planning unit that is currently protected (Fig. 4). Cut-off levels to define protection were set at 80%, i.e., a planning unit with 80% or more of its total river and stream length was flagged as "protected" in some of the Zonation analyses as described below. The basis of this cut-off was derived from Death & Collier (in press) who found that catchments with >80% indigenous vegetation cover were associated with macroinvertebrate faunas characteristic of non-degraded conditions. This information was also used to construct a "cost" layer for some of the analyses described below, calculated as the proportion of river and stream habitat that is unprotected in each planning unit, i.e., the larger the land area requiring protection, the higher the cost. A more refined cost layer could be constructed taking into account the expected land costs, given different predominant land uses, but was not attempted for this analysis.

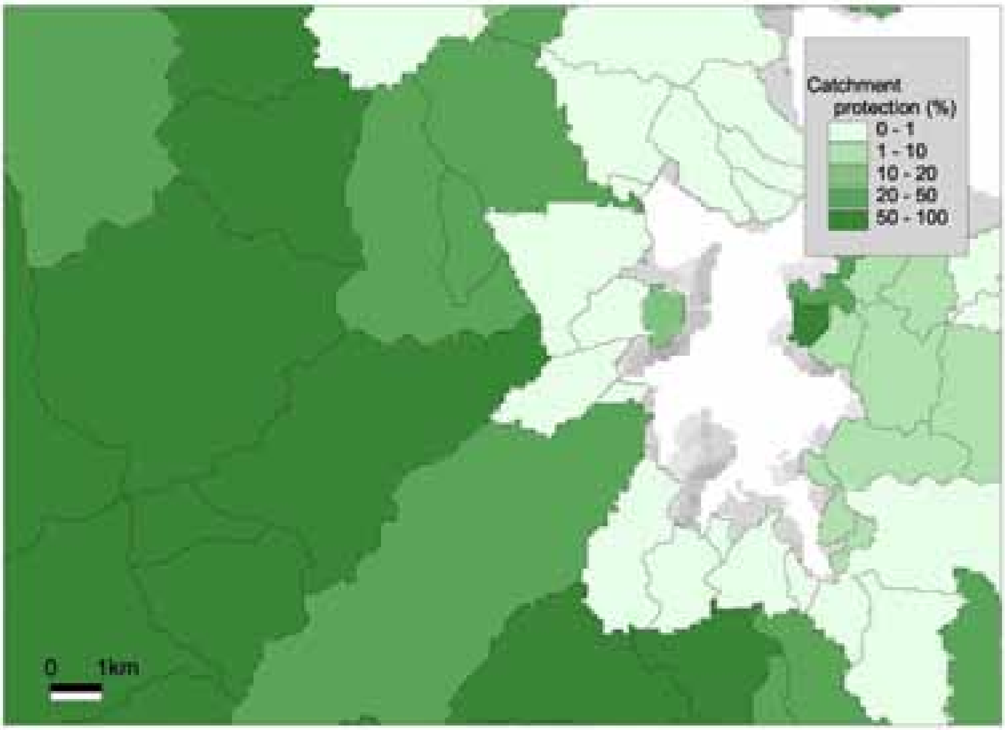

Figure 4: Variation in protection for conservation purposes across the catchments of rivers and streams flowing into the Whitianga Harbour.

2.2 Analysis methods - Zonation

All rankings were calculated using the conservation planning software Zonation (Moilanen et al. 2005, Moilanen 2007). This software is designed to identify those parts of a landscape that produce maximum benefit in terms of SNAs at minimum cost. Working with gridded data layers describing the spatial distribution of biodiversity features – FWENZ classification groups or predicted distributions of native fish – it progressively removes those grid cells that have the smallest marginal contribution to overall SNA outcomes. During the removal process it calculates both a ranking or priority for each grid cell, and the degree of protection that would be accorded to each biodiversity feature at any step during the removal process.

Zonation provides two features that are particularly relevant to the analysis of input layers describing the distributions of biodiversity patterns across river and stream networks (Moilanen et al. 2008).

First, planning units can be specified that consist of groups of adjacent grid cells. Removal then occurs by planning unit rather than by individual grid cell, i.e., the planning unit having the lowest marginal contribution to SNA outcomes is removed at each step of the removal process. In this analysis, the planning units consisted of the 3rd order catchments and sub-catchments described above.

Second, connectivity constraints can be applied between adjacent planning units, allowing the importance of longitudinal connectivity along river systems to be taken into account. At each stage of the removal process the value of remaining planning units is diminished according to the degree to which their connected upstream and downstream planning units have been removed. We assume here that the removal of upstream planning units generally has greater impacts on downstream values than does the loss of downstream units on the value of headwater catchments. We therefore used settings in which the removal of downstream planning units has a relatively muted effect on the biodiversity value of a planning unit still remaining in the solution, while removal of upstream planning units results in a more dramatic decline in the biodiversity value of downstream units.

2.2.1 The analyses

Four Zonation analyses were performed separately on the environmental classification and fish distribution datasets, all of which used the Core Area Zonation removal rule. This aims to protect at least some core occurrences of all biodiversity features (FWENZ groups or species), which is achieved by applying the following rules during the removal of planning units: (i) of two otherwise equal planning units, that with a lower occurrence for the highest weighted biodiversity feature is removed first; (ii) assuming two otherwise equal planning units, that with the occurrence of a lower-weight feature is removed before the one with an equal occurrence for a high-priority feature; (iii) assuming two identical planning units with identical original occurrence levels for two different features, the one is retained that contains a feature that has lost more of its distribution; (iv) of two otherwise identical locations, that with higher cost is removed first. Where equal weights are used for biodiversity features, removal of planning units is mostly governed by the third of these rules, i.e., at any stage in the removal process, Zonation aims to protect even proportions across the features used in the analyses – where weights are used the first two rules come into play to provide higher protection for features with higher weights. The final rule only applies where variable costs are used across planning units, and was implemented only in the final analysis for each dataset.

The four analyses performed (separately) on the environmental classification and predicted fish distribution data sets used the following settings:

1. *Z* – Core Area Zonation (*CAZ*) applied with no consideration of either connectivity constraints or current condition. Results can be used to identify the set of planning units that would maximise conservation benefits, given a nominated level of geographic protection, and assuming no human impacts.

2. *ZC* = *CAZ* + connectivity – as for '1', but with connectivity constraints applied to encourage the identification of sets of connected planning units to allow for the benefits of maintaining upstream-downstream linkages on conservation outcomes. Note that this did not allow for the effects of disrupted connectivity caused by dams or culverts, this being allowed for in the pressure index described below.

3. *ZPC* = *CAZ* + connectivity + pressure – as for '2', but taking into account the expected loss in biodiversity values from human impacts. For this analysis, Zonation loaded the pressure layer at the outset of the analysis, and values in the input grid layers were diminished according to the pressure index scores. For example, where a FWENZ class occurred at two locations with pressure scores, for example, of 0.3 and 0.8, input values of '1' would be down-graded to 0.3 and 0.8, respectively. In selecting planning units to remove, the latter grid cell would clearly be identified as providing a better example of the affected classification groups than the former. Results indicate optimal sets of planning units once human impacts are taken into account.

4. *ZPC-Cons* = *CAZ* + connectivity + pressure + conservation estate – as for ‘3’, with the addition of information about the distribution of planning units having 80% or more of their land area already designated for conservation management. These planning units were preferentially retained in the Zonation analysis until all other planning units had been removed as described above. Results can be used to indicate (i) the conservation benefits that are derived from currently protected planning units, (ii) the relative efficiency of conservation lands compared to protection of an equivalent area without respect to current land use, and (iii) those planning units that would contribute the greatest gains in conservation benefits, given their ability to complement the biodiversity features that are already protected. In this analysis, an additional grid layer indicating the proportion of each planning unit that is unprotected was used as a cost layer. As a consequence, if choosing between two planning units with identical biodiversity values, Zonation would retain the unit having a larger proportion of its area already protected. This analysis is considered most useful for identifying high value sites on private land under contemporary conditions, with a particular focus on complementing those values already protected in the conservation estate.

2.2.2 Environmental classification data

Prior to running the Zonation analyses on the environmental classification we manipulated the classification data to allow consideration of similarities between the different environmental groups. This was achieved by creating a set of 78 gridded data layers at 100 m resolution, each which described the spatial distribution of one of the FWENZ groups at a 200 group level of classification. Grid cells where the target FWENZ group occurred were allocated a value of 1, while locations occupied by other FWENZ groups were allocated values reflecting the similarity between them and the target FWENZ group. For example, where a cell was occupied by a closely related group, it might be allocated a value of 0.5 or 0.8, but where that cell was occupied by a markedly different environment, the value allocated might be as low as 0.1 or even less. All FWENZ groups were equally weighted.

2.2.3 Predicted fish distribution data

The fish distribution data was used without any modification, i.e., the distribution of each species was represented as a gridded (raster) data layer at a resolution of 100 m, with values within each layer ranging from 0–1, and indicating the predicted probability of capture for that grid cell when using standard fishing methods. Species with a formal threat classification, i.e., longfin eel, giant kokopu, shortjaw kokopu and lamprey, were given twice the weight of other species.

2.3 Analysis methods – national rankings

National rankings for 4th order planning units throughout New Zealand (Leathwick & Julian (2008b), calculated using the same procedure as for the *Env-ZPC* analysis described above were imported and summarised against the 3rd order planning units for the Waikato Region.

2.4 Analysis methods – rare and threatened species

A variety of information describing the distributions of rare or threatened species was assembled as follows:

1. Rare or threatened native fish species – data describing the distributions of longfin eel, shortjaw kokopu, giant kokopu and lamprey were assembled for all river and stream segments, and averages were then calculated for each species in each planning unit. Values estimate the average probability of capture for each species and were predicted from regression models fitted to catch data from approximately 13,400 sites throughout New Zealand, and contained in the New Zealand Freshwater Fish Database. A description of the methods used to make these estimates is contained in Leathwick & Julian (2008a).

2. Koura – the average probability of capture was calculated for each planning unit using predictions from a regression model using the same dataset and methods as used for freshwater fish (Leathwick unpublished).

3. Blue duck – estimated relative probability of occurrence were provided for all river segments by Amy Whitehead (University of Canterbury), and these summarised across planning units. Predictions of occurrence were based on observations of blue duck distribution, coupled with background samples of average environmental conditions, analysed using similar methods to those used for native fish and koura.

4. Hochstetter's frog – known locations for this species within the Waikato Region (n = 475) were provided by the Department of Conservation. In the absence of background environmental data for terrestrial sites with which to fit a predictive model, we simply identified those planning units within which occurrences had been reported allocating presences a score of 1, and absences a score of 0, acknowledging that this database does not provide a comprehensive picture of Hochstetter frog distribution.

Data for these seven species were combined into a single index of rare or threatened species occurrence by summing the individual species occurrences for each planning unit using weights allocated according to threat status as listed in Table 2. This weighted sum was then divided by the sum of the weights (14) to give final values ranging between 0 (no occurrences) and 1 (high occurrence of all species).

2.5 Analysis methods – species richness

Estimates of species richness (alpha diversity) for both native fish and aquatic macro-invertebrates were derived for all river and stream segments in the Waikato Region from environment-based regression models (Leathwick unpubl. data). Estimates of fish species richness used the same dataset as that used to estimate capture probabilities for individual fish species, while estimates of invertebrate species richness were based on a compilation of approximately 2800 macro-invertebrate sampling sites from throughout New Zealand. Both regression models used the same (or a subset of the) environmental predictors used to predict individual fish species distributions as described by Leathwick & Julian (2008a).

Table 2: Rare or threatened species, grouped by their status, and the weights used in calculating a single index of rare species occurrence for each planning unit.

Status	Species	Weight
Sparse	Shortjaw kokopu, lamprey, Hochstetter's frog	1
Gradual decline	Longfin eel, giant kokopu, koura	2
Nationally endangered	Blue duck	5

3. Results

3.1 Zonation analyses of FWENZ classification groups

Results from the initial Zonation analysis of FWENZ classification groups (*Env-Z*) identify a set of units that would maximise biodiversity returns under natural (pre-human) conditions, but without assuming any requirement for connectivity. High ranked planning units from this analysis are widely dispersed through the Waikato Region (Fig. 5), and would protect a diverse range of environments, including high elevation planning units on Ruapehu and in the Kaimanawa Mountains, hill-country units on the Coromandel and Herangi Ranges, and units containing low-gradient rivers and streams on the Hauraki Plains and in the Hamilton Basin.

The relationship between conservation effectiveness (CE) and the proportion of cells under protection is shown by the dotted blue line in Figure 6. This indicates that reserving the highest ranked 10% of planning units would deliver biodiversity protection of approximately 0.54 (10% is used here as an arbitrary level of protection for comparative purposes). Note however that this initial estimate of conservation returns not only assumes that no environmental degradation has occurred due to human activity, but also makes no allowance for connectivity effects on biodiversity protection.

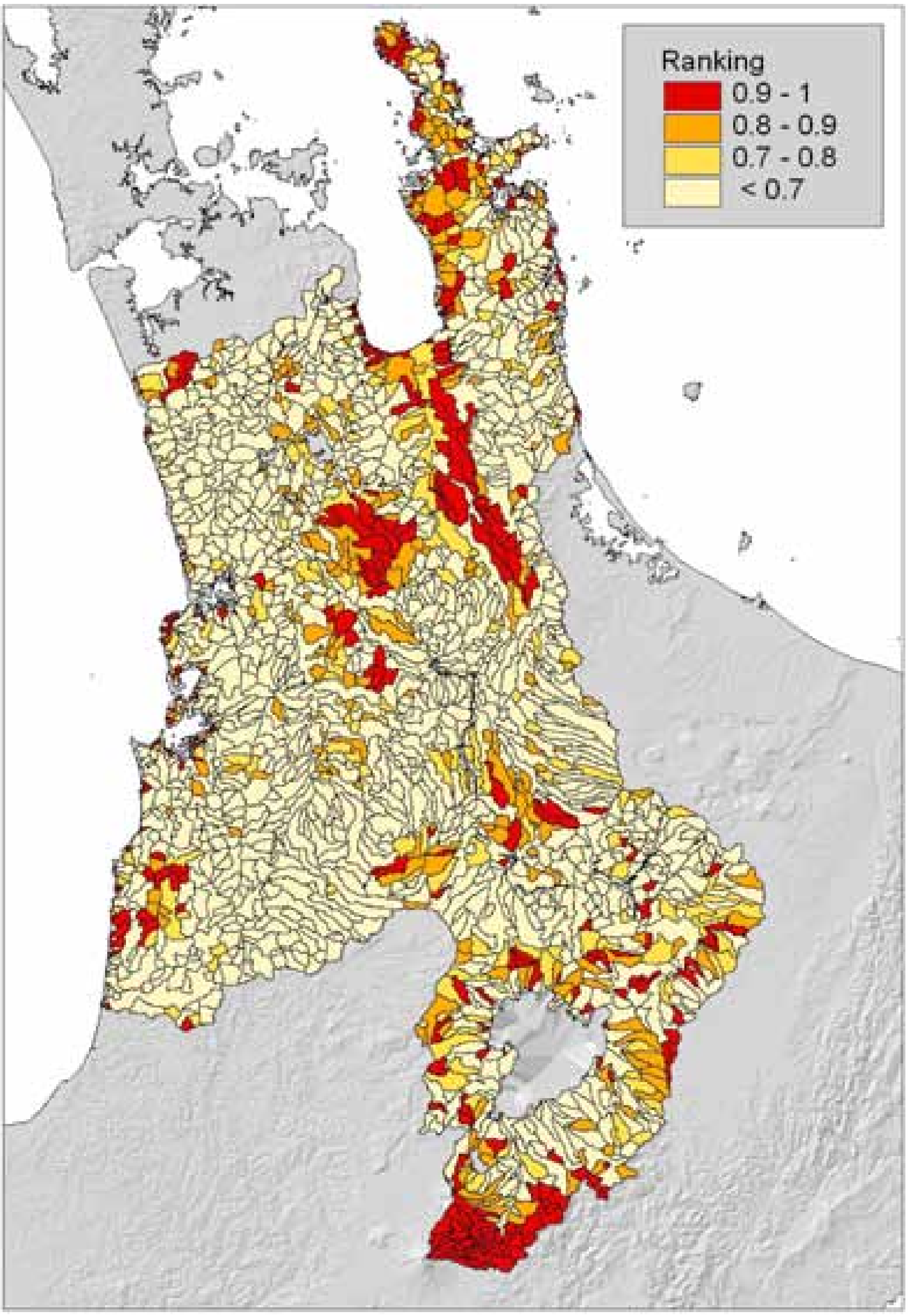

Figure 5: Zonation rankings (higher numbers indicated higher priority) from the *Env-Z* analysis for the Waikato Region, assuming pristine conditions and with no connectivity constraints. Values indicate the removal rank, so that protection of sites with values from 0.9–1 would protect 10% of the river and stream network. Note that "Rankings" are not the final ranking for SNA purposes.

Addition of connectivity constraints in the *Env-ZC* analysis produces a more geographically compact set of highly-ranked planning units (Fig. 7), because it encourages the identification of planning units that are inter-connected. This is particularly apparent on the Hauraki Plains, where rankings are adjusted so that a much more interconnected set of highly-ranked units are identified, centred on the Piako River. Taken at face value, protection of the top ranked sites would deliver benefits differing little from those identified by the *Env-Z* analysis (solid line in Fig. 6). However, this comparison is somewhat misleading because the negative impacts of not accounting for connectivity requirements have not been included for the initial *Env-Z* analysis. To more accurately assess the comparative benefits from these analyses, we re-calculated the conservation effectiveness for the *Env-Z* analysis, but applied the connectivity constraints for the *Env-ZC* analysis (dashed line in Fig. 6). This indicates that, once connectivity considerations are taken into account, the high-ranked sites from the unconstrained *Env-Z* analysis would actually deliver much lower benefits, e.g., at 10% geographic protection the CE for the *Env-Z* analysis reduces to 0.46 versus 0.54 for the *Env-ZC* analysis.

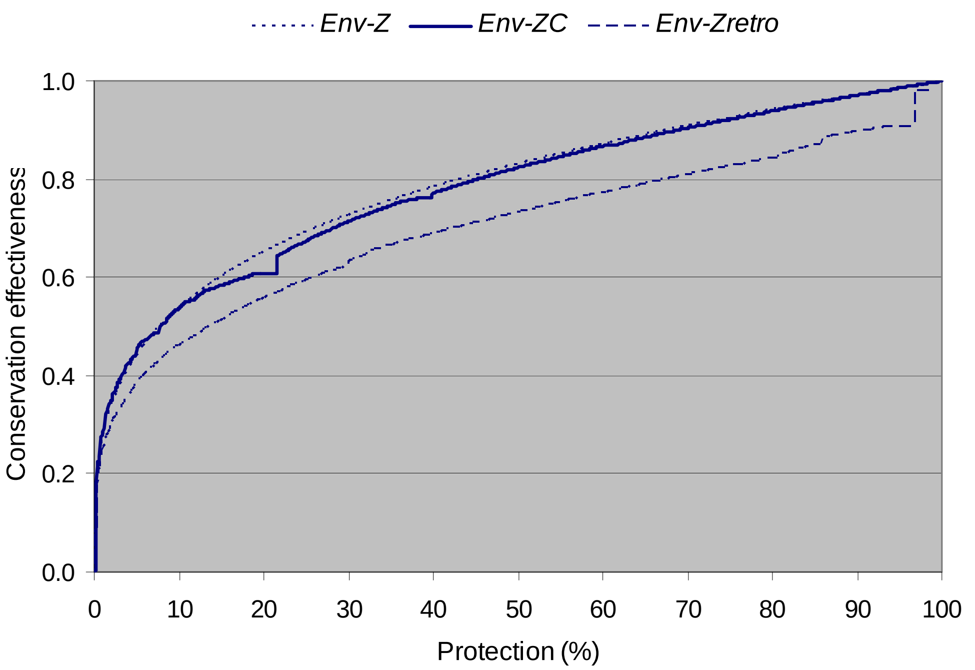

Figure 6: The relationship between conservation effectiveness and geographic protection of planning units as estimated from the *Env-Z* and *Env-ZC* analyses. The dashed line (*Env-Z-retro*) was calculated by retrospectively analysing the spatial configuration produced by the *Env-Z* analysis, but applying the connectivity penalties used in the *Env-ZC* analysis. Note the initially rapid increase in conservation returns when protecting a small proportion of planning units, but the diminishing gains with protection of larger areas.

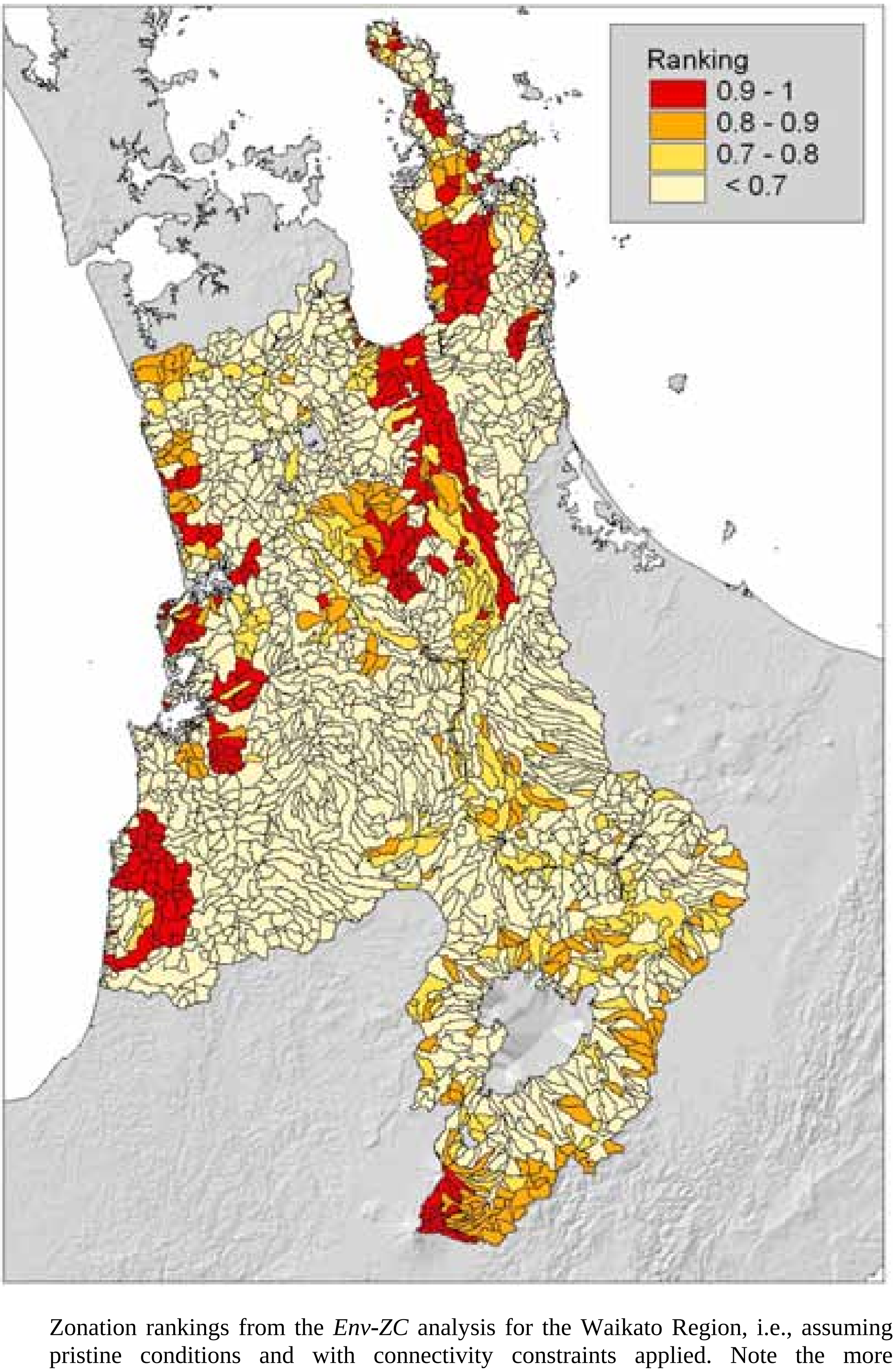

Figure 7: Zonation rankings from the *Env-ZC* analysis for the Waikato Region, i.e., assuming pristine conditions and with connectivity constraints applied. Note the more aggregated arrangement of high value planning units compared to that in Figure 5.

Adding consideration of human impacts on river and stream conditions makes a dramatic difference to the potential conservation benefits that are achievable under any given level of geographic protection (Fig. 8). These are reduced significantly compared to those possible under pristine conditions, with the maximum achievable CE, assuming complete geographic protection, reducing by around 25% from 1.0 to 0.74. However, because Zonation identifies the best condition sites to protect where possible, protection of the best 10% of planning units would still produce a conservation effectiveness of 0.47.

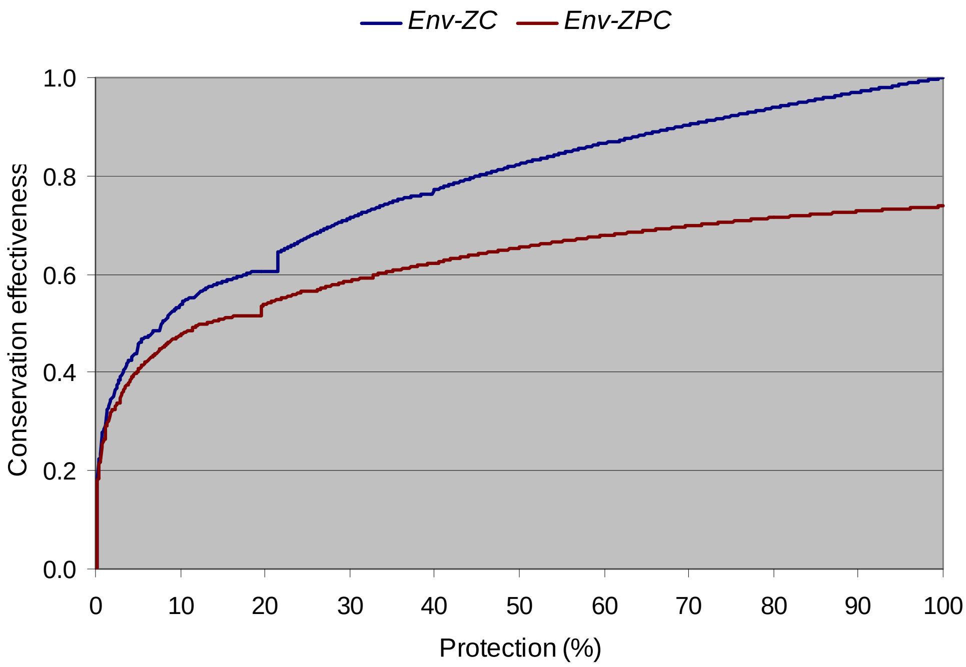

Figure 8: The relationship between conservation effectiveness and geographic protection of planning units as estimated by the *Env-ZC* and *Env-ZPC* analyses. Note the lower maximum conservation effectiveness that can be achieved, reflecting the effects of human impacts on river and stream ecosystems.

The geographic configuration produced from this analysis (Fig. 9) shows a marked shift in the distribution of high ranked units, these now being biased towards higher elevation and/or steeper terrain in which human activities are less intensive. Planning units in the top 10% of rankings are largely confined to Ruapehu, the Coromandel Ranges, and hill-country from the head of Raglan Harbour south to the Herangi Range. However, several planning units on the Hauraki Plains are still allocated high rankings, despite their relative poor current condition. Similarly, the main stem of the Waikato River has a moderate ranking, reflecting the value that Zonation recognises in trying to maintain connectivity between inland planning units and the sea.

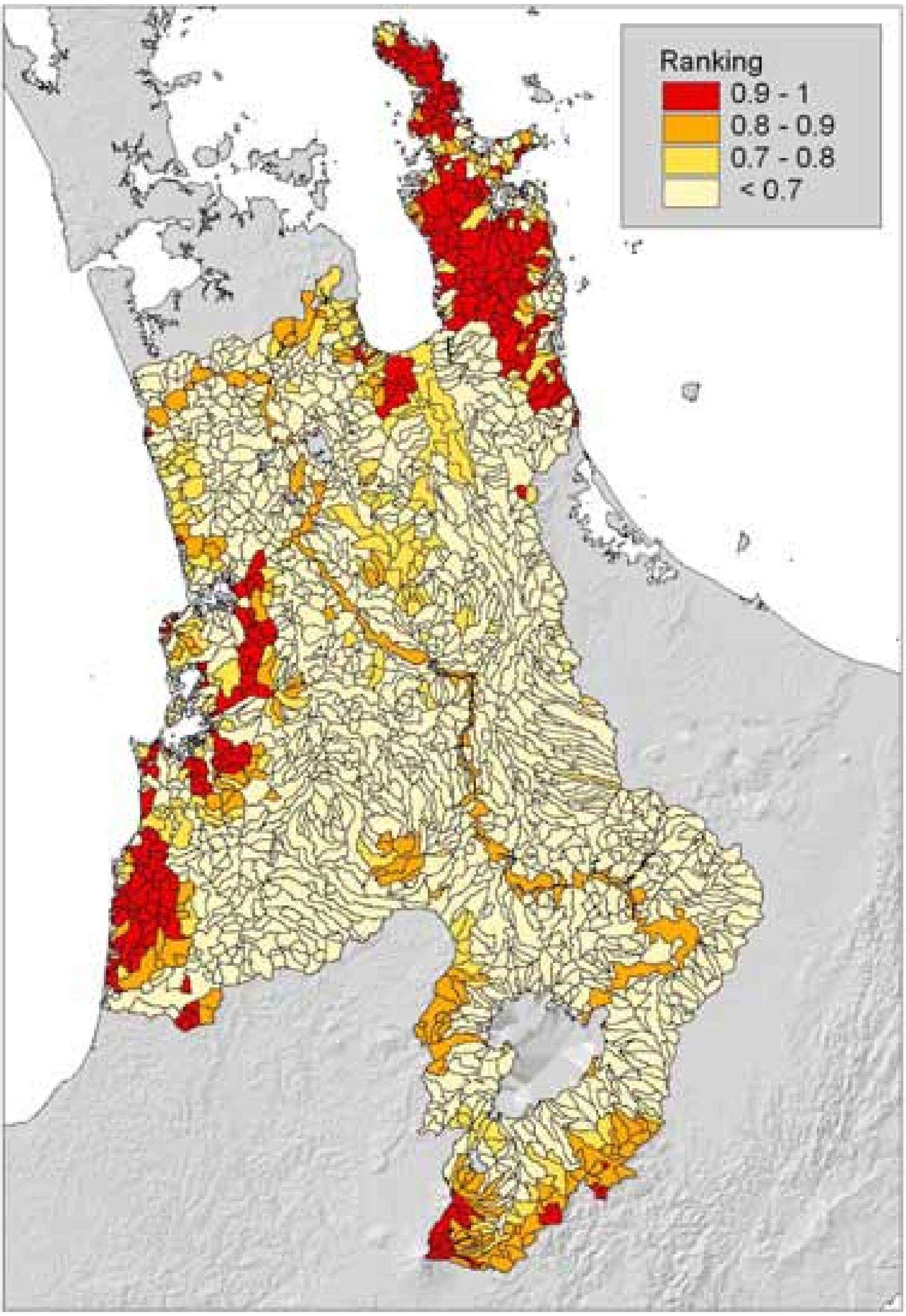

Figure 9: Zonation rankings from the *Env-ZPC* analysis for the Waikato Region, accounting for current pressures and with connectivity constraints applied. Note the reduced extent of high ranking planning units in the lowlands.

Finally, we show results from the *Env-ZPC-Cons* analyses (Figs. 10–11) in which planning units having at least 80% of their land area protected for conservation were retained until all other planning units had been removed. This analysis gives a good indication of both the efficiency of current protected areas in protecting freshwater biodiversity values, and those areas that would best complement those areas that are currently protected. For example, results from the *Env-ZC-Cons* analysis, which also includes consideration of human impacts, indicates that those planning units having at least 80% protection for conservation (6.3% of the Region) deliver total conservation effectiveness of around 0.37. This is only 15% lower than the predicted effectiveness that could be achieved if an equivalent area was set up from scratch to maximise conservation returns, this achieving a value of 0.43. Planning units that would best complement those units that are already substantially protected are mostly located in lowland environments (Fig. 11). Many of the high-ranked units provide more complete linkages between higher elevation (already protected) planning units and the sea, e.g., in the Coromandel and Herangi Ranges, reflecting the effects of the connectivity constraints applied in these analyses.

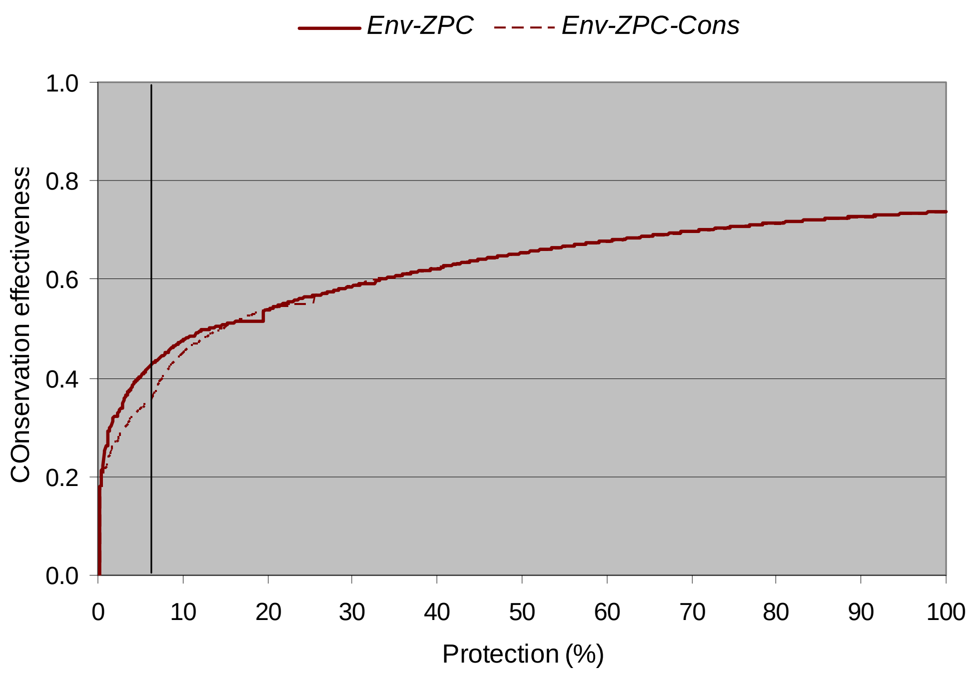

Figure 10: The relationship between conservation effectiveness and geographic protection of planning units as estimated by the *Env-ZPC* and *Env-ZPC-Cons* analyses. For the latter analysis, planning units with 80% or more of their land area protected were retained until all other planning units had been removed. The vertical black line indicates the point in the Zonation removal process at which all "unprotected" planning units had been removed.

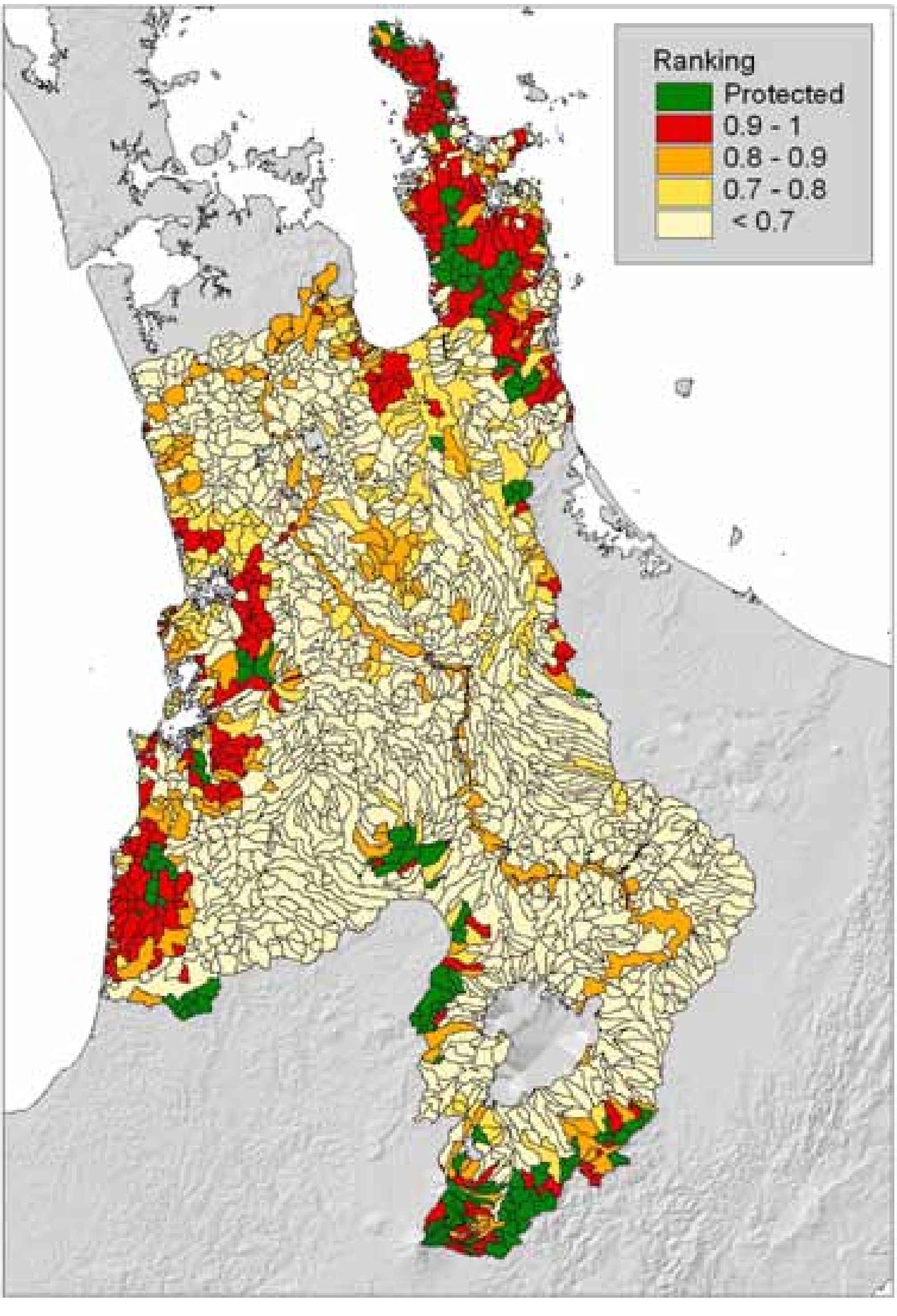

Figure 11: Zonation rankings for currently unprotected planning units from the *Env-ZPC-Cons* analysis for the Waikato Region, assuming current conditions and with connectivity constraints applied. Planning units already substantially protected are coloured green, and priorities for non-protected units are shown using the same colours as for the previous maps.

3.2 Zonation analyses of predicted fish distributions

Results from the Zonation analyses of predicted fish distributions broadly parallel those from the analyses of FWENZ classification groups presented in the previous section, but with important differences, particularly in the spatial distribution of high priority planning units. This is apparent for example, in a comparison of the rankings from the *Env-Z* and *Fish-Z* analyses (Fig. 5 versus Fig. 12), with the *Fish-Z* analysis allocating high priorities to a much smaller number of inland planning units around Lake Taupo than occurs with the *Env-Z* analysis. However, this is compensated for by the identification of a much larger number of high priority planning units in low elevation and/or coastal locations, particularly along the Herangi and Coromandel Ranges, in the upper Waipa catchment, and on the low gradient floodplains of the lower Waikato and Piako Rivers. This is a direct reflection of the strong coastal bias in distribution of the majority of the native fish species occurring in the Waikato Region, and the relative paucity of native fish in the Taupo basin.

Differences are also apparent between these two sets of analyses in the relationship between conservation outcomes and geographic protection, although in part this reflects differences in the way that conservation returns are expressed. In particular, conservation outcomes for the FWENZ classification analyses were expressed using a power relationship that is not appropriate as a summary of the protection provided for individual fish distributions; for these we simply report conservation outcomes as the proportion of the range protection provided by any level of geographic protection, averaged across species. As a consequence, the relationship between conservation outcomes from these Zonation analyses and the extent of geographic protection is more linear, compared to that for the Zonation analyses of FWENZ groups. Protection of the best 10% of planning units in the Waikato Region, assuming pristine conditions, would provide average species range protection of nearly 0.24 for the 17 species analysed (dotted line in Fig. 13). Increasing the extent of geographic protection to 20% would increase the average range protection to nearly 0.41.

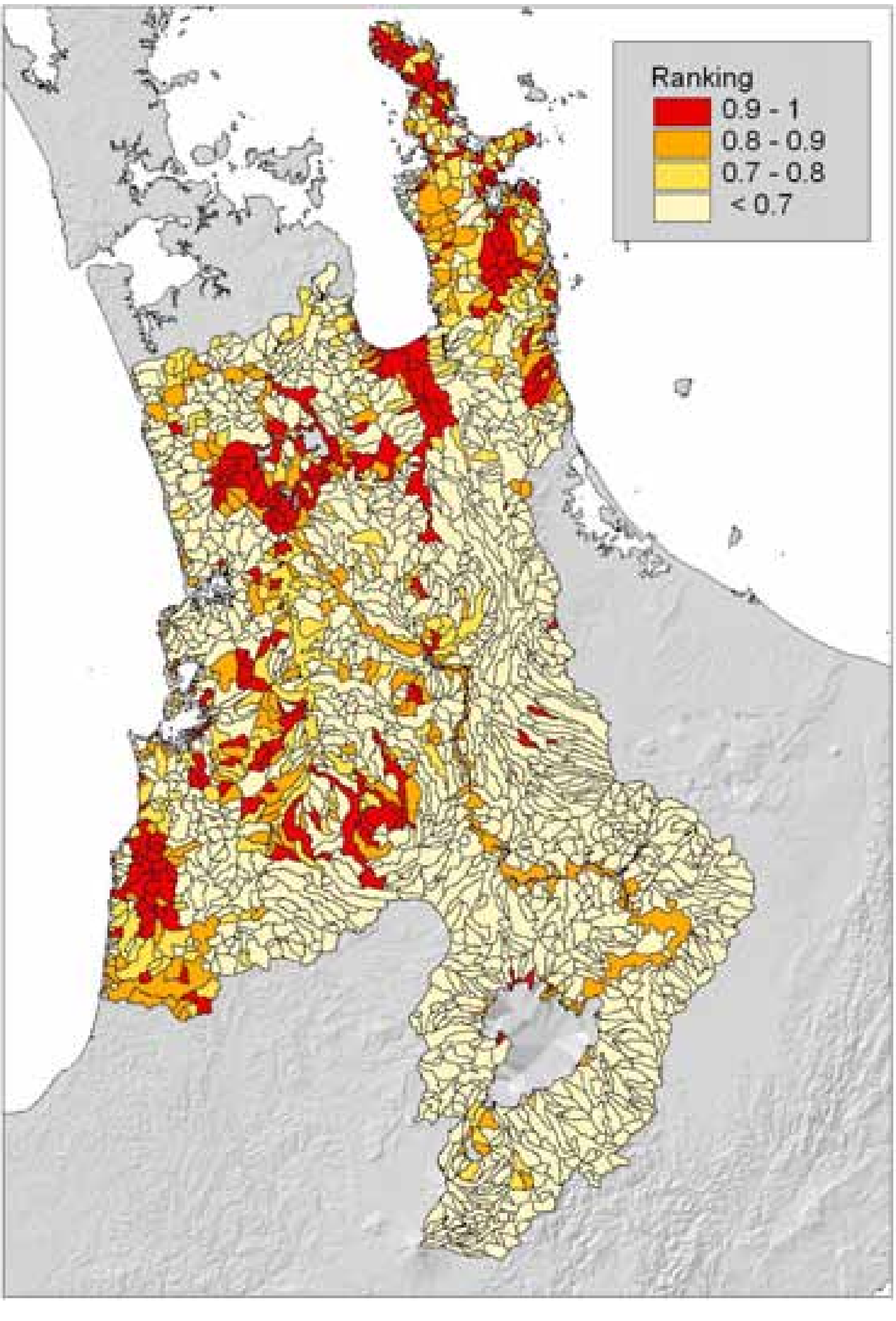

Figure 12: Zonation rankings (higher numbers indicated higher priority) from the *Fish-Z* analysis for the Waikato Region, assuming pristine conditions and with no connectivity constraints. Values indicate the removal rank, so that protection of sites with values from 0.9–1 would protect 10% of the river and stream network. Note that "Rankings" are not the final ranking for SNA purposes.

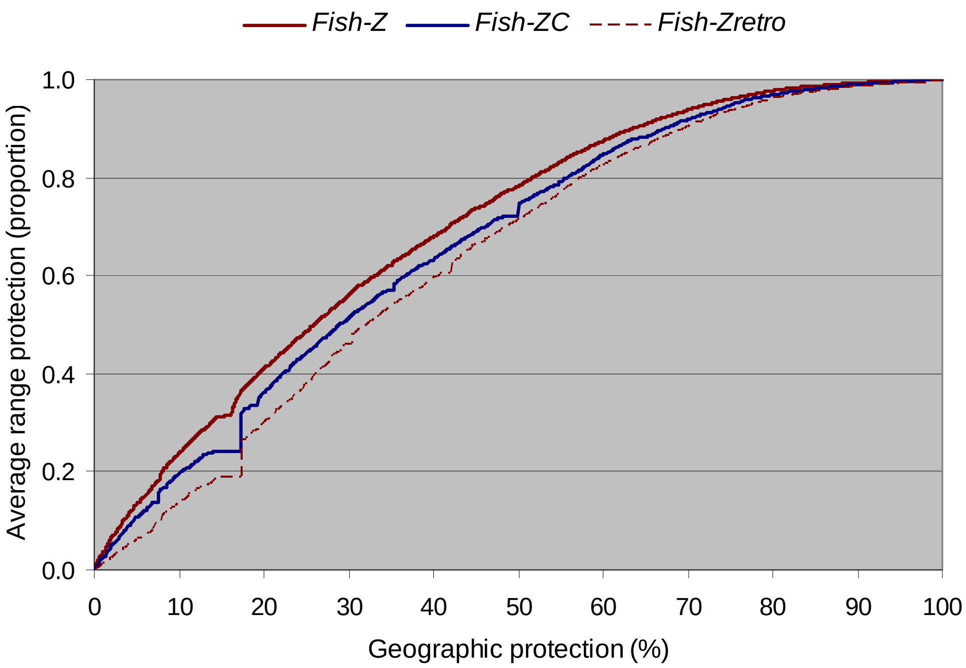

Figure 13: The relationship between average species range protection and geographic protection of planning units as estimated from the *Fish-Z* and *Fish-ZC* analyses. The dashed line (*Fish-Zretro*) was calculated by retrospectively analysing the spatial configuration produced by the *Fish-Z* analysis, but applying the connectivity penalties used in the *Fish-ZC* analysis.

The introduction of connectivity constraints in the *Fish-ZC* analysis produces a much more spatially compact set of high priority planning units (Fig. 14), recognising the need for connectivity to protect the migratory movements of many of these species, and to maintain habitat quality across entire catchments. As with the *Env-ZC* analysis, this produces an apparent reduction in the range protection provided to fish species (Fig. 13), the average species range protection provided by 10% geographic protection reducing from 0.24 to 0.20. However, reassessment of the *Fish-Z* spatial pattern using the same connectivity constraints as used in the *Fish-ZC* analyses reduces the estimated average species range protection to 0.14, given this level of geographic protection.

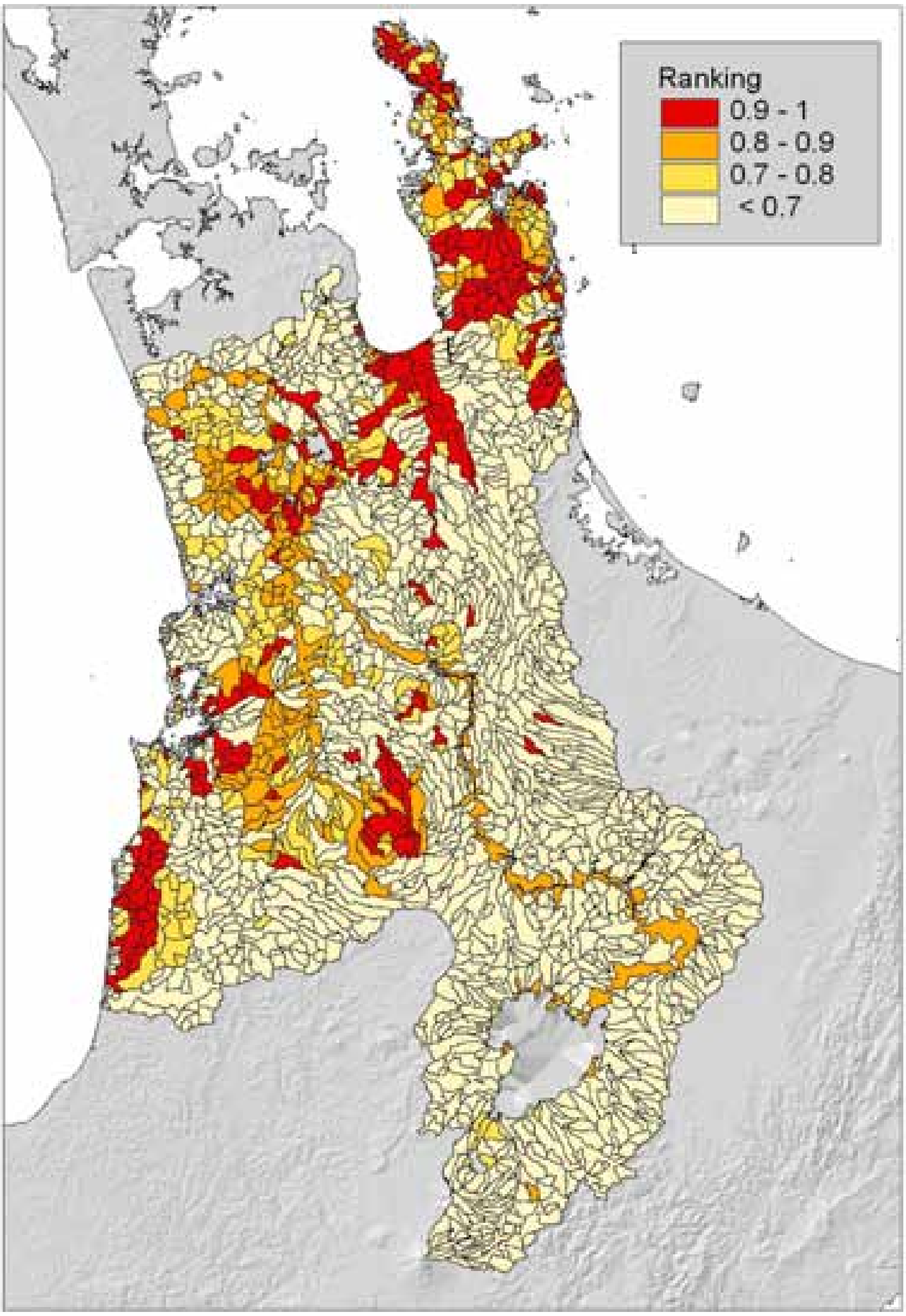

Figure 14: Zonation rankings from the *Fish-ZC* analysis for the Waikato Region, i.e., assuming pristine conditions and with connectivity constraints applied. Note the more aggregated arrangement of high value planning units compared to that in Figure 12.

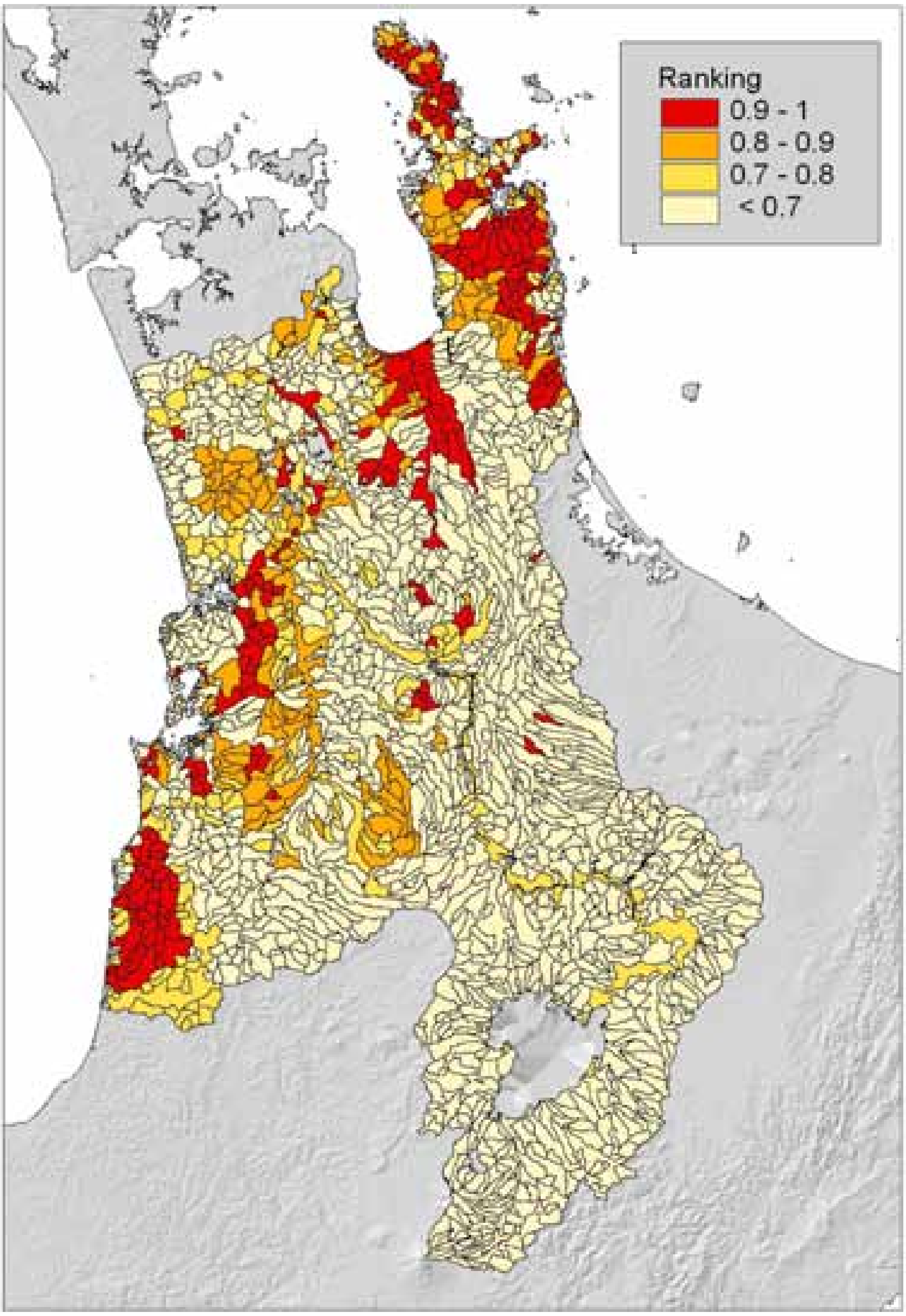

Figure 15: Zonation rankings from the *Fish-ZPC* analysis for the Waikato Region with connectivity constraints and accounting for current pressures. Note the reduced extent of high ranking planning units in the lowlands compared to Figure 14.

Further alteration of this pattern is evident when condition effects are considered in the *Fish-ZPC* analysis, with a greater priority given to less impacted planning units, e.g., in hill-country with at least some native vegetation cover. High ranked units are most extensive on the Herangi Range (Fig. 15), along the hill-country extending from the coastal flanks of Pirongia to the Hakirimata Range, and along the Coromandel Peninsula. Generally lower priorities are allocated to planning units on the intensively farmed basin floors, although high priorities are still allocated to several planning units in the lower Waikato and Piako catchments, despite moderate to high levels of human pressure.

Including the effects of human pressures reduces markedly the maximum species range protection that can be achieved (Fig. 16), the maximum attainable protection declining from 1 to a value of 0.34. However, because Zonation specifically aims to protect those parts of species ranges that are in good condition, the range protection provided by protection of the best 10% of planning units declines less markedly, i.e., from 0.20 in the *Fish-ZC* analysis to 0.10 when pressure effects are included.

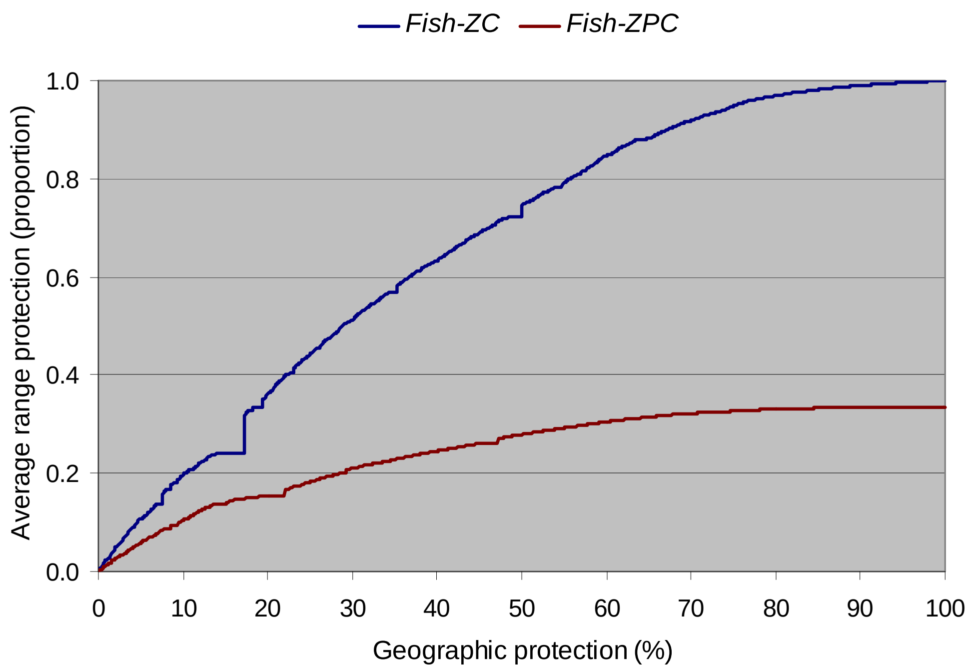

Figure 16: The relationship between average species range protection and geographic protection of planning units as estimated by the *Fish-ZC* and *Fish-ZPC* analyses, with the latter including consideration of human impacts.

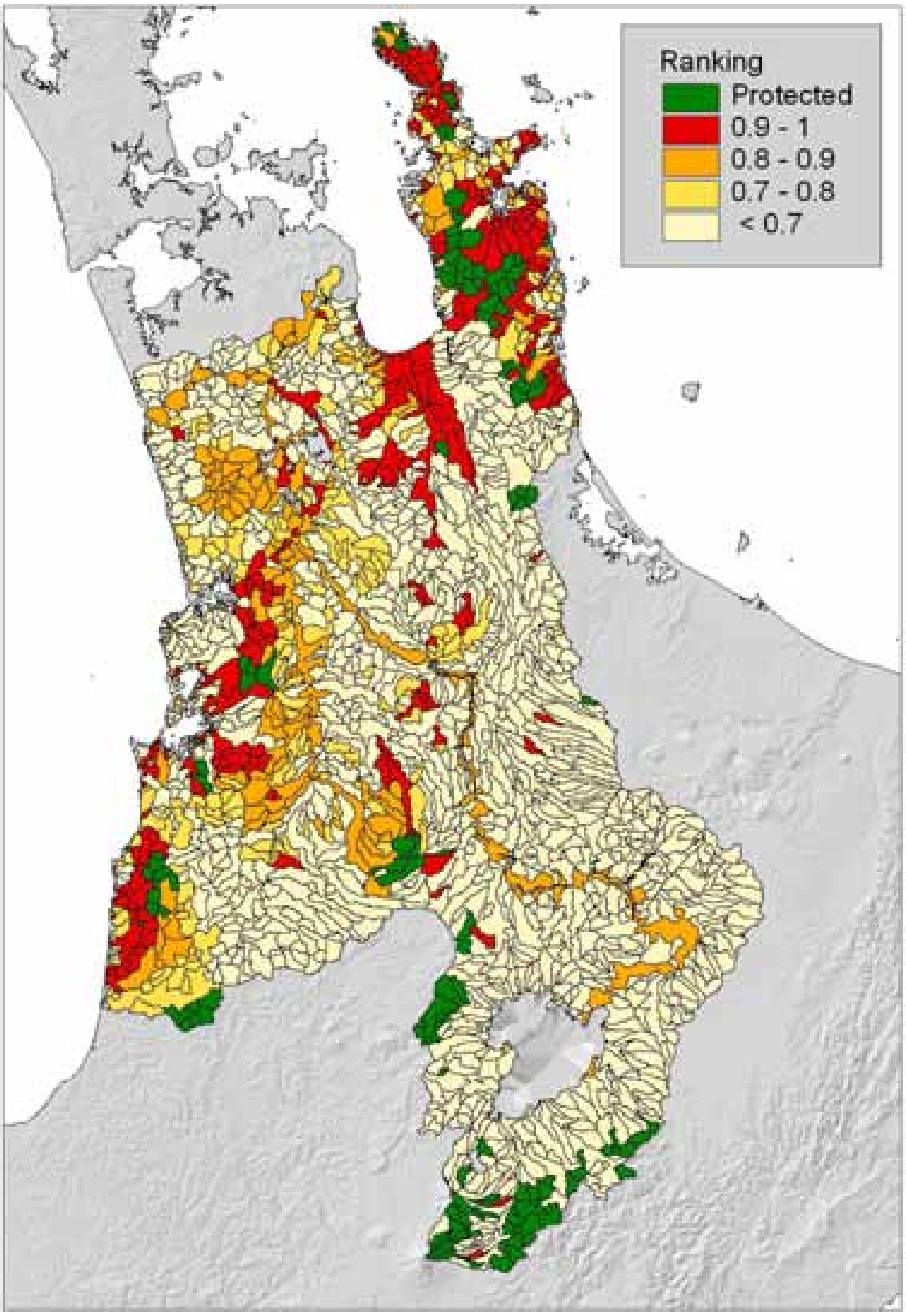

Figure 17: Zonation rankings for currently unprotected planning units from the *Fish-ZPC-Cons* analysis for the Waikato Region, assuming current conditions and with connectivity constraints applied. Planning units already substantially protected are coloured green, and priorities for non-protected units are shown using the same colours as for the previous maps.

The broad geographic pattern of high-ranked planning units is mostly maintained in the final *Fish-ZPC-Cons* analysis (Fig. 17), in which planning units with 80% or more existing protection (shown in green) are retained until the end of the removal process. However, some re-sorting occurs both to take account of the existing pattern of protection, and to provide greater connectivity between these predominantly high-elevation protected areas and the coast. Use of a cost layer in this analysis also influences outcomes, with selection biased towards those planning units that already have partial protection, reflecting the lower cost of extending protection in these compared to in those units that are completely unprotected at present.

The relatively inefficient protection provided for native fish by current protected areas is also clearly apparent in results from this analysis. Planning units with 80% or more protection constitute approximately 6.3% of the Waikato Region, but these provide average fish species range protection of only 0.018 (Fig. 18). By contrast, selection of an equivalent area specifically chosen to protect fish distributions could deliver average range protection of 0.072 – four times the amount.

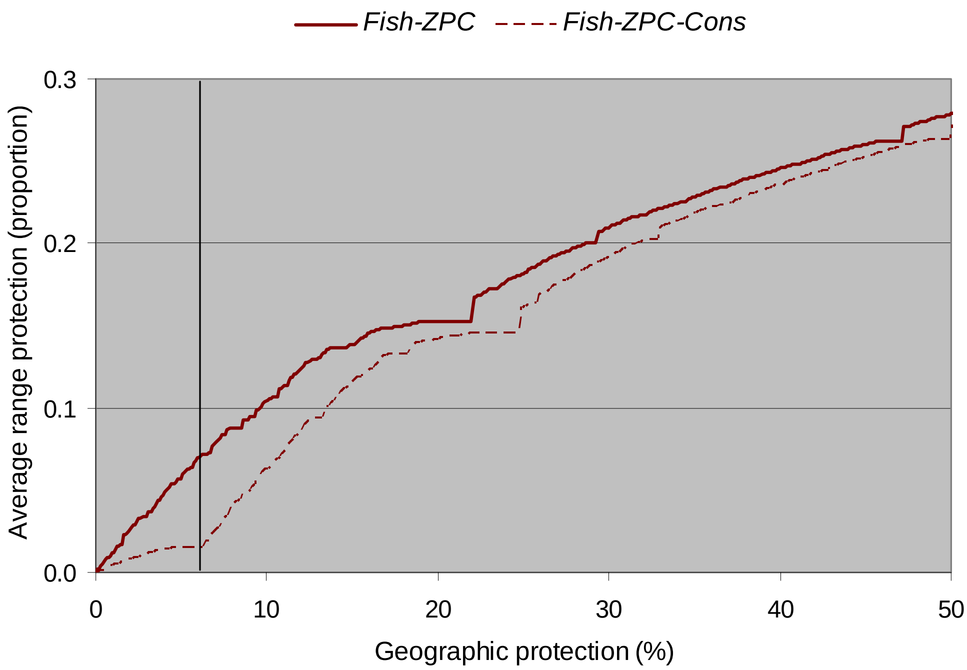

Figure 18: The relationship between average species range protection and geographic protection of planning units as estimated by the *Fish-ZPC* and *Fish-ZPC-Cons* analyses. For the latter analysis, planning units with 80% or more of their land area protected were retained until all other planning units had been removed. The vertical black line indicates the point in the Zonation removal process when all "unprotected" planning units had been removed. Note that value ranges on both axes have been reduced compared to Figure 16 to add interpretability.

Finally, we highlight the manner in which averaging results across species results in some loss of information about the protection provided to individual species. We illustrate this for two contrasting species, giant kokopu (Fig. 19) and koaro (Fig. 20); the first of these occurs predominantly in low gradient lowland streams and the second in steeper streams in moderate to high elevation hill country.

Results indicate that if 10% protection of the Waikato Region was implemented based on the *Fish-ZC* analysis, koaro would receive approximately twice the range protection of giant kokopu (0.21 versus 0.10). Comparison of these two graphs also indicates that, once consideration of human impacts is added (*Fish-ZPC* analysis), protection of the core habitat of giant kokopu is much more difficult than for koaro. Here, the protection provided for koaro declines by only a fifth to 0.16, but that for giant kokopu declines by a half to 0.05; this discrepancy reflects the much greater human impacts on those environments preferred by giant kokopu than on those occupied by koaro.

Finally, marked discrepancies are also apparent in the species protection provided to these two species by those planning units that already have high levels of formal protection for conservation (*Fish-ZPC-Cons* analysis). These sites, whose levels of geographic protection are indicated by the solid vertical lines in Figures 19 and 20, protect less than 1% of the predicted range of giant kokopu but nearly 5% of the predicted range of koaro. This discrepancy is largely explained by the contrasting environmental preferences of these two species, coupled with the marked bias in current protection towards higher elevation, steeper terrain, i.e., the land “left-over” after development for agriculture and/or forestry.

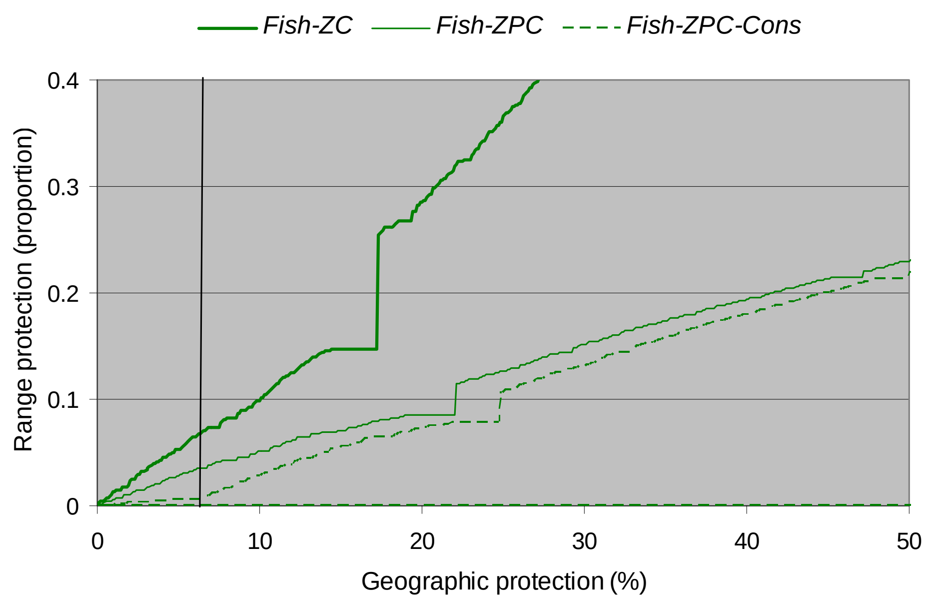

Figure 19: The relationship between range protection provided for giant kokopu and geographic protection of planning units as estimated by the *Fish-ZC*, *Fish-ZPC* and *Fish-ZPC-Cons* analyses. The vertical black line indicates the point in the Zonation removal process when all "unprotected" planning units had been removed.

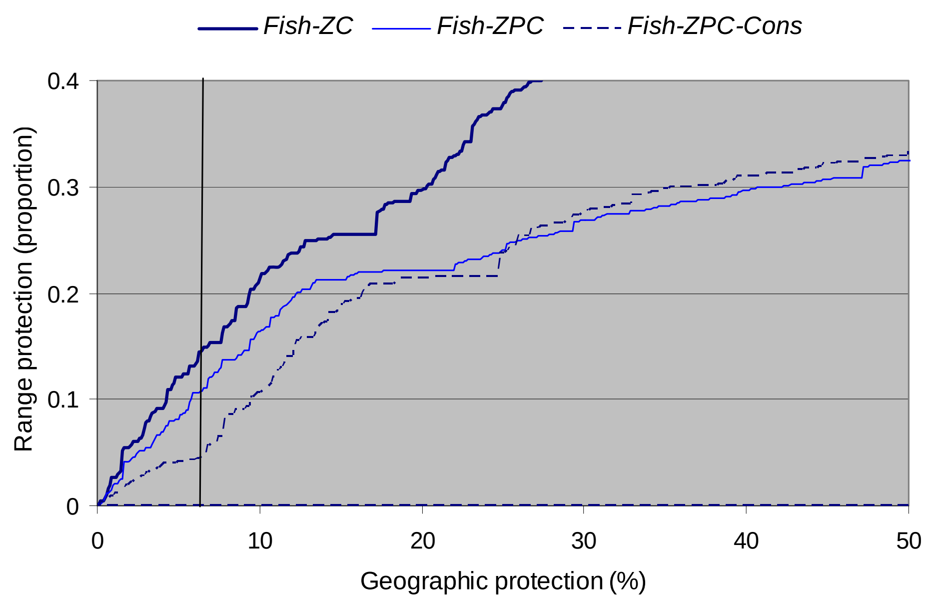

Figure 20: The relationship between range protection provided for koaro and geographic protection of planning units as estimated by the *Fish-ZC*, *Fish-ZPC* and *Fish-ZPC-Cons* analyses. The vertical black line indicates the point in the Zonation removal process when all "unprotected" planning units had been removed.

3.3 Zonation analyses of national priorities

A total of 215 planning units (out of 1890) from the Waikato Region have provisional national rankings that place them in the top 10% of sites nationally. This national analysis was performed using 4th order planning units, and using the FWENZ classification at a 100 group level of detail. Current condition and connectivity requirements were considered in the same manner as for the *Env-ZPC* analysis. Highly ranked sites are located predominantly along the Herangi Range and on the Coromandel Peninsula (Fig. 21).

3.4 Rare and threatened species

Final scores for the combined index of rare species occurrence range from 0 to 0.5, with a mean of 0.16. However, only one very small planning unit in the Rangitoto Range has a score exceeding 0.4 — planning units with scores greater than 0.3 occur mostly at high elevations on the Herangi, Rangitoto and Coromandel Ranges (Fig. 22). Values are generally low in the Taupo basin and in the lower Waikato lowlands.

3.5 Species richness

Marked differences are apparent both in the ranges of values and spatial patterns of species richness predicted for native fish (Fig. 23) and macro-invertebrates (Fig. 24). Average native fish species richness is predicted to vary between 0.2 and 4.5 with a mean of 1.61. It is predicted to be highest in coastal and lowland areas, highest values occurring in small catchments around the Coromandel coast. Values less than one are predicted for virtually all planning units in the Waikato catchment upstream from about Lake Karapiro. Although dams now largely block access by diadromous species to these waters, fish migration was also restricted historically at this point by major rapids in the Waikato River.

Predicted species richness for stream macro-invertebrates varies between 5.7 and 40.8 with a mean of 15.1. Planning units with average predicted values greater than 25 occur mostly on the eastern flanks of the Tongariro volcanoes and along the western side of the Coromandel Peninsula north of Thames. Moderate values (16-24) are predicted for most of the other ranges of the Region; lowest values are predicted for the low gradient streams, often with extensive peat catchments, that occur in the Hamilton basin.

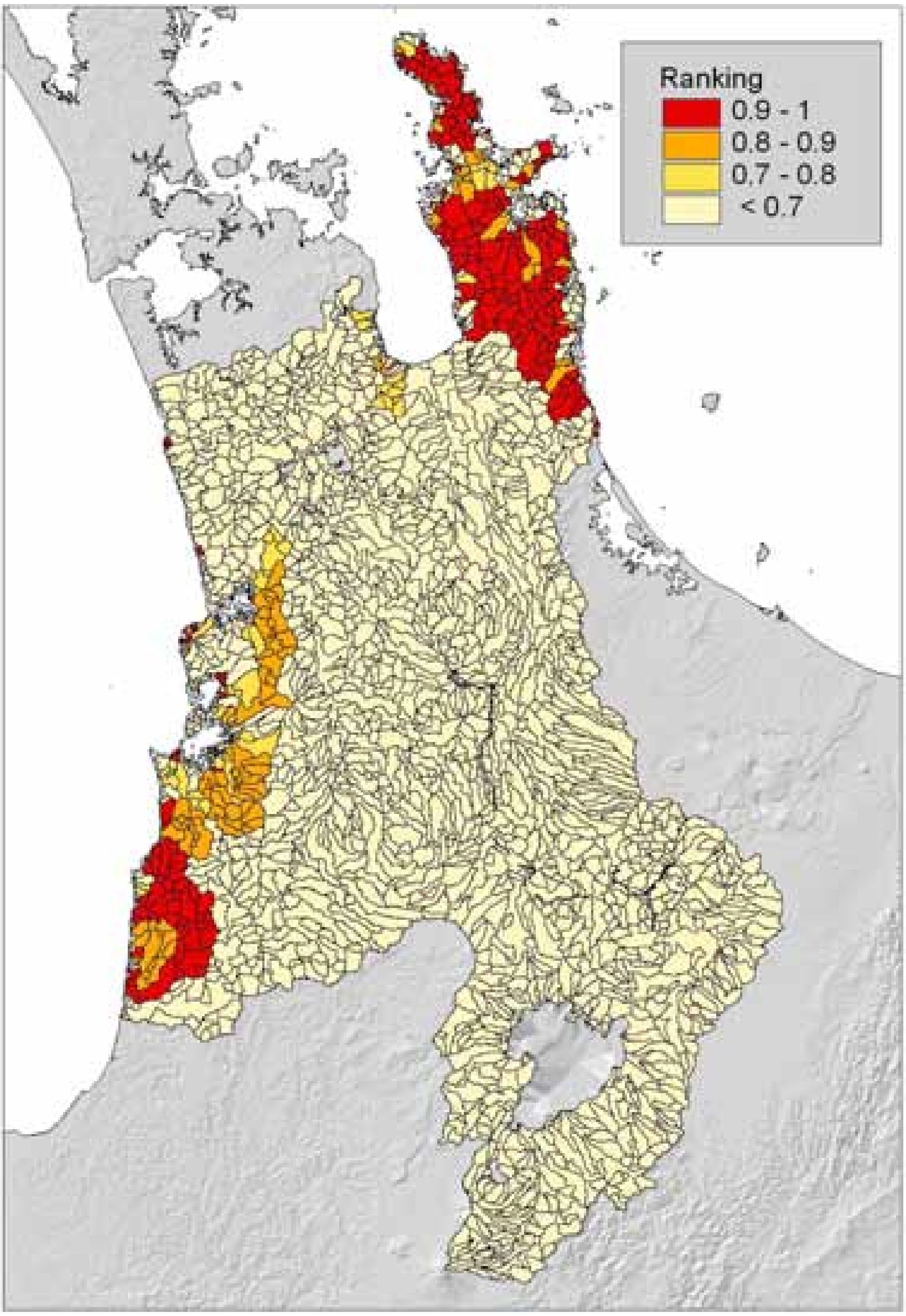

Figure 21: Provisional national conservation rankings from a national analysis of FWENZ groups for all of New Zealand at a 100 group level, and take account of both current condition and connectivity requirements.

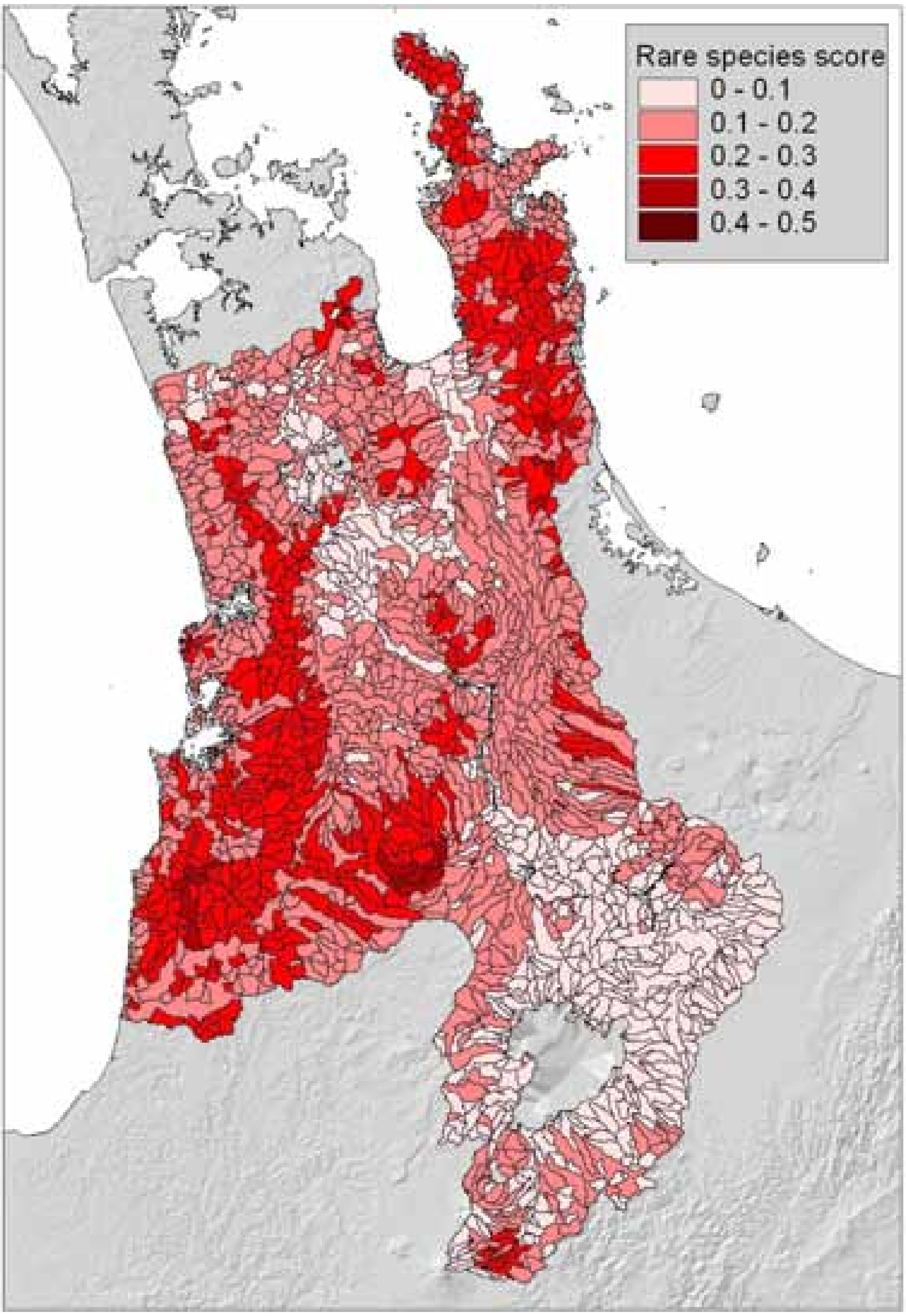

Figure 22: Combined rare and threatened species index computed to take account of the distributions of longfin eel, giant kokopu, shortjaw kokopu, lamprey, koura, Hochstetter's frog and blue duck – see text for computation details.

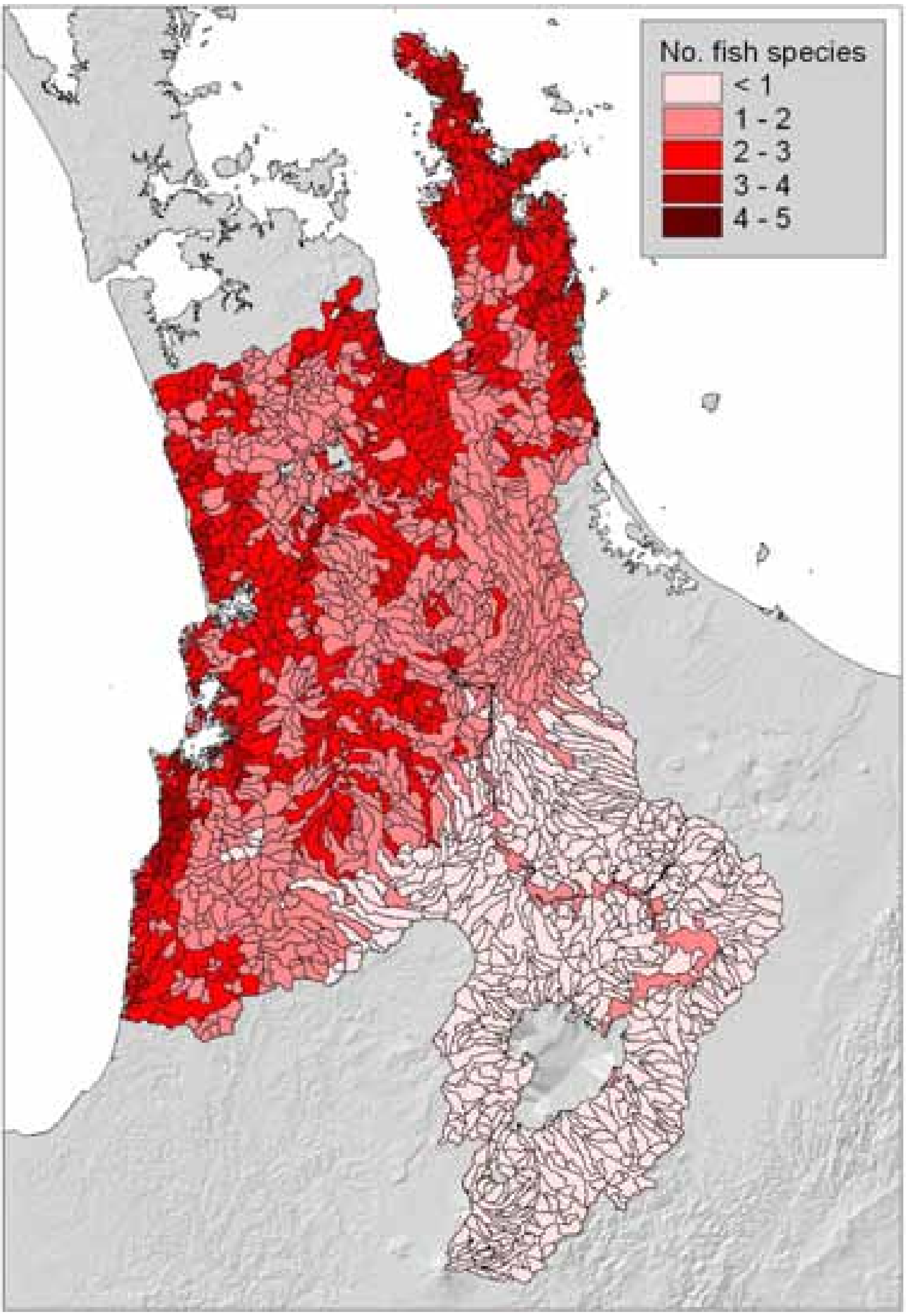

Figure 23: Average fish species richness as predicted from a regression analysis relating fish catch to environmental predictors – see text for computational details.

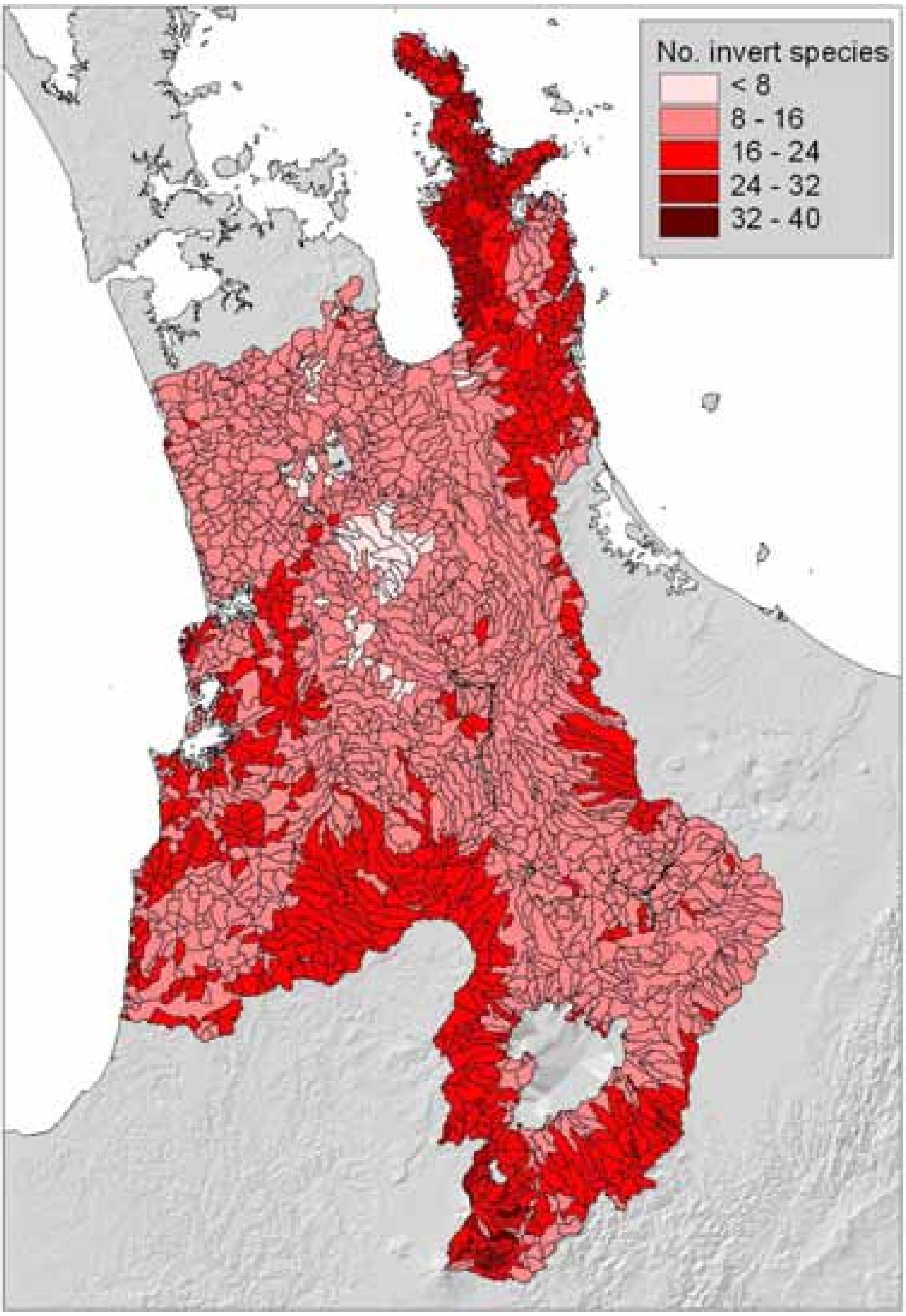

Figure 24: Average macro-invertebrate species richness as predicted from a regression analysis relating invertebrate catch in standard samples to environmental predictors – see text for computational details.

4. Discussion

Results from this project demonstrate our ability to calculate rankings for rivers and streams at a regional scale using newly developed tools for site prioritisation in freshwater ecosystems. These rankings can be used to identify optimal sets of planning units to maximise stream and river SNA outcomes, given varying assumptions that include: (i) treating all planning units as if they are in natural condition; (ii) reducing the expected conservation returns from planning units according to their estimated degree of human modification; (iii) taking account of the likely consequences of loss of upstream or downstream planning units on biodiversity values in a target planning unit; (iv) taking account of current patterns of conservation protection to identify those planning units that would best complement those planning units already having high levels of protection. Together with other information assembled here, and describing the distributions of rare species, the estimated species richness for fish and aquatic invertebrates, and national rankings of conservation priority, these tools provide a valuable basis for identifying SNAs. This will be achieved by merging results from our physical and biological analyses into a ranking system that identifies stream and river SNAs based as much as possible around Criteria for Determining Significance as defined in the Regional Policy Statement.

Further refinement would be possible in the methods used here. In particular, we acknowledge that lacustrine recruitment of diadromous fish species is not always well captured, both in our predictions of the distributions of individual fish species, and in the connectivity constraints applied in Zonation. While we have used downstream distances to lakes as a predictor in our regressions models of individual species, this was less effective than anticipated for most species, probably reflecting an adequate intensity of sampling in sites adjacent to lakes; a strong effect was noted for only one species, koaro. In Zonation, we could possibly include a term accounting for downstream lake effects, but this would probably require adaption of the software.

Similarly, our treatment of the current extent of protection is relatively simplistic and assumes that protected areas provide generally good conditions for the maintenance of biodiversity, while non-protected areas do not. A more complex treatment of this would allow, for example, for the loss of conservation benefits resulting from downstream obstructions that prevent recruitment of migratory species into protected headwater sites. Conversely, it might recognise the conservation benefits that are protected by the maintenance of riparian vegetation cover in well-managed plantation forests. Upgrading of Zonation to account for these types of effects is planned, but implementing such analyses would also require detailed site specific data about the actual management practices being applied in different parts of the landscape.

What these potential refinements underline is the reality that any analytical model, including those used here, involve the abstraction of complex ecological realities. This does not invalidate their use; rather, it highlights the manner in which such analytical results should be used – not as complete answers that make complex decisions for the end-user, but as tools that encourage structured and informed decision making. In this respect, they must be seen and used as decision *support* tools that help inform and guide a decision making process that also draws on other sources of ecological insight as and where appropriate.

5. References

Abell, R.; Allan, J.D.; Lehner, B. (2007). Unlocking the potential of protected areas for freshwaters. *Biological Conservation 134*: 48-63.

Death, R.G.; Collier, K.J. (in press). Measuring stream invertebrate responses to gradients of vegetation cover: when is enough enough? *Freshwater Biology*.

Ferrier, S.; Manion, G.; Elith, J.; Richardson, K. (2007). Using generalised dissimilarity modelling to analyse and predict patterns of beta-diversity in regional biodiversity assessment. *Diversity and Distributions 13*: 252-264.

Ferrier, S.; Powell, G.V.N.; Richardson, K.S.; Manion, G.; Overton, J.M.; Allnutt, T.F.; Cameron, S.E.; Mantle, K.; Burgess, N.D.; Faith, D.P.; Lamoreux, J.F.; Kier, G.; Hijmans, R.J.; Funk, V.A.; Cassis, G.A.; Fisher, B.L.; Flemons, P.; Lees, D.; Lovett, J.C., van Rompaey, R.S.A.R. (2004). Mapping more of terrestrial biodiversity for global conservation assessment. *BioScience 54*: 1101-1109.

Leathwick, J.R.; Julian, K. (2007). Production of pressure estimates for New Zealand river catchments. NIWA Client Report HAM2007-027 prepared for the Department of Conservation.

Leathwick, J.R.; Julian, K. (2008a). Predicting the distributions of freshwater fish species for all New Zealand's rivers and streams. NIWA Client Report HAM2008–005 prepared for the Department of Conservation.

Leathwick, J.R.; Julian, K. (2008b). Updated conservation rankings for New Zealand's rivers and streams. NIWA Client Report HAM2008–077 prepared for the Department of Conservation.

Leathwick, J.R.; Julian, K.; Elith, J.; Chadderton, L.; Ferrier, S.; Snelder, T. (2008). A biologically-optimised environmental classification of New Zealand rivers and streams: reanalysis excluding human impacts variables. NIWA Client Report HAM2008-027 prepared for the Department of Conservation.

Linke, S.; Pressey, R.L.; Bailey, R.C.; Norris, R.H. (2007). Management options for river conservation planning: condition and conservation revisited. *Freshwater Biology 52*: 918–938.

Margules, C.R.; Pressey, R.L. (2000). Systematic Conservation Planning. *Nature 405*: 243–253.

Moilanen, A. (2007). Landscape Zonation, benefit functions and target-based planning. Unifying reserve selection strategies. *Biological Conservation 134*: 571–579.

Moilanen, A.; Leathwick, J.R.; Elith, J. (2008). A method for spatial freshwater conservation prioritization. *Freshwater Biology 53*: 577–592.

Moilanen, A.; Franco, A.M.A.; Early, R.; Fox, R.; Wintle, B.; Thomas, C.D. (2005). Prioritising multiple use landscapes for conservation: methods for large multi species planning problems. *Proceedings of the Royal Society Part B 272:* 1885–1891.

6. Appendix I - Interpreting Zonation outputs for the environmental group analyses

Results from the Zonation analyses are presented using two main outputs. First, spatial results indicate the ranking allocated to each planning unit during the removal process. Planning units with low values are those that are removed last, and have the highest ranking – selecting those with values in the range 0–0.1 would protect 10% of the total landscape, while selecting those with values in the range 0–0.2 would protect 20% of the landscape, etc.

Second, the conservation effectiveness can be calculated as a function of the geographic extent of protection to enable comparison between analyses. For the analyses of fish distributions the conservation effectiveness (CE) is simply computed as the mean protection of species distributions ranges, given the degree of geographic protection, values varying between 0 and 1.

For the FWENZ groups, the calculation of conservation effectiveness is complicated by the adjustments made to account for inter-group similarities. Here, the benefits delivered by any particular protection scenario are calculated as:

$$CE \approx \sum_{i=1}^{n} \left(cf_i * \left[\frac{\sum_{j=1}^{n} S_{ij} L_j P_j}{\sum_{j=1}^{n} S_{ij} L_j} \right]^{0.25} \right) \tag{1}$$

where S_{ij} describes the similarity between FWENZ classes i and j with values ranging between 0 (no similarity) and 1 (identical), L_j describes the amount of river segment representing environment j, and P_j describes the proportion of environment j that is protected under any given scenario (Ferrier et al. 2004). The term cf_i is a correction factor that accounts for the inflation of the apparent amount of each environment that is present after taking account of similarities between environments, and is computed as:

$$cf_i = \frac{\dfrac{L_i}{\sum_{j=1}^{n} S_{ij} L_j}}{\sum \dfrac{L_i}{\sum_{j=1}^{n} S_{ij} L_j}} \tag{2}$$

The term within the square brackets in equation 1 therefore describes the proportion of each environment that is protected under any given protection scenario, taking into account similarities between environments. That is it recognises that protection of a particular environment also contributes to protection of the values of other similar environments. By contrast, it also recognises that protection of highly distinctive environments (those having no closely related environments) must be achieved largely through their direct protection.

7. Appendix II - Metadata for spatial data supplied at completion of project

Digital results from this project have been supplied as a polygon-based theme in shape file format, mapped on the New Zealand Map Grid. The file supplied contains 1890 polygons, each of which delineates a catchment or sub-catchment based planning unit. These were constructed so that all streams of 3rd order or less were treated as an individual planning unit, and all rivers and streams of greater than 3rd order were split into their 3rd or higher-order sub-catchments and their main stem. Attribute data for each polygon are contained in 23 fields as listed in Table 1.

Table 1: Data fields contained in the shape file of analysis results.

Field	Derivation
Id	A unique numeric identifier for the polygon
Nzreach	The River Environment Classification identifier (Nzreach) of the terminal river or stream segment in the planning unit
Order	The river or stream order – ranges from 1 to 7
Hectares	The planning unit area in hectares
Angdie	Average predicted probability of capture of longfin eel in rivers and streams within the planning unit – ranges from 0 to 1
Galarg	Ditto for giant kokopu
Galpos	Ditto for shortjaw kokopu
Geoaus	Ditto for lamprey
Parpla	Ditto for koura
Hochstr	Indicates recorded presence (1) or absence (0) of Hochstetters frog within the planning unit
Blue_duck	Average predicted probability of occurrence of blue duck in rivers and streams within the planning unit – ranges from 0 to 1
Rare_spp_score	Integrated score for rare species as described in methods (Section 3.4)
Fish_rich	Average predicted fish species richness for river and stream segments occurring in the planning unit
Invert_rich	Ditto for invertebrates
Env_Z	Average rankings from the Env-Z analysis for rivers and streams within the planning unit – values range from 0 to 1 with high values indicating high rankings
Env_ZC	Ditto for the Env-ZC analysis
Env-ZPC	Ditto for the Env-ZPC analysis
Env-ZPC-Cons	Ditto for the Env-ZPC-Cons analysis
Fish_ZC	Ditto for the Fish-ZC analysis
Fish_ZC	Ditto for the Fish-ZC analysis
Fish-ZPC	Ditto for the Fish-ZPC analysis
Fish-ZPC-Cons	Ditto for the Fish-ZPC-Cons analysis
Z-ntl-pc	Average rankings from the national Env-ZPC analysis for rivers and streams within the planning unit.