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Integrated biodiversity ranking and prioritisation for the Waikato region

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Project Goals

This document describes an updated set of rankings for natural ecosystems of the Waikato Region. While these are broadly similar to an earlier, interim set of regional rankings of terrestrial indigenous ecosystems (Hill et al. 2015) they differ in several important respects. In particular, the input data have been expanded to include consideration of lakes and rivers, while also using an updated description of terrestrial ecosystems. In addition, to reflect this broader biological scope, significant changes have been made in the ranking process to allow for ecological connectivity both across the landscape for terrestrial ecosystems and lakes, and longitudinally along river and stream networks.

These updated rankings are intended to provide a high-level view of indigenous biodiversity priorities within the Waikato Region, with an emphasis on identifying sites at a broad scale that will meet Council goals of protecting a representative range of indigenous ecosystems, both terrestrial and aquatic. The rankings will support decision making by Council staff around the allocation of funding for biodiversity management, and in particular the maintenance of a full range of indigenous dominated ecosystems in good condition. This work is aligned to a broader Regional Council objective of providing “preliminary decision support to catchment managers on priority locations within management zones for implementation of soil conservation, water quality and biodiversity initiatives”.

Analysis scope and approach

The analysis described here has been expanded to consider all indigenous-dominated terrestrial ecosystems, along with lakes, rivers and streams. Terrestrial ecosystems have been identified across a total area of just under 700,000 ha across the Waikato Region, with 71 different ecosystem types distinguished, based on differences in species composition and structure (Singers & Rogers 2014). Information from geological mapping has also been included to describe the distribution of limestone given that it has an important influence on biodiversity. Coverage of terrestrial ecosystems extends across both private land and public conservation land. A total of 274 lakes have been included in the analysis, grouped into seven lake types based on their origins (after Lowe & Green 1987), and totalling 74,069 ha in extent. River network data describing over 50,000 separate river segments and totalling nearly 40,000 km in length have been used to describe the distributions of river and stream ecosystems, described using a biologically-tuned environmental classification designed to capture variation in biodiversity character (Leathwick et al. 2011).

Ranking analyses were performed using the spatial conservation prioritisation software, Zonation (Moilanen et al. 2005) , which calculates a continuous ranking of priority for all locations across a landscape of interest. Information used for ranking by Zonation consists of gridded data layers, with one layer describing the spatial distribution of each biodiversity feature of interest, in this case ecosystem types. Additional layers can be used to describe the condition of biodiversity features, the difference that management would make and its cost, or to define planning units. During ranking, grid cells are removed in a backwards stepwise process where the grid cell(s) making the lowest contribution to the representation of biodiversity features are removed at each step.

Analysis outputs include gridded maps showing the biodiversity priority or ranking of all sites, and tabular data describing the protection provided to each biodiversity feature as a function of site priority. Priorities in this report are expressed on a 0–1 scale with the top 10% of sites having values in the range 0–0.1, the next highest 10% of sites having values in the range 0.1–0.2, and so on. In broad terms, this means that if the management goal is to protect or manage the top 30% of sites, management should be applied to all sites with scores of 0.3 and below. However, if the available budget allows actions to be applied only to the top 10% of priorities, sites with scores in the range from 0–0.1 would be selected for management.

The ranking process

Distribution data for terrestrial, lake and river ecosystems

Terrestrial ecosystem data used in calculating the rankings were created by combining updated mapping of the potential distribution of ecosystems, with information contained in the Council's Biovegetation layer (Waikato Regional Council 2014). This was achieved by intersecting an updated digital map of the Council's Potential Ecosystems layer for the entire Region (Singers, unpublished) with a digital map of indigenous-dominated ecosystems as mapped in the Council's Bioveg 2012 layer (a map of contemporary vegetation cover based on version two of the Land Cover Database, LCDB2). This analysis created new polygons identifying all unique combinations of potential ecosystem cover (Potential Ecosystems version 2 layer) and current vegetation cover (Bioveg 2012 layer). New data fields were added to this intersected layer, one for each of the potential ecosystem classes, and one for each of the LCDB2 secondary vegetation and general wetland classes (refer Appendix I). Values were then assigned to these fields for each unique combination of potential ecosystem and current land cover as follows:

1. Where the Bioveg classification for a polygon indicated that it contained 'indigenous forest', 'subalpine shrubland' or 'tall tussock grassland', the field matching the potential ecosystem mapped in that polygon was given a value of 100; values for all other fields remained zero. Where a polygon had been mapped as a mixture of two potential ecosystem classes, values of 50 were allocated to the two relevant fields;
2. Where the Bioveg classification for a polygon indicated that it contained secondary vegetation ('manuka-kanuka', 'broadleaved indigenous hardwoods', or 'fernland'), the

corresponding Bioveg field was given a value of 95 and the relevant potential ecosystem field was given a value of 5. Use of two values in this way allowed secondary vegetation units to be differentiated in the Zonation analysis according to the potential vegetation cover that is likely to develop in each polygon in the absence of further disturbance;

3. Where the Bioveg classification for a polygon indicated that it contained a general wetland type ('herbaceous freshwater vegetation', 'herbaceous saline vegetation'), the corresponding Bioveg field was given a value of 100. In many cases, insufficient information was available to identify the corresponding wetland type as described in the potential ecosystems classification. This is because the Bioveg mapping contains many small polygons derived from satellite imagery that were below the minimum size threshold discriminated in the potential vegetation mapping;
4. Where the Bioveg classification for a polygon indicated that it contained "deciduous hardwoods", and the potential ecosystem class indicated that the historic cover was a wetland, the bioveg "deciduous hardwoods" field was allocated a value of 80 and the wetland field from the potential ecosystems layer was allocated a value of 20.
5. Where the Bioveg classification for a polygon indicated that it contained mangroves, the potential ecosystem field for mangroves (SA1) was allocated a value of 100.

The final combined terrestrial layer was then checked for consistency, particularly where the 'broadleaved indigenous hardwoods' class used in the Bioveg layer had been applied at higher elevation, where it appeared to have often been used to map primary forest of low stature. In a number of such cases, polygons mapped as 'broadleaved indigenous hardwoods' were treated as primary forest rather than a secondary ecosystem.

Lake data use in the ranking analyses were imported from the Freshwater Ecosystems of New Zealand database (FENZ – Department of Conservation, 2010), supplemented by data prepared for a subset of Waikato lakes in a previous Regional Council lake ranking study (Wildland Consultants, 2011). Lakes were classified into seven groups based on their geomorphic character (DOC, unpublished), broadly following the classification of Lowe & Green (1987). Lake types included artificial, dune, geothermal, karst, peat, riverine and volcanic. Classifications for a number of smaller lakes were checked against geological and topographic maps, and corrected as necessary. Seven new attribute fields were created in the spatial dataset, one for each of the seven geomorphic classification groups, and were used to indicate group membership for each lake. For example, all lakes in the volcanic lake group were allocated a value of '1' in the 'volcanic' attribute field, but '0's were allocated to the six remaining attributes.

River ecosystem data were imported from the Freshwater Ecosystems of New Zealand database (FENZ – Department of Conservation 2010), which was originally based on spatial data contained in the River Environment Classification network (REC – Snelder & Biggs 2002[1]). However, for this analysis, the data were cross referenced to an updated spatial description of New Zealand's river network (REC2, NIWA undated), using river segment identifiers common to both networks. Level 2 of the FENZ river classification (Leathwick et al. 2011) was used to categorise river ecosystems. This has 100 groups nationally, 33 of which occur within the Waikato Region. A very small number of new river segments, created in the REC2 network but not present in the original REC, were manually classified based on the closest adjacent stream of similar size and occurring on similar terrain, as described by 1:50,000 topographic maps. New data attributes were then created to indicate occurrences of each of the 33 classification groups, river segment by river segment, as described above for lakes.

Once all the ecosystem data had been populated across the three (vector) spatial layers, a script was used to convert them into a set of raster data layers at a spatial resolution of 50 m, with one layer indicating the spatial distribution of each of the 111 ecosystems (71 terrestrial, 7 lake, and 33 river and stream ecosystems).

Development of condition layers

Three separate condition layers were used in the ranking analysis, describing the expected condition of terrestrial, lake and river ecosystems respectively. All three were grid data layers corresponding in coverage to the ecosystem grid data, and with values ranging between 0 (loss of all ecological integrity) through to 1 (retaining full ecological integrity).

While the values of these condition layers may appear somewhat arbitrary, they are consistent with the way that the information is used in the ranking analyses. That is, Zonation primarily uses the condition scores to identify best condition examples of each biodiversity feature. Because the values are primarily used for comparison only among different examples of the same biodiversity feature, it is the *relative scores within individual features* that have influence, rather than their absolute values. Additionally, the scores do not influence the relative weighting or priority given to different biodiversity features, for example, wetlands versus forest ecosystems. This is controlled by biodiversity feature weights which are described below.

Terrestrial condition layer

The terrestrial condition layer was the most complex to construct, and was created by combining information about the effects of vegetation fragmentation, human population pressure, historic logging, and current management activities. Final values were constructed by combining two separate components, the first describing the estimated 'intrinsic condition' of all terrestrial

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[1] See also https://www.mfe.govt.nz/environmental-reporting/about-environmental-reporting/classification-systems/fresh-water.html

polygons in the region, and the second describing the expected difference made through biodiversity management interventions over the last five years.

The **intrinsic condition** layer aimed to capture three main effects on terrestrial ecosystem patches including logging, which primarily affects native forests, and fragmentation and weed invasion, which both affect all types of terrestrial ecosystems. Logging primarily results in loss of key structural elements of forests, particularly emergent podocarps that were generally most valued for their timber. The effects of fragmentation are more diverse (Young & Mitchell 1994, Burns et al. 2011), and include loss of microclimate, increased access for predators and domestic stock, increased vulnerability to invasion by introduced weeds, and greater susceptibility to the effects of adjacent land uses including impacts such as hydrological alteration and drift of fertiliser and/or sprays. The threat of weed invasion is also strongly influenced by human populations, with weed invasion pressure on surviving indigenous vegetation fragments generally increasing with proximity to human settlements (Timmins & Williams 1991).

The effects of logging were captured in a spatial layer that drew on the broad-scale forest class map (FSMS6) produced by the former New Zealand Forest Service[2], and in which unlogged and logged indigenous forests are broadly differentiated in the map classification. The logging effects layer was further developed using satellite data to identify broad-scale logging carried out since the production of the FSMS6 mapping, although this was limited to larger indigenous forest remnants. Many, if not the majority of smaller, lowland forest remnants have also been partially logged, typically to remove kauri or merchantable podocarps, but insufficient time was available to gather information about the exact distribution of these impacts. Areas of forest known to have been logged were allocated a score of 0.5 and unlogged forests were allocated a score of 1.0.

Fragmentation effects were captured by first creating a polygon layer representing the distribution of all predominantly indigenous terrestrial ecosystem patches across the Region as described by the Council's Bioveg layer. Note that in creating this layer, internal boundaries between adjacent polygons containing different indigenous ecosystem classes were ignored. This layer was then buffered internally to identify the core parts of each indigenous ecosystem patch, that which lay more than 50 m inside the patch boundary. The area of the identified core was then used to estimate the proportion of the ecosystem patch that could be considered to provide core habitat where impacts from edge effects may be more minimal. Values were rescaled into a range from 0.2–1 for subsequent combination with other factors, with low values allocated to patches with very little of no core habitat and high values to patches with high proportions of core habitat.

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[2] Available for download from https://koordinates.com/layer/300-nz-fsms6-north-island/

To capture the effects of human population-driven weed pressure, mesh block spatial data from the latest national population census[3] was used to calculate human population densities across the region, expressed as numbers of residents per hectare for each mesh block unit. The terrestrial ecosystem polygons were overlaid onto this population density layer and the mean population density was calculated for each polygon. These values were rescaled into a range from 0.2–1 for subsequent combination with other factors, with low values allocated to sites with the highest population pressures and high values to those with very low human populations.

The standardised estimates of logging impact, core habitat loss and mean human population density were combined to form an estimate of intrinsic condition; *the condition or ecological integrity expected in the absence of active biodiversity management*. This was calculated as:

Intrinsic condition = Logging impact * Core habitat loss * Population impact * 0.5.

Inclusion of a multiplier of 0.5 in the calculation of intrinsic condition resulted in the final values ranging from 0.02 for very small ecosystem patches (< 1 ha) with no core habitat and located in areas with high human populations, up to 0.47 for extensive ecosystem patches with minimal human population pressure in their surrounds, and no logging if they contained forest ecosystems. Values for extensive areas of logged forest reached a maximum of around 0.37.

Data pertaining to conditional benefits from **recent terrestrial biodiversity management actions** was derived from a number of sources. These included Regional Council data describing priority possum control areas, areas where possum control has been implemented by the Animal Health Board, and community restoration (Halo) sites documented by the Council. Additional information was provided by the Department of Conservation about recent management they have implemented, including in Biodiversity Management Units established to meet the Department's goals related to the maintenance of a full range of ecosystems in a healthy functioning state, and, to ensure the persistence of threatened species.

Areas receiving recent management were represented spatially by polygons, with value estimates made for each polygon regarding the degree of control applied to both browsers and predators. Estimates of pest reduction were expressed on a scale from 0–1, and were intended to indicate the proportional achievement of the maximum level of control that can be realistically delivered over a sustained period using methods currently practiced within New Zealand.

Values of one were allocated to offshore islands where complete eradication of browsers and/or predators has been successful. Values of 0.9 to 0.95 were allocated to mainland sites subject to

[3] Available for download from http://www.stats.govt.nz/Census/2013-census.aspx

sustained and intensive control of browsers and predators. Values of 0.45 were generally used for mainland sites where possums have been reduced to a residual trap catch of less than 5%, but where other ground browsers have not been systematically controlled. Similar values were used where control has been implemented for mustelids but not for other predators.

Estimates of browser and predator control were combined by averaging to form an overall estimate of the degree of difference likely to have been made by management.

Management gain = (browser gain + predator gain)/2.

While consideration was given to the feasibility of including the conditional benefit of weed control, it was more technically challenging. In particular, while most predators and browsers are generally widespread through the entire region, there is marked local variation in the degree of threat posed by weeds. For low-stature ecosystems, for example above the treeline and in dunes and wetlands, there is marked spatial variation in occurrences of weeds such as wilding conifers, marram grass, or willows. As a consequence, accurate estimation of weed management gains and their impacts on overall ecological integrity would have required spatially comprehensive information about the local distributions of significant weed threats. Incorporating weed threats and management was therefore considered out of scope for the present analysis.

The estimates of intrinsic condition and management benefits were combined to create an estimate of **current condition** calculated as:

Current condition = intrinsic condition * (1 + management gain).

For sites where no management action has been implemented, the current condition value defaults to the intrinsic condition value. By contrast, condition estimates for sites where comprehensive management actions have been implemented for both predators and browsers approach a value of one as the management becomes comprehensive across all browser and predator threats. The final condition estimates for all terrestrial polygons were converted into a grid (raster) data layer (Figure 1) with the same extent and spatial resolution as the ecosystem grid layers. Final values for current condition estimates ranged between 0.02 and 0.87 with a mean of 0.42.

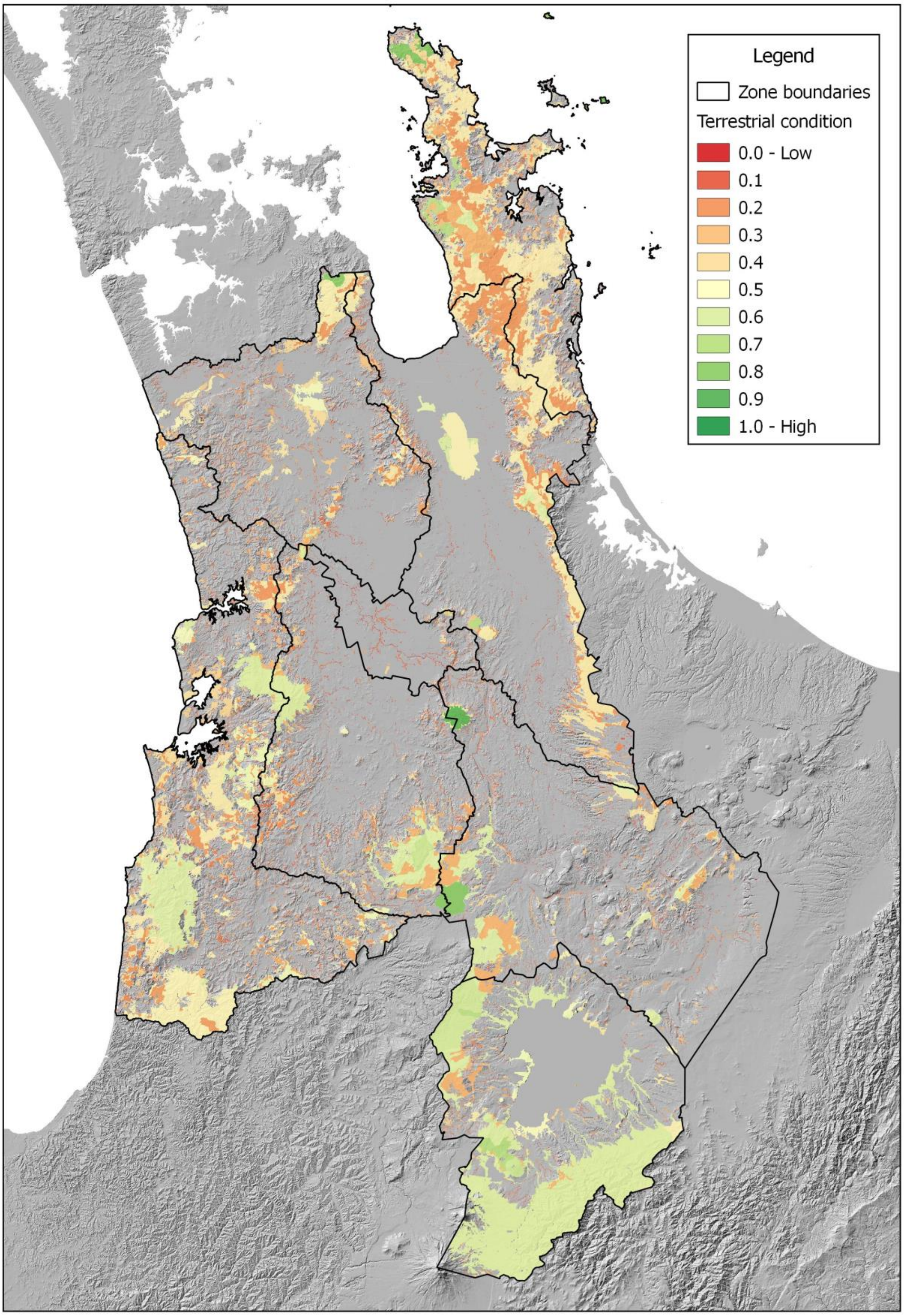

Figure 1. Estimated condition of terrestrial sites, as calculated by combining estimates of intrinsic condition and recent management gain – see text for explanation.

Geographic variation in terrestrial condition is considerable, reflecting both strong geographic variation in the amount of fragmentation of natural vegetation patterns, and the patchiness of management interventions. Offshore islands (the Alderman Islands, smaller islands of the

Mercury Group) have the highest condition scores, reflecting their generally pest-free status and relatively intact indigenous vegetation cover. Maungatautari has been allocated the highest current condition score for a mainland site, reflecting the sustained removal of most vertebrate pest species from this predator-proof fenced sanctuary. High levels of management benefits have also been recognised for the Waipapa Ecological Area and the northern end of the Coromandel Peninsula centred on Moehau. Slightly lower levels of management benefit have been recognised at various sites on the Coromandel Peninsula and immediately southwest of Turangi. Lower levels of management benefit have been recognised across extensive areas where recent aerial control of possums has been carried out, including in the Kaimanawa Mountains, Tongariro National Park, the Hauhungaroa and Rangitoto Ranges, the Herangi Range, and on Pirongia and Karioi.

Aquatic condition layers

Aquatic condition estimates for both lakes and rivers and streams were derived from the FENZ database (DOC 2010). For lakes, we used the FENZ pressure estimate *SumPressureEQ1a*, which combines estimates of natural cover, impervious cover, and land use pressure in the lake catchment, along with estimates of the impacts of dams on both upstream and downstream connectivity. *SumPressureEQ1a* excludes information about the distributions of pest fish and invasive macrophytes due to the lack of such data for many lakes. Values in the final grid pressure layer ranged between 0.07 and 0.99 with a mean of 0.43. High values generally occurred in lakes with extensive natural cover in their immediate catchment while low values were associated with lakes whose catchments contained extensive urbanisation and/or high intensity land uses (Figure 2).

Similarly, pressure estimates for rivers were derived from FENZ, using the *SumMinimum* values. *SumMinimum* combines estimates of catchment-scale impacts due to impervious surfaces, reductions in indigenous vegetative cover, segment-scale nitrogen concentrations, industrial, mine and geothermal discharges, flow alteration by dams, and invasion by introduced fish species. Minor changes to the river condition estimates were made to take account of more recent CLUES-based estimates of segment-scale nitrogen concentrations updated by Regional Council staff to reflect more recent land use patterns. Values in the final grid pressure layer ranged between 0.0 and 0.99 with a mean of 0.31. High values generally occurred in rivers with a high proportion of indigenous vegetation cover in their catchment, while low values were associated with rivers whose catchments support intensive land uses, particularly in which all indigenous vegetation cover has been cleared, where significant point discharges occur, and/or that contain extensive urban areas (Figure 2).

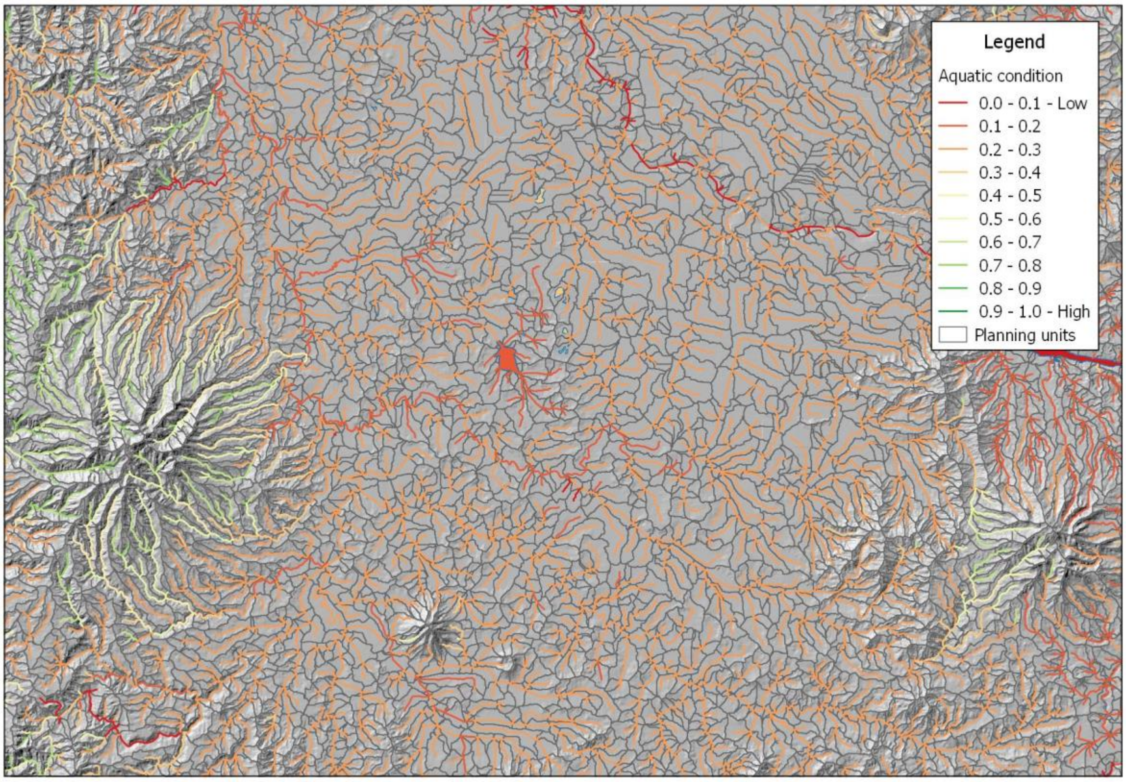

Figure 2. Estimates of condition for aquatic ecosystems including lakes, and, rivers and streams, shown here for the lower Waipa Catchment. Water-shed based planning units are shown as grey polygons.

Calculation of biodiversity rankings

Calculation of biodiversity rankings using the layers described above required a number of technical changes to the ranking process used previously, as described in Hill et al. (2015).

These were:

(i) **the use of sub-catchment-based planning units,** required so that all cells occurring in each river or stream segment (along with any associated terrestrial or lake cells) were removed at the same step in the removal process;

(ii) the use of longitudinal connectivity settings applied to river features so that the contribution of any river segment is adjusted to reflect the removal of upstream or downstream river segments;

(iii) the use of non-directional smoothing routines and an interaction matrix to allow for consideration of connectivity effects among the various terrestrial and lake ecosystems; and

(iv) calculation of rankings at a whole-of-region scale without consideration of the eight within-Region zones used in the previous analysis.

Watershed-based planning units

In initial trial analyses covering the Waipa River catchment, planning units consisting of first-order sub-catchments (the immediate watershed surrounding each individual river segment) functioned very effectively. However, when the analysis scope was extended to include the entire Waikato Region, use of first-order planning units (n=55,000) proved too computationally demanding, and would have resulted in the regional ranking analysis taking a number of weeks to calculate.

To make the analysis more tractable, a reduced set of larger planning units based on 2nd order watersheds was created (n = 27,000). First-order watersheds were combined with the watershed of the downstream second order watershed into which they flowed. This enabled the calculation of rankings for the entire region in approximately 48 hours, while still maintaining a useful level of spatial resolution in the final prioritisation results.

Longitudinal connectivity for rivers

Longitudinal connectivity along the river network was allowed for in the ranking process using the approach described in Moilanen et al. (2008) in which the value of any river segment reflects not only the biodiversity values that occur there, but also the protection that is being given to other river segments both upstream and downstream of the target river segment. In addition to the planning units described above, this required information describing the river-flow linkages between planning units, and a set of rules specifying how ecosystem values in a river segment are reduced as the upstream or downstream river segments with which they are connected are removed from the ranking solution.

Linkages between planning units were specified by creating a unique numeric identifier for each planning unit. Information from the river network spatial layer was then used to create a text file containing pairs of numeric values, each consisting of a planning unit number and the identifier of its immediate downstream neighbour. These values were read into Zonation along with the planning unit spatial data, and the software used this information to create the entire network of planning unit linkages prior to calculating the rankings.

During the analysis setup stage, values were also specified for each river ecosystem determining how the value of any individual river segment should be reduced as upstream or downstream planning units were removed. A common rule was applied to all river ecosystems for the reduction in value as upstream planning units were removed. Specifically, the contribution of a river ecosystem in a particular planning unit retained all of its original value when all of its upstream planning units were still present; however, as upstream planning units were removed the value of the river ecosystem in the target planning unit declined gradually. Values reduced to 75% of the original when one third of the upstream planning units were removed, to 45% of the original when two-thirds of the upstream planning units were removed, and to zero when all of the upstream planning units are removed.

Three levels of penalties were applied for the removal of downstream planning units, depending on the average distance of each ecosystem type from the coast reflecting the potential importance as habitat for migratory native fish species. Coastal river types, (those of greatest importance for migratory fish) received the strongest penalties for loss of their downstream connections, declining gradually to 85% of their original value when a third of their downstream planning units were removed, to 65% when two-thirds of their downstream planning units were removed, and to 33% when all downstream planning units were removed. River ecosystems occurring at more inland locations, but still within the distances penetrated by one or more native migratory fish species, received less severe penalties, declining respectively to 90%, 80% or 67% of their original value, when one third, two-thirds, or all of their downstream planning units were removed respectively. Inland river ecosystems occurring generally at distances from the sea greater than those normally penetrated by migratory fish, were not penalised for the removal of their downstream planning units.

Interactions between ecosystems

The importance for landscape-scale conservation of conserving sequences of related ecosystems in preference to stand-alone examples of individual ecosystems is widely recognised in conservation science (Thompson & Nicholls 1973, Christenson et al. 1996). This allows for natural processes which can occur over widely varying spatial scales, and that frequently cross arbitrarily defined ecosystem boundaries. Related to this is the greater practicality of managing larger, contiguous areas, which is beneficial particularly for actions that are more cost-effective and/or more long-lasting when applied across connected ecosystems in a landscape. For example, when controlling browsers or predators for which reinvasion from uncontrolled surrounding areas affects the time period over which control is effective.

Accounting for such connections is relatively straight forward in Zonation through the use of spatial smoothing routines that extend the influence of each ecosystem patch for some specified distance beyond its boundary. For cells lying close to a boundary between two ecosystems, this allows the software to recognise both the dominant ecosystem at the site and the influence of the adjacent ecosystem. These interactions can be further controlled using a matrix of values between zero and one that defines the strength of interactions between different pairs of ecosystems (refer Lehtomäki et al. 2009). Higher values indicate more important interactions, and zero values indicate that a particular interaction should be ignored. These interactions can also be asymmetric, indicating that while an ecosystem provides a strong beneficial effect on another ecosystem in its neighbourhood, it receives little benefit in return.

The overall effect of these settings is to give higher priority to planning units containing sequences of related ecosystems, compared to those containing either a single ecosystem, or multiple ecosystems occurring in unconnected fragments. In addition, the magnitude of this effect can be varied so that greater priority is given to planning units where connections are likely to play an important ecological role.

Spatial smoothing was defined for the analyses using a kernel smoother that expands the edges of remnants for each ecosystem type by 500 m for all forest ecosystems and 250 m for non-forest ecosystems. These interactions were not applied to river ecosystems, given that the river condition layer already reflects the amount of catchment cover provided by indigenous-dominated ecosystems. A relatively conservative approach was taken when defining interactions between ecosystem types (Table 1). It was assumed that all ecosystems will benefit most strongly from proximity to other ecosystems classified within their broad grouping, for example, forests with forests, and wetlands with wetlands. This is indicated by the values of 1 occurring diagonally from top left to bottom right in Table 1.

Interactions between different ecosystem groups were more complex. First, it is assumed that proximity to a forest ecosystem will generally be beneficial for all other ecosystem groups. These benefits arise, for example, from the physical buffering forests provide, the maintenance of good water quality in lakes and waterways, or the provision of seed sources required for successional development in secondary ecosystems. Non-forest ecosystems, wetlands and saline ecosystems are assumed have a moderate positive interaction with each other, with values varied to reflect their degree of ecological similarity (and expected geographical proximity). For example, coastal dunes are assumed to have a stronger interaction with coastal cliffs than with ecosystems of temperature inversion basins and braided rivers. Similarly, zeros are specified for the interaction between sub-alpine ecosystems and both dunes and saline wetlands. Secondary ecosystems are assumed to provide much weaker benefits for other ecosystems, with the exception of lakes, around which they can provide valuable riparian protection.

Table 1. Interaction settings between ecosystem groups used in Zonation analyses for the Waikato Region. Values indicate the relative magnitude of beneficial interactions between Affecting Ecosystems (columns) and Affected Ecosystems (rows).

		Affecting Ecosystem						
		Sub-alpine	Forest	Non-forest	F/w wetland	Saline	Secondary	Lakes
Affected Ecosystem	**Sub-alpine**	1	0.5	0–0.75	0.25	0	0.25	0.25
	Forest	0.25	1	0.25	0.25	0	0.25	0.25
	Non-forest	0–0.5	0.5	0.25–1.0	0.25–0.5	0–0.5	0.25	0.25–0.5
	F/w wetland	0.5	0.5	0.25–0.5	1	0.75	0.25	0.5
	Saline	0	0.5	0.25–0.5	0.75	1	0.25	0.5
	Secondary	0.5	0.5	0.25–0.5	0.25	0.25	1	0.25
	Lakes	0.5	0.5	0.25–0.5	0.5	0.5	0.5	1

Setting ecosystem weights

An essential step when setting up Zonation analyses is the setting of weights. These are mandatory for all biodiversity features, and indicate their relative importance in contributing to the overall goals of the analysis. Where all biodiversity features are equally important, setting all feature weights to “one” could be appropriate. However, weights are often varied to give greater emphasis to biodiversity features that are considered more ecologically important, for example, endemic species in a ranking analysis that is based on species distribution data. Alternatively, higher weights might be used for threatened species, or for biodiversity features whose geographic ranges have been most reduced through human activity.

Terrestrial ecosystem weights for the analyses of the Waikato Region (refer Appendix I) were varied to reflect the estimated degree of loss in extent by comparing their current and predicted historic extents, as well as their naturalness. Forest ecosystems reduced to less than 30% of their estimated historic extent were given a weight of 3, while those reduced to between 30% and 60% of their estimated former extent were given a weight of 2. Weights of 2 were also allocated to all indigenous dominated wetland ecosystems, while weights of 1 were allocated to all the remaining primary ecosystem classes. Secondary vegetation LCDB2 classes from the Bioveg layer ('manuka and or kanuka', 'broadleaved indigenous hardwoods', and 'fernland') were allocated weights of 0.1, reflecting their generally lower value for biodiversity conservation, while willow dominated wetlands were allocated a weight of 0.05. The limestone substrate layer was allocated a weight of 0.5.

Trials were run to explore how best to achieve an adequate balance between terrestrial and river ecosystems, following which river ecosystems were allocated a weight of two. Similar trials were run for lake groups which resulted in lakes being allocated a weight of 0.5, with the exception of the artificial lake group (reservoirs and dams), which was allocated a weight of zero.

Choice of removal rule

The earlier ranking project carried out for the Waikato Region (Hill et al. 2015), used the 'core area zonation' removal rule (CAZ), which aims to retain core habitat for a full range of biodiversity features throughout the ranking process. The CAZ removal process assesses the value of each cell, focusing on the most valuable biodiversity feature within each cell, resulting in effective protection of a full range of biodiversity features, including those that only occur in species poor areas.

By contrast, the '*additive benefit function*' removal rule (ABF) assesses the value of each cell by calculating the sum of values across all of the species (or ecosystems) that occur there. This process favours areas of high diversity. When used with species data the ABF rule typically provides higher average protection across all species, although species that only occur only in low diversity areas typically receive lower levels of protection.

Following trials of both the CAZ and ABF removal rules for this analysis, it was determined that the ABF removal rule operated more effectively in conjunction with the spatial smoothing routines described above and was therefore retained for all analyses.

Post-ranking processing

While the ranking approach described provided strong consideration of linkages between terrestrial and aquatic ecosystems, it necessitated some additional post-ranking processing before individual biodiversity management targets for terrestrial, river and lake ecosystems could be identified without ambiguity. In particular, because of the difficulty in precisely balancing the average rankings given to each of these three ecosystem groups, the raw rankings didn't accurately indicate the proportion of each group of ecosystems that would be included through adoption of some particular ranking threshold. For example, the top 30% of terrestrial ecosystem remnants (by area) would be identified using a threshold rank of 0.23 from the integrated results, indicating that these ecosystems were favoured in the ranking process over lakes and rivers. By contrast, the top 30% of lakes (by number) would be identified using a threshold rank of 0.25, while the top 30% of rivers (by length) would be identified using a threshold rank of 0.41 from the integrated results .

To overcome this difficulty, separate terrestrial, lake and river priorities layers were extracted from the final integrated ranking layer. These were then each converted into rank order and the ranking values were reassigned across the range from zero to one. These rescaled rankings preserved the order of grid cells from the original integrated ranking, whilst the further standardising enabled consistent interpretation of rankings between the separate terrestrial and river ecosystem ranks. Consequently, the top 30% of sites for either terrestrial or river ecosystems can be selected from the rescaled layers using a priority threshold of 0.3; similarly, both layers can be shown on a map using the same colour-ramp ranges without ambiguity.

By contrast, because lakes comprise a relatively small number of discrete sites their priority in the final ranking outputs is indicated by an integer rank (1–234) that orders the lakes according to scores from the integrated results. Additional data fields have been provided that describe the accumulated extent of lakes along this order, expressed both in hectares and as a percentage of the total area of all lakes.

Results

The rankings of indigenous dominated ecosystems for the Waikato Region from this Zonation analysis provide a more integrated view of biodiversity priorities than in the previous ranking analysis (Hill et al. 2015). Two factors have contributed to this. First, the ranking analysis was performed using data describing terrestrial (n = 71), lake (n = 7) and river ecosystems (n = 35), rather than only terrestrial ecosystems. Second, substantial improvements were made in consideration of ecological connectivity, which was applied both across the landscape for terrestrial and lake ecosystems, and longitudinally along river and stream networks.

Terrestrial priorities

The top 30% of terrestrial sites are contained within a set of 658 priority areas totalling just under 210,000 ha and occurring throughout the Waikato Region (Figure 3). These range in size from 1 to 50,672 ha with a mean of 291.7 ha. Small areas greatly outnumber large areas with 515 sites 100 ha or less in size, while only 25 exceed 1000 ha in extent.

Together these priority areas provide representation of 10% or more of the surviving extent of all 71 candidate terrestrial ecosystem types (refer Appendix I). However, while the representation of individual ecosystem types averages 0.83 (17%), representation of ecosystem types is generally inversely proportional to their extent. Representation averages 0.95 (5%) for those that are less than 1000 ha in extent, 0.88 (12%) for those between 1000 and 5000 ha in extent, 0.59 (41%) for those between 5000 and 20,000 ha in extent, and 0.19 (81%) for those that are 20,000 ha or more in extent. As a consequence, there are marked differences in representation among broad ecosystem groups. Representation exceeds 80% for all non-forest primary ecosystem types, which are mostly of restricted extent (Table 1). However it is lower for more extensive forest groups, declining to a mean of 16% for the most extensive group, forest ecosystems of warm climates. The four secondary ecosystems and willow dominated wetlands are also less represented, reflecting their lower weightings in the ranking analyses. The limestone substrates layer had a locally important influence on priorities, with 60.2% of its total area (830 ha) retained within the top 30% of terrestrial sites.

The twenty-five priority areas exceeding 1000 ha in size occur throughout the Region, including in most of the catchment-based Zones, with the exception of the Central Waikato (Figure 3). A summary of a selection of these large priority areas and their representation of the broad regional biodiversity pattern follows. Many of the distinctive features of the Region remain only in small fragments, and the location of these can be established using a combination of the digital data layers used as input to the ranking process, and the ranking outputs themselves.

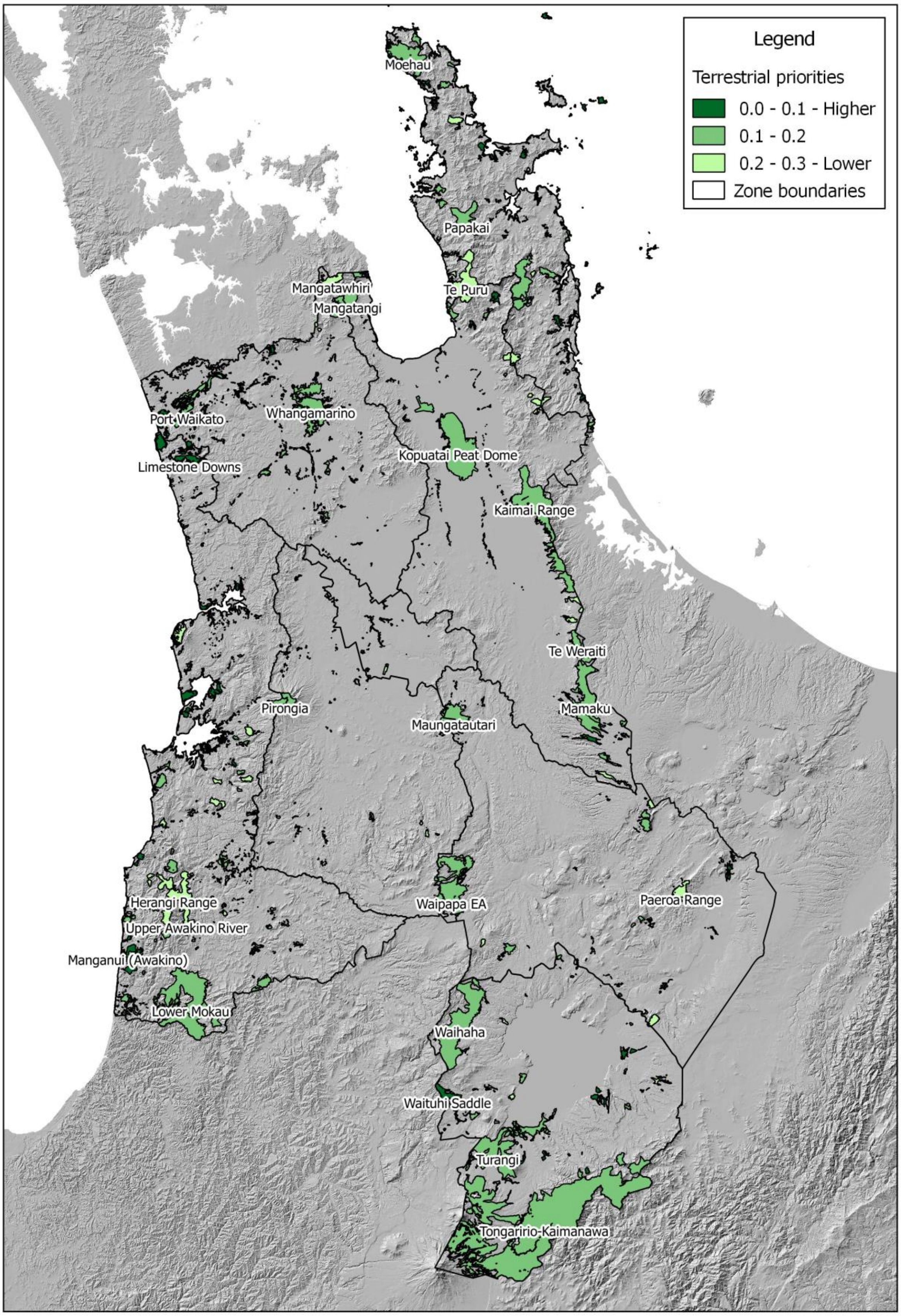

Figure 3. Priority sites comprising 30% of the Waikato Region's surviving native -dominated terrestrial cover.

Table 2. Total extent of broad terrestrial ecosystem groups and their representation in the top 30% of terrestrial priorities. Numbers of ecosystem types in each broad group are shown in brackets. Full results are given in Appendix I.

Ecosystem group (count)	Total extent (ha)	Top 30% (ha)	Representation (%)
High sub-alpine (2)	5,534	5,478	99.0
Low sub-alpine (2)	11,768	10,444	88.8
Cold forest (5)	27,842	19,858	71.3
Cool forest (7)	42,376	20,828	49.1
Mild forest (14)	174,155	57,295	32.9
Warm forest (12)	211,010	34,674	16.4
Cliffs (2)	312	284	91.0
Geothermal (1)	580	519	89.4
Temperature inversion (3)	1,244	1,234	99.2
Braided rivers (2)	120	120	99.9
Dunelands (2)	2,195	2,076	94.5
Freshwater wetland (10)	23,348	19,858	85.1
Saline wetland (5)	1,367	1,284	93.9
Total primary (66)	501,850	173,950	34.7
Willows (1)	19,370	8,818	45.5
Secondary (4)	178,719	27,161	15.2
Overall	699,939	209,930	30.0

The largest priority area in the Region is in the Lake Taupo Zone (Tongariro-Kaimanawa), and covers more than 50,000 ha extending from the Kaimanawa Mountains around the southern boundary of the Region into the Tongariro National Park (Figure 3; Map 1, Appendix II). It includes extensive beech dominant forests, with podocarps prominent at lower elevations; extensive sub-alpine scrub and tussock-grasslands occur both above treeline and at lower elevations in the Tongariro National Park, where volcanism and/or fire have locally removed the former forest cover. Further north in the Lake Taupo Zone a large priority site (Turangi) contains podocarp and beech-dominated forests on the slopes of the volcanic cones, Pihanga and Kakaramea, connecting to the north with extensive wetlands occurring around the southern shores of Lake Taupo, including on the deltas of the Tongariro, Waiotaka and Waimarino Rivers. Two large priority areas occur on the Hauhungaroa Range to the west of Lake Taupo, the first containing a mix of wetlands in lower elevation basins and mixed podocarp-broadleaved hill-slopes forests east of the Waituhi Saddle, and the second containing extensive dense podocarp forests and successional ecosystems in the upper Waihaha River.

Three large priority areas occur in the Upper Waikato Zone (Map 2, Appendix II). Extensive podocarp-dominant forests and wetlands occur in the Waipapa Ecological Area with tawa more abundant than in the Lake Taupo Zone, reflecting the warmer climatic conditions. Extensive tawa-dominant forests predominate in the Maungatautari priority area, extending over a wide elevation range and currently in excellent condition as a consequence of intensive predator and browser control, coupled with the erection of a pest-proof perimeter fence. Similar forests occur in a third priority area to the south-east on the Paeroa Range, but these have been more heavily modified by logging and have received less benefit from recent pest control than those in the Waipapa Ecological Area or Maungatautari.

Six large priority areas occur in the West Coast Zone (Map 3, Appendix II), with the largest of these located in the lower reaches of the Mokau River. This area contains mixed podocarp-tawa-black beech forests growing on steep, dissected hill-country, with strong ecological affinities with the hill-country forests of northern Taranaki. Similar forests, although with hard beech rather than black beech, occur on a coastal site in the Manganui River, just north of Awakino. Two priority areas immediately to the north-east and extending to higher elevations contain tawa-dominant forest sequences with the highest elevation sites on the Herangi Range supporting montane forests dominated by Hall's totara and pahautea emergent through a canopy of kamahi and quintinia. Similar montane forests occur in the priority area centred further north on the upper peaks of Pirongia. The extensive lower elevation tawa-dominant forests on Pirongia are not, however, ranked within the top 30% of sites regionally due to the occurrence of similar forests on Maungatautari which are currently managed to a high level of condition. The final large priority in the West Coast Zone is located at Limestone Downs, just south of Port Waikato (Map 4, Appendix II). This area contains extensive stands of kauri and taraire close to their southern geographic limit on the west coast of New Zealand and some of these occur on limestone substrates.

The Lower Waikato Zone contains three large priority areas (Map 4, Appendix II), two containing extensive wetlands along the lower Waikato River, and the third containing hill-country forests in the north-east of the Zone. The Whangamarino Wetland contains extensive manuka-restiad wetlands, although has suffered extensive invasion by willow in more fertile areas in the west and south. A large area of modified vegetation occurs in the lower reaches of the Waikato River towards Port Waikato, containing mostly willow-dominated wetlands with some kahikatea stands on an extensive set of islands in the river delta. A nearby mosaic of secondary communities and modified podocarp-taraire-tawa forest remnants is located on the southern banks of the river. The third of the large priority areas in the Lower Waikato is centred at the top of the Mangatawhiri catchment in the Hunua Ranges and contains mostly tawa-kohekohe forests, with rimu-towai forests at higher elevation. Currently the area is managed intensively by the Auckland Council to maintain a population of kokako and protect other biodiversity values.

Five large priority areas occur in the Waihou-Piako Zone (Map 5, Appendix II), with four of these forest-dominated and the fifth containing a wetland. Three large priority areas occur along the eastern margin of the Zone, containing altitudinal sequences of mostly tawa-dominant forest extending up onto the dissected western flanks of the Mamaku Plateau in the south, and the more sharply uplifted escarpment of the Kaimai Range along the eastern boundary of the Zone. Montane forests with pink pine and pahautea occur at higher elevation in the south in the Weraiti priority area, and further north on the high point Ngatamahinerua. High-elevation silver beech forests also occur at several points along the range crest, including on mount Te Aroha, while kauri-conifer-broadleaved-beech forests occur on the plateau south-east of Te Aroha. The fourth forest-dominated priority area is located in the north-east of the Zone on the flanks of the Hunua Ranges north of Mangatangi. The site contains extensive areas of kauri-conifer-broadleaved forest with hard beech and is arguably New Zealand's most extensive remaining area of this ecosystem type. By contrast, the Kopuatai peat dome, located in the centre of the Hauraki Plains, is the largest restiad wetland surviving in the Waikato Region, notable for the dominance of *Sporodanthus* species.

The Coromandel Zone contains four priority areas greater than 1000 ha in extent (Map 6, Appendix II). The southernmost of these is located on the coast just north of Thames extending from behind Te Puru north to Tapu. It contains a mix of coastal pohutukawa forest, kauri-conifer-broadleaved forest and rimu-towai forest. Much of the area is heavily modified resulting in a complex mosaic of secondary manuka and/or kanuka, modified broadleaved forest, and smaller enclaves of less modified forest. The Kapowai-Hikuai priority area is located on the east of the Coromandel Range inland from Tairua. The area contains some of the least modified kauri stands remaining on the Peninsula, particularly in the Kapowai Ecological Area, where the steep bluffs precluded logging. Despite this, the vegetative cover on many of the broad ridge crests has been widely modified by burning and now supports extensive stands of manuka and/or kanuka.

Further north on the Coromandel Peninsula the large Papakai priority area contains a mix of modified forests typical of those that were once widespread in this Zone. Kauri dominant forests are the most widespread with tawa dominant at higher elevations and rimu-towai forest on the range crest. The fourth large priority area in the Coromandel Zone is centred on Moehau in the far north. The site spans a wide elevation range and includes coastal pohutukawa forest, and kauri growing with a range of other species including tawa and northern rata at lower elevations and towai at high elevations. There has been widespread modification of these forests both for timber and in attempted clearance for agriculture, resulting in extensive areas of either manuka and/or kanuka or of low-stature broadleaved regeneration. The area has an extended history of control of predators and browsers.

Lake priorities

Seventy out of a total of 234 lakes have priorities within the top 30% of lakes (by number) from the final ranking (Figure 4; Table 3). However, as with the terrestrial ecosystems, there is a negative relationship between lake size and lake priority, with higher priority lakes having a lower average size (55 ha) than the average size for all lakes (316 ha). This reflects the manner in which the prioritisation algorithm allocates higher priorities to smaller lakes to maintain its ability to represent a full range of lake types when only a small proportion of them can be managed.

The strongly skewed distribution of lake size also has a strong influence on ranking outcomes. In particular, Lake Taupo contributes nearly 83% of the total extent of all lakes in the Region; by contrast, 85% of lakes are less than 20ha in size. As a consequence of the strongly skewed size-class distribution and the preferential ranking smaller lakes, the top ranked 30% of lakes totalled 1261 ha in area, only 1.7% of the areal extent of all lakes. Raising the integrated threshold rank from 0.3 to 0.5 increases the overall representation of lakes by number to 56%, but these still only comprise 8.7% of all lakes by area. Alternatively, using an integrated threshold rank of 0.8 increases the numerical representation of lakes to 83%, but the areal representation would still only be 11.6%. Finally, a further increase in the integrated ranking threshold to 0.9 raises the numeric representation of lakes to 87% and their areal representation to 95%, reflecting the inclusion of Lake Taupo.

The tendency for smaller lakes to have higher priority in turn influences the spread of prioritised lakes among the different lake types (Table 3). This is most apparent for the riverine lakes, which have both the largest average size (3437 ha) and lowest proportion of lakes prioritised (16.4%). Volcanic lakes, which have the next largest average size (2870 ha), have 45% representation, and the even smaller peat lakes (average size = 91.8 ha) achieve 79% representation. By contrast, the very low representation for artificial lakes does not reflect their size but rather the zero weighting allocated to them in the ranking analyses.

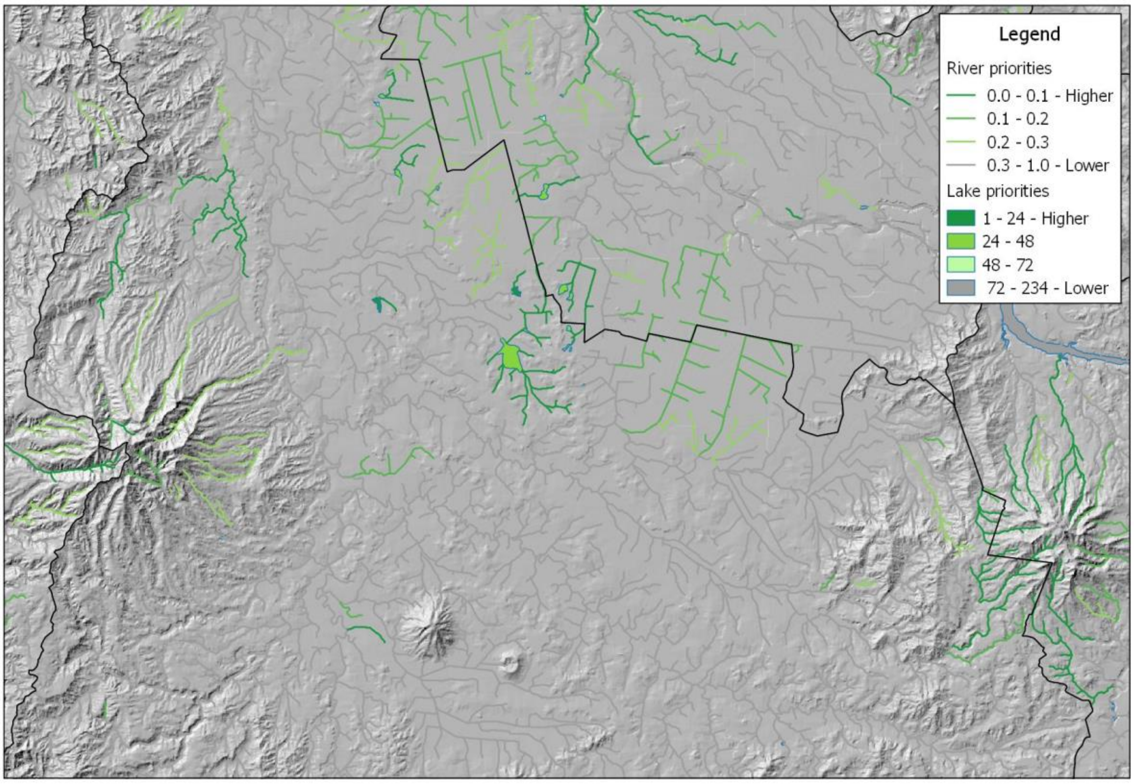

Figure 4. Typical lake and river priorities for part of the lower Waipa catchment, along with their terrestrial counterparts. Relative priority is shown by colour intensity for both lakes and rivers; river segments or lakes falling outside the top 30% are coloured grey, but rankings for these sites would allow priorities to be expanded if required.

Table 3. Lake ecosystem groups, and their representation in the top 30% of lake priorities. Values indicate numbers of lakes in each ecosystem group, mean size and condition, and representation within the top 30% of lakes (by number) as identified from an integrated regional ranking.

Lake ecosystem	No.	Mean size (ha)	Mean condition	Mean priority	Number prioritized	Percentage prioritized	Mean size (prioritized)
Artificial	47	938.8	0.29	0.767	2	4.3	12.4
Dune	13	216.5	0.85	0.113	10	76.9	30.2
Geothermal	1	7.0	0.70	0.001	1	100.0	7.0
Karst	2	6.0	0.33	0.016	2	100.0	6.0
Peat	33	91.8	0.28	0.145	26	78.8	15.2
Riverine	116	3437.4	0.30	0.496	19	16.4	25.0
Volcanic	22	2870.4	0.56	0.377	10	45.5	5.0
Total/Average	234	316.5	0.33	0.462	70	29.9	18.0

River priorities

A total of 11,806 km of river length are contained within the top 30% of river segments in the Waikato Region, on average providing 84% representation across all river ecosystems (Table 4; refer to previous Figure 4 for an example as well as maps in Appendix II). As with the terrestrial and lake ecosystems, however, commonly occurring river ecosystems generally have lower representation than river ecosystems that are less common. For example, river ecosystems with total lengths less than 500km achieve average levels of representation of 99%, those with total lengths between 500 and 1000km have average representation of 64%, and those with total lengths exceeding 1000 km achieve average levels of representation of 21%. The most extensively occurring river type, a lowland hill country stream ecosystem (C9), has 17% of its total length represented within the top 30% of rivers.

Table 4. River ecosystems, and their representation in the top 30% of river priorities. Values indicate for each ecosystem group the total count of river and stream segments, their length and their mean condition, and representation within the top 30% of rivers and streams as identified from an integrated regional ranking.

River ecosystem	Total Length (km)	Total Count	Condition	Prioritised Length (km)	Prioritised Count	Representation (%)
A1	8,293.6	10555	0.251	1771.4	2329	21.4
A2	869.9	1224	0.239	763.3	1049	87.8
A3	7.4	10	0.299	7.4	10	100.0
A4	1,122.5	1622	0.289	688.6	926	61.3
B1	863.7	966	0.259	852.5	937	98.7
C1	269.5	438	0.620	247.3	390	91.8
C2	106.8	139	0.243	104.0	135	97.4
C3	1.8	3	0.721	1.8	3	100.0
C4	1,206.4	1753	0.376	651.0	936	54.0
C5	4,389.6	6589	0.521	1146.8	1682	26.1
C6	4,388.3	5952	0.283	893.5	1177	20.4
C7	910.3	1493	0.587	606.4	997	66.6
C8	3,265.5	4516	0.316	871.2	1084	26.7
C9	12,471.0	14836	0.226	2112.2	2323	16.9
C10	108.8	191	0.693	108.8	191	100.0
C11	2.8	5	0.551	2.8	5	100.0
C12	26.8	43	0.531	26.8	43	100.0
G1	8.0	17	0.477	8.0	17	100.0
G2	571.0	679	0.434	533.1	644	93.4
G7	1.3	1	0.337	1.3	1	100.0
H1	141.3	152	0.540	141.3	152	100.0
H3	21.4	38	0.479	21.4	38	100.0
H5	11.6	21	0.469	11.6	21	100.0
H6	79.8	126	0.638	79.8	126	100.0
J1	1.7	2	0.470	1.7	2	100.0
N1	26.9	26	0.506	26.9	26	100.0
N2	73.2	68	0.502	73.2	68	100.0
N3	7.3	9	0.433	7.3	9	100.0
N4	1.8	1	0.425	1.8	1	100.0
N5	2.1	4	0.484	2.1	4	100.0
P1	8.1	5	0.601	8.1	5	100.0
Q1	12.3	9	0.900	12.3	9	100.0
Q2	14.9	10	0.761	14.9	10	100.0
S1	4.7	4	0.989	4.7	4	100.0
Total/average	39,297.2	51,516	0.313	11,805.7	15,357	84.2

Discussion

Interpretation of the rankings

Having a clear understanding of the meanings of the rankings is important for their robust use. As calculated within Zonation, the rankings identify those sites at which an appropriate set of management actions (for example protection, predator control, pest fish control, riparian planting) could be implemented to maintain a full range of biodiversity features in good condition, assuming that a decision has been made to protect or manage some specified proportion of the landscape. As presented in this report, the site rank-values from the Zonation analysis show the proportion of the Region that would need to be managed for that site to be included. That is, a value of 0.1 indicates that a site would be included if management were to be applied to 10% of the Region while a site with a score of 0.2 would only be included when 20% of the Region is to be managed.

Difficulties can arise with the interpretation of these results when users attempt to assess the relative value of different sites *within* some set of sites that have been chosen by identifying some threshold rank above which management will be applied. For example, for a landscape in which management is to be applied across the top 30% of sites, is a site with a score of 0.1 'more valuable' than a site with a score of 0.2? The answer is sometimes yes and sometimes no.

When a biodiversity feature is rare, occurring in only one or a few places, Zonation will allocate high scores to those sites to ensure that they are represented, even when only a very small proportion of a landscape is to be managed. In this case, their high scores can be seen as reflecting their irreplaceability, which makes them of high value.

By contrast, when a biodiversity feature is widespread, interpretation of the relative value of the sites at which it occurs is more complicated. This is because Zonation attempts to maximise the representation of a full range of features throughout a full range of implementation choices, including when only a very small proportion of the landscape is to be managed. As a result, it allocates high ranks to at least some small sites containing widespread features to ensure that these features are represented under a scenario when only minimal management is to be applied, for example, < 5% of a landscape. Conversely, more extensive examples of these widespread ecosystems, which can be expected to deliver a higher contribution to biodiversity protection when more of the landscape is to be managed, may have lower ranks. In this case, the lower rank accorded to extensive sites does not reflect a lower conservation value, but simply that Zonation has ranked smaller examples of these widespread ecosystems more highly to ensure their inclusion in the event that only a small part of the landscape is to be managed.

Overall, once a decision has been made to protect a certain proportion of a landscape, say 30%, care should be exercised when using relative rankings to allocate resources across the sites to be managed. Sites containing highly distinctive biodiversity features will tend to have higher ranks regardless, while for widespread features, the lower ranked but more extensive sites may be more important in a functional sense. Management of the full set of sites required to achieve optimal biodiversity gain over the total managed area should be the overarching goal, as this will ensure maximum biodiversity gains for the chosen level of management action.

Finally, users of the rankings must be aware that should they decide to manage a different proportion of the landscape, for example the top 20% of sites as opposed to the top 30% as described above, then these must be identified from the underlying gridded priority layer, rather than selecting a subset of the top 30% polygons. Choosing from the 30% polygon set those with average ranking scores less than 0.2 can result in highly misleading outcomes, reflecting the strong local variation in rank that can occur within the individual polygons. For example, the Paeroa Range polygon described in the Upper Waikato Zone (Map 2, Appendix II), has an average rank of 0.212, but contains both widespread forest ecosystems with ranking scores of around 0.23, and a smaller area of geothermal ecosystems at Te Kopia with ranking scores of 0.04. If a decision to manage the top 20% of sites regionally was to be implemented by selecting from the top 30% polygons those with mean scores less than 0.2, these very highly ranked geothermal sites would be omitted. However, they would be correctly identified if the underlying continuous ranking layer was used to identify all grid cells with ranks less than 0.2. The grid cells can then be delineated by polygons if desired, as has been done for the top 30% polygons described above.

Scale limitations

The purpose of this analysis was to identify broad-scale biodiversity management priorities within a Regional context, identifying sites that provide representation of a full range of ecosystems, and comprising around 30% of the Region's terrestrial, lakes and rivers ecosystems. Given the limited time within which this work was completed, it relied predominantly on existing, broad-scale descriptions of both current and potential ecosystems patterns, much of which was derived from remote sensed imagery, expert interpretation of broad landscape patterns, or statistical analysis.

While this broad scale data is adequate for establishing regional-scale patterns of protection that maximise biodiversity representation, care will need to be exercised when interpreting the priority values assigned to individual terrestrial ecosystem remnants, lakes or river segments, particularly those that are of limited extent. The use of these results to indicate relative conservation priority within local contexts should be treated with caution and field-checking of sites to verify the local accuracy of the input data is strongly recommended before rankings are used to guide management decisions.

Future improvements

While the current rankings provide a robust initial prioritisation of indigenous ecosystems for the Waikato Region, several aspects of the analysis could be strengthened or improved.

First, ranking outcomes are strongly influenced by the current classification status of indigenous vegetation cover as described by the LCDB2 categories used in the Council's Bioveg 2012 layer. In particular, it would be worth investing time in systematically checking of the consistency with which the LCDB secondary vegetation classes, particularly 'manuka and/or kanuka' and 'broadleaved indigenous hardwoods', have been applied within the region. If any such inconsistencies were corrected, it would be relatively straight forward to recalculate rankings using the same settings as currently used, but with updated ecosystem distribution layers.

Second, the spatial distribution of high ranked sites is moderately influenced by the estimates of gains in ecological condition made by recent management, as recorded in the condition layer. Collecting reliable and comprehensive descriptions of such management is time-consuming given the number of groups and agencies carrying out this work. Investing further time in collating accurate management data would provide greater confidence that all significant endeavours have been captured.

On the other hand, it could be argued that incorporation of management information into the ranking process runs the risk that existing biodiversity projects will be given high priority, not so much because of the values that they protect, but because of the difference that has already made been made at these sites. While not all current projects might be optimally located, there are several reasons why relocating them should be treated with extreme caution. First, recognition needs to be given to the high cost of relocating major projects. This includes not only the costs of relocating project infrastructure, but also the gradual loss of biodiversity values at sites where management is ceased, as well as the likely delay in delivery of equivalent values at sites where new management is initiated. Second, at least some of these existing managed sites were selected based in part on information describing the distributions of threatened species. Although this information has not been included in this analysis it would provide a more complete picture of biodiversity priorities. Third, careful comparison of the *overall* biodiversity benefits delivered from management of the top 30% of sites identified from analyses with and without management gains reveals that they are almost identical. This reflects the degree to which several of the sites currently receiving intensive management contain widespread ecosystems for which a range of spatial choices is possible, all giving broadly similar outcomes. Therefore, relocating at least some of these projects to new locations identified from an analysis omitting management gains is unlikely to give major net benefits for the ecosystems that they contain. Gains are more likely where new sites contain examples of ecosystems that are not present in other intensively managed sites.

Finally, consideration should be given to how best to handle issues of scale and context, that is, how would these regional-scale priorities compare with priorities calculated using equivalent data layers analysed across the entire North Island? In particular, it is likely that some of the high priority sites identified at a regional scale in this analysis would be been given lower scores, had data describing the distribution of relevant ecosystems in adjacent regions been included. This is likely for ecosystems that have a restricted extent within the Waikato Region, but are widespread in adjacent regions. For example, the mixed broadleaved-beech ecosystems (MF21, MF22 of Singers and Rogers 2014) that occur locally in the southwest of the Waikato Region are widespread in the Taranaki Region. This suggests value in Regional Councils working together in the identification of biodiversity priorities, allowing rankings to take account not only of the broader distributions of ecosystem types, but also of work that is being undertaken to protect them in adjacent regions.

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Appendix I – Terrestrial ecosystems

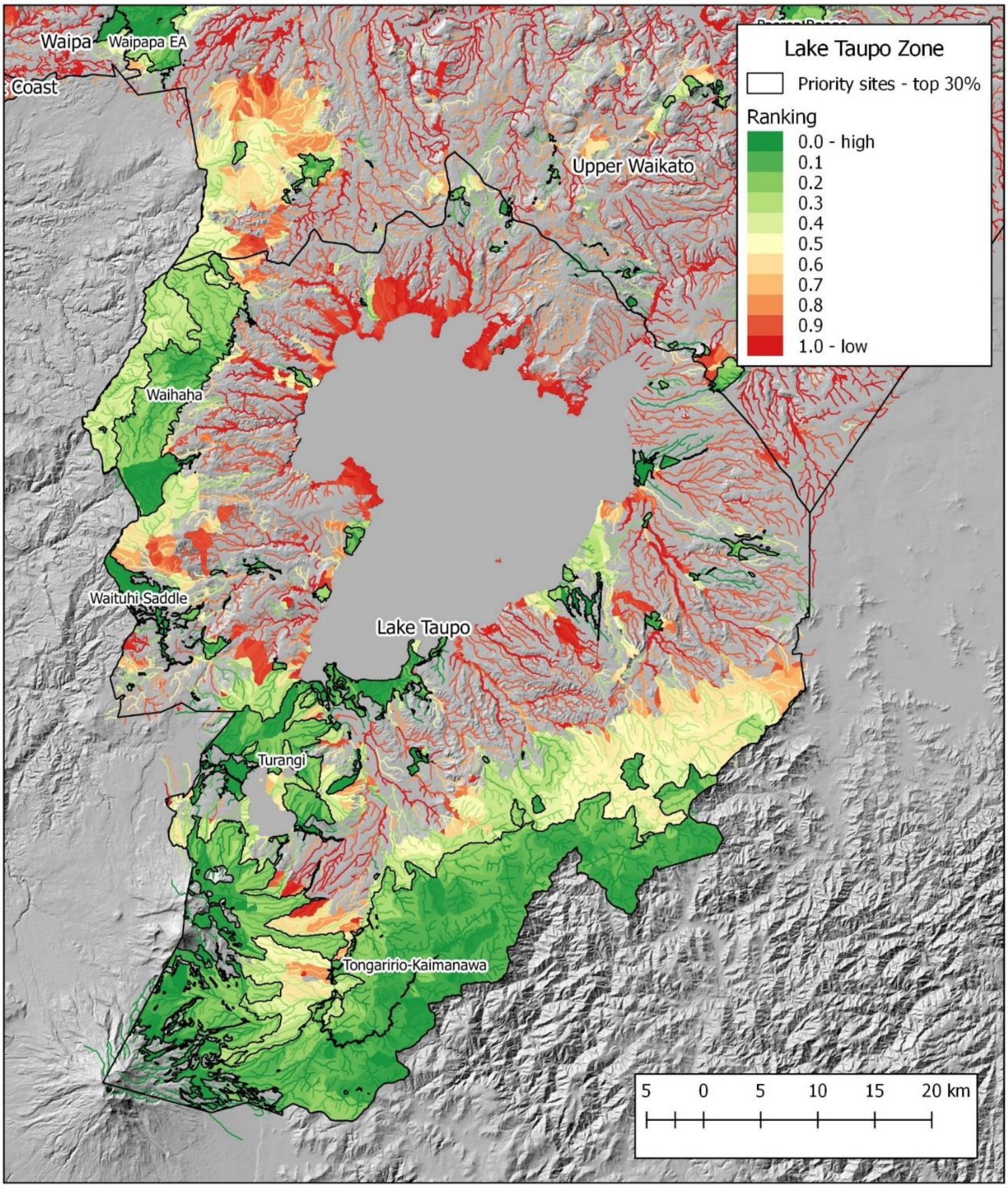
Table entries identify for each ecosystem type its weight, name, total extent, and representation in the top 30% of terrestrial sites, expressed both by extent and proportion.

Ecosystem	Wt.	Name	Total extent (ha)	In top 30% (ha)	Prop.
AH1	1.0	Gravelfield/stonefield	1,164.0	1,161.8	0.998
AH4	1.0	Woolly moss,bristle tussock, blue tussock mossfield/ tussockland/ stonefield	4,370.0	4,316.0	0.988
AL3	1.0	Red tussock tussockland/shrubland	2,599.5	2,439.8	0.939
AL4	1.0	Mid-ribbed and broad-leaved snow tussock tussockland/shrubland	9,168.1	8,004.4	0.873
CDF3	1.0	Mountain beech forest	10,227.0	9,297.3	0.909
CDF4-1	1.0	Hall’s totara, pahautea, kamahi forest	11,130.3	4,563.8	0.410
CDF4-4	1.0	Pink pine, pahautea forest	1,800.7	1,692.2	0.940
CDF6	1.0	Olearia, Pseudopanax, Dracophyllum scrub	4,527.8	4,148.5	0.916
CDF7	1.0	Mountain beech, silver beech, montane podocarp forest	156.1	156.1	1.000
CLF5	3.0	Matai, Hall’s totara, kamahi forest	480.9	428.6	0.891
CLF9	1.0	Red beech, podocarp forest	10,263.9	5,034.8	0.491
CLF9-3	1.0	Red beech, mountain beech	3,007.8	2,945.8	0.979
CLF10	1.0	Red beech, silver beech forest	23,444.1	7,476.1	0.319
CLF11	1.0	Silver beech forest	2,743.7	2,519.1	0.918
CLF11-3	1.0	Silver beech, kamahi forest	24.1	24.1	1.000
CLF12	1.0	Silver beech, mountain beech	2,411.4	2,399.0	0.995
MF4	3.0	Kahikatea forest	48.7	45.9	0.942
MF5	1.0	Black beech forest	226.4	152.6	0.674
MF7-1	3.0	Tawa mangeao forest	14,785.8	9,649.3	0.653
MF7-2	2.0	Rata, Tawa, kamahi, podocarp forest	60,710.8	12,514.9	0.206
MF7-3	3.0	Tawa, pukatea, podocarp forest	38,239.0	9,298.8	0.243
MF8-1	1.0	Kamahi, broadleaved, podocarp forest	32,836.4	8,175.9	0.249
MF10	2.0	Totara, matai, kahikatea forest	3,371.3	1,778.5	0.528
MF11	1.0	Rimu forest	69.3	69.3	1.000
MF11-3	2.0	Rimu, matai forest	9,297.1	6,719.5	0.723
MF20	1.0	Hard beech forest	152.7	152.4	0.998
MF21	1.0	Tawa, kamahi, rimu, northern rata, black beech forest	4,331.0	4,141.5	0.956
MF22	1.0	Tawa, rimu, northern rata, beech forest	428.7	405.1	0.945
MF24	1.0	Rimu, towai forest	8,094.9	2,741.6	0.339
MF25	1.0	Kauri, towai, rata, montane podocarp forest	1,562.6	1,449.7	0.928
WF2	3.0	Totara, matai, ribbonwood forest	351.8	296.0	0.841
WF4	2.0	Pohutukawa, puriri, broadleaved forest	2,339.1	1,816.2	0.776
WF5	2.0	Totara, kanuka, broadleaved forest [Dune forest]	52.9	50.3	0.952
WF7-2	3.0	Puriri, taraire forest	530.5	514.7	0.970
WF7-3	3.0	Kahikatea, puriri forest	193.4	160.0	0.828
WF8	3.0	Kahikatea, pukatea forest	2,066.5	1,430.6	0.692
WF9	3.0	Taraire, tawa podocarp forest	2,612.8	2,244.4	0.859

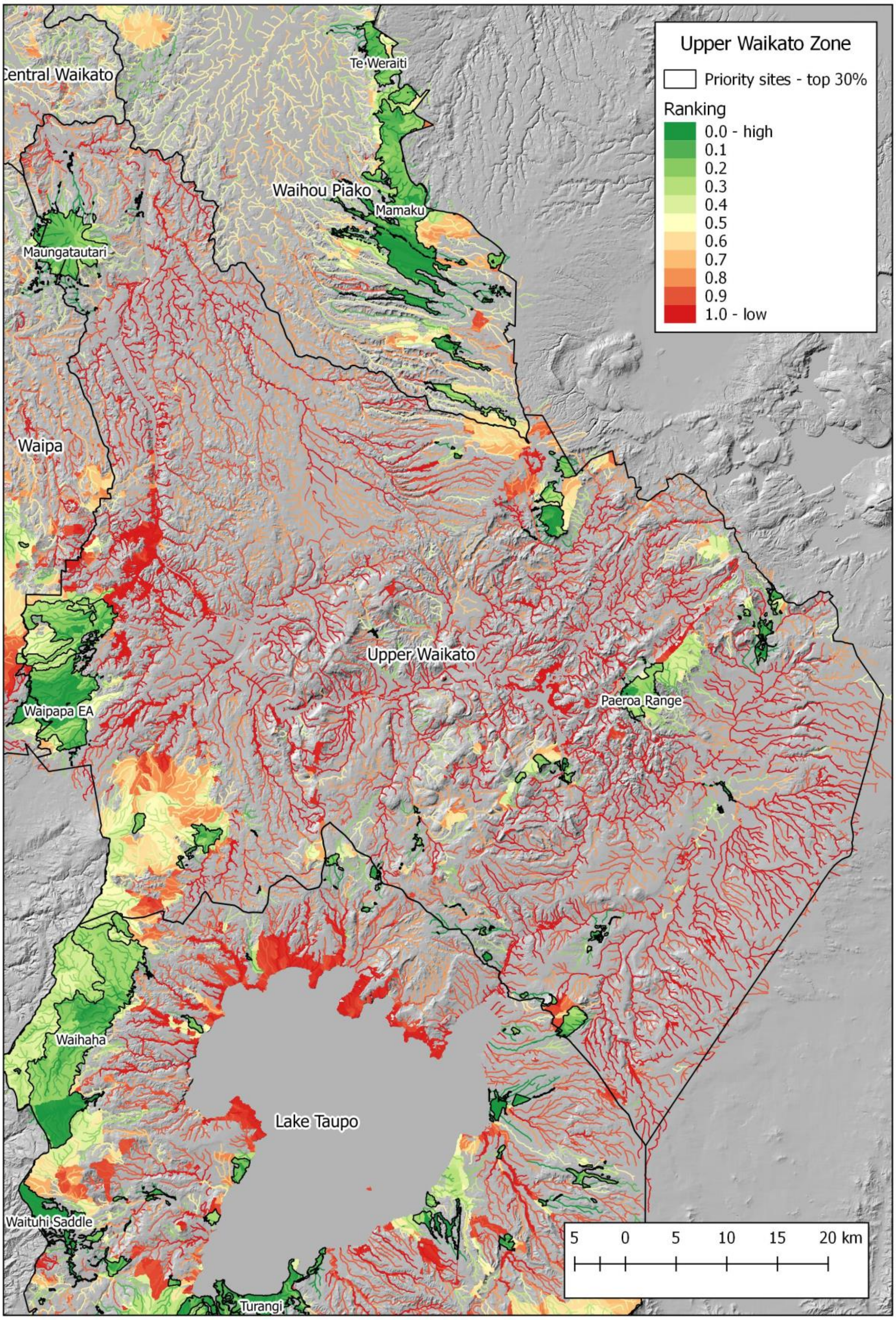
Ecosystem	Wt.	Name	Total extent (ha)	In top 30% (ha)	Prop.
WF11-1	2.0	Kauri, podocarp, taraire forest	538.8	505.1	0.938
WF11-2	1.0	Kauri, podocarp, tawa forest	78,303.7	10,006.9	0.128
WF12	2.0	Kauri, podocarp, broadleaved beech forest	10,328.5	4,234.0	0.410
WF13	2.0	Tawa, kohekohe, rewarewa, hinau, podocarp forest	112,768.1	12,560.8	0.111
WF14	2.0	Kamahi, tawa, podocarp, hard beech forest	923.8	854.9	0.925
CL1	1.0	Pohutukawa treeland/flaxland/rockland	304.0	275.9	0.908
CL2	1.0	Ngaio, taupata treeland/herbfield/rockland	8.0	7.9	0.989
Geothermal	1.0	Geothermal	580.5	519.0	0.894
TI3	1.0	Monoao scrub/lichenfield	573.9	565.5	0.985
TI5	1.0	Bog pine, mountain celery pine, silver pine scrub/forest	529.7	528.2	0.997
TI6	1.0	Red tussock tussockland	140.3	140.3	1.000
BR1	1.0	Hard tussock, scabweed gravelfield/stonefield	59.3	59.1	0.998
BR3	1.0	Bristle tussock, Raoulia, Muehlenbeckia gravelfield/sandfield	61.0	61.0	1.000
DN2	1.0	Spinifex, pingao grassland/sedgeland	1,320.3	1,251.8	0.948
DN5	1.0	Oioi, knobby clubrush sedgeland	875.0	823.8	0.942
SA1-2	2.0	Mangrove forest and scrub	434.8	427.0	0.982
SA1-3	2.0	Searush, oioi, rushland [Saltmarsh]	488.8	439.2	0.899
SA1-5	2.0	Shellfield (Chenier Plain)	2.0	2.0	1.000
SA1-6	2.0	Saltmarsh, ribbonwood, ngaio, akeake scrub	13.3	13.3	1.000
WetlandSaline	2.0	LCDB2 class	427.8	402.2	0.940
WetlandBog	2.0	Bog	0.0	0.0	1.000
WetlandFen	2.0	Fen	2,458.8	2,178.8	0.886
WetlandSwamp	2.0	Swamp	5,500.7	3,449.3	0.627
WL2	2.0	Manuka, greater wire rush restiad rushland	4,851.2	4,830.7	0.996
WL3	2.0	Bog	7,534.7	7,471.0	0.992
WL11	2.0	Machaerina sedgeland	69.0	66.9	0.969
WL16	2.0	Red tussock, Schoenus pauciflorus tussockland	21.3	21.3	1.000
WL18	2.0	Flaxland	225.5	195.5	0.867
WL20	2.0	Coprosma, twiggy tree daisy scrub	91.4	91.4	1.000
WetlandFreshwater	2.0	LCDB2 class	2,595.6	1,553.0	0.598
DeciduousWetland	0.05	LCDB2 class – willow dominated	19,370.1	8,818.3	0.455
BroadleavedShrubland	0.1	LCDB2 class	62,309.9	7,924.7	0.127
Fernland	0.1	LCDB2 class	5,571.9	1,437.9	0.258
ManukaKanuka	0.1	LCDB2 class	110,836.9	17,798.6	0.161
Total/average			699,939.0	209,929.8	0.786

Appendix II – Maps of terrestrial priority sites

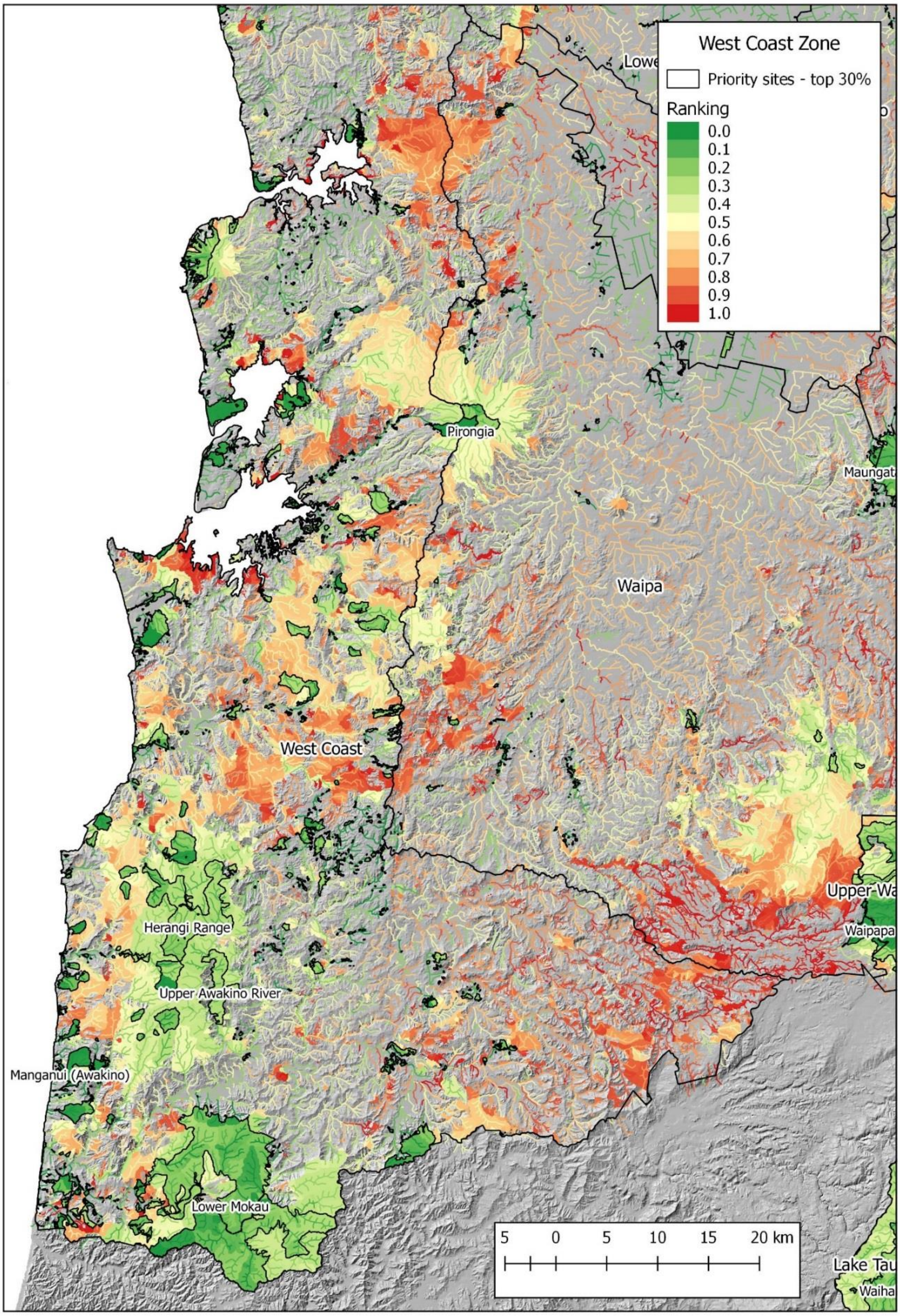
The following maps show terrestrial priority sites for the Waikato Region, overlaid across the continuous, rescaled terrestrial and river ranking results, and the lake rankings. All ranks are expressed as the proportion of the total area of that ecosystem group that would be included if the rank value were to be used as a threshold for management action. For example, the top 10% of the rivers, lakes and indigenous-dominated terrestrial ecosystems occurring within the Waikato Region are those with ranks less than 0.1, the top 20% of ecosystems are those with ranks less than 0.2, and so on.



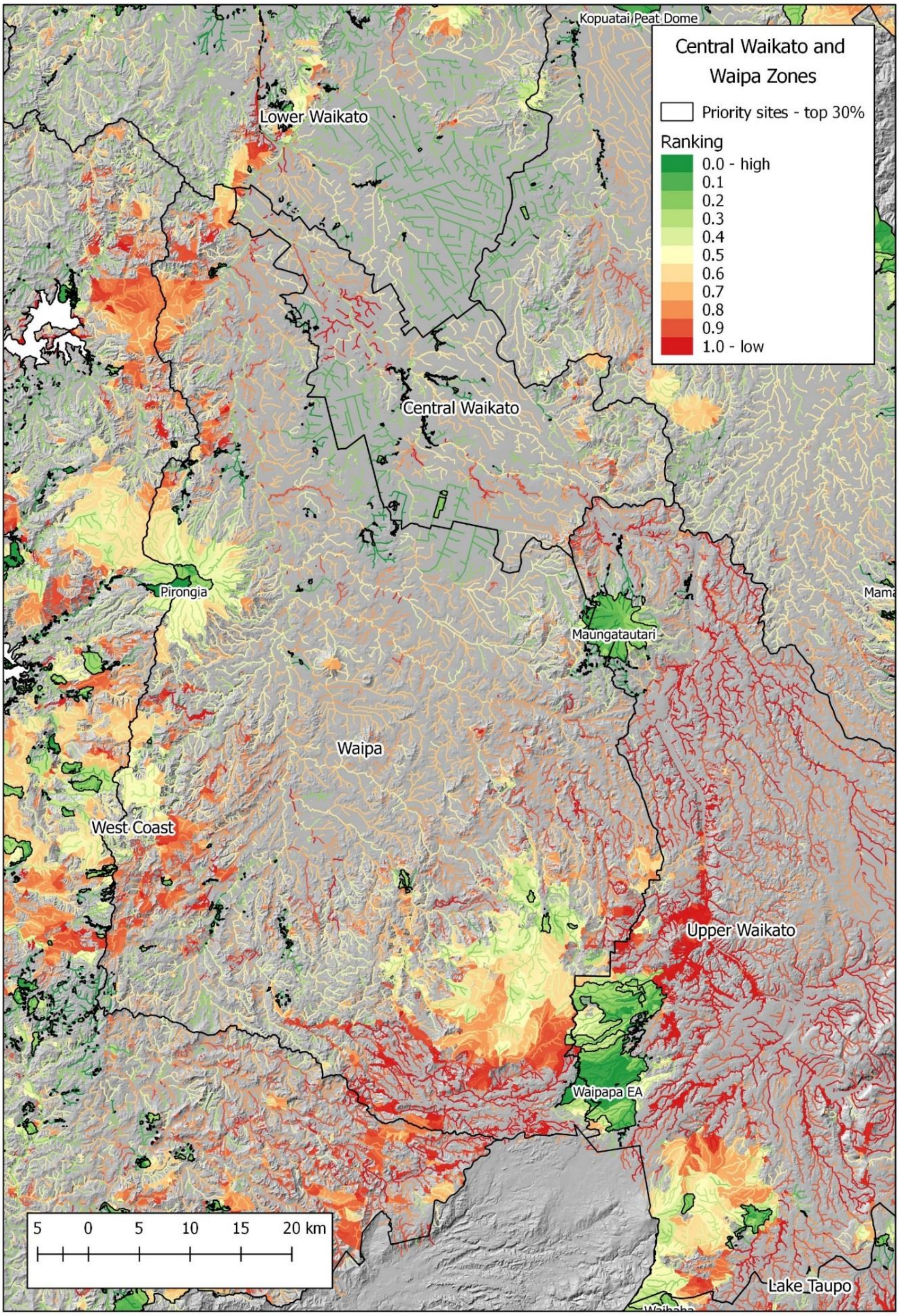
Map 1-Lake Taupo Zone



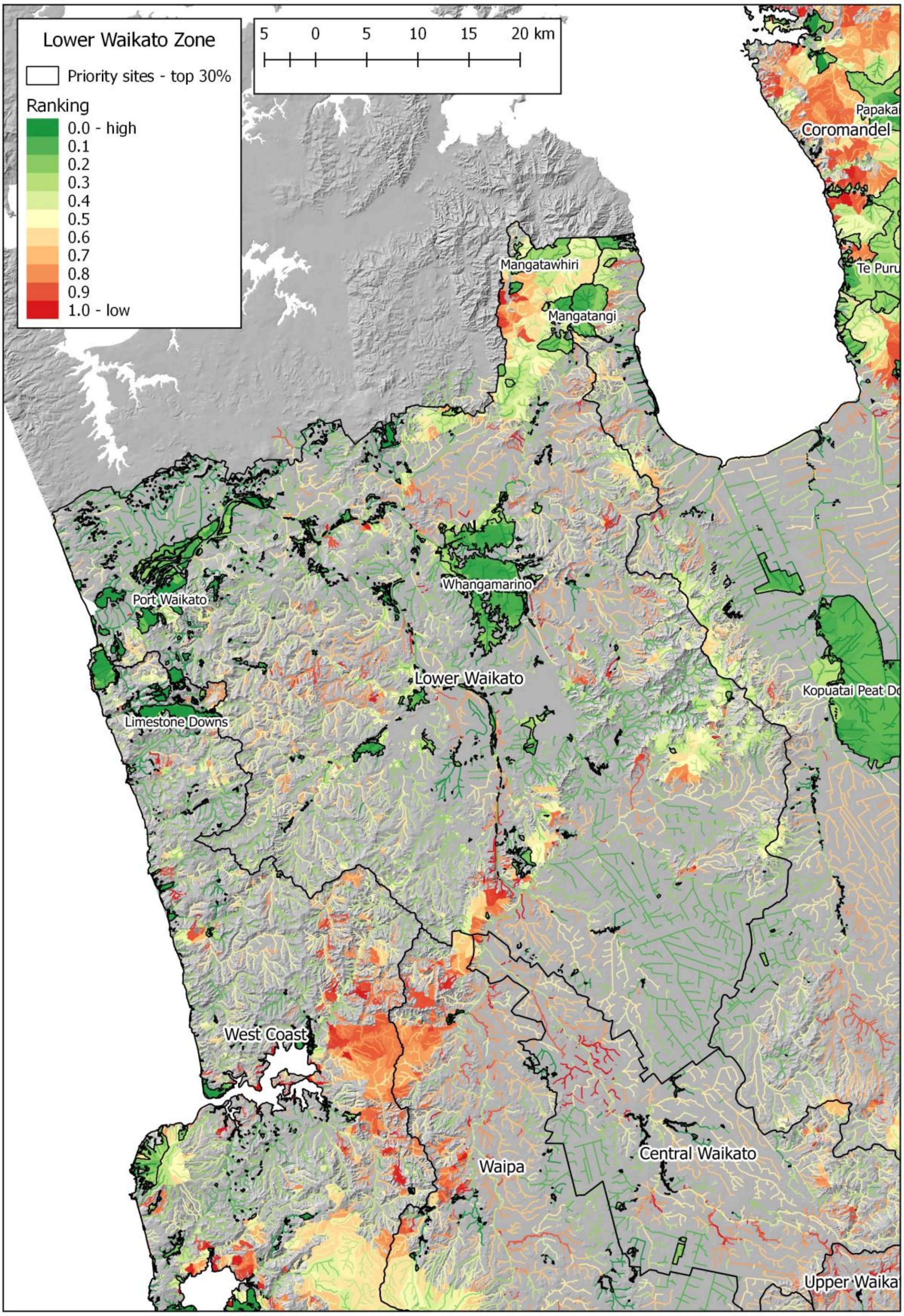
Map 2 - Upper Waikato Zone



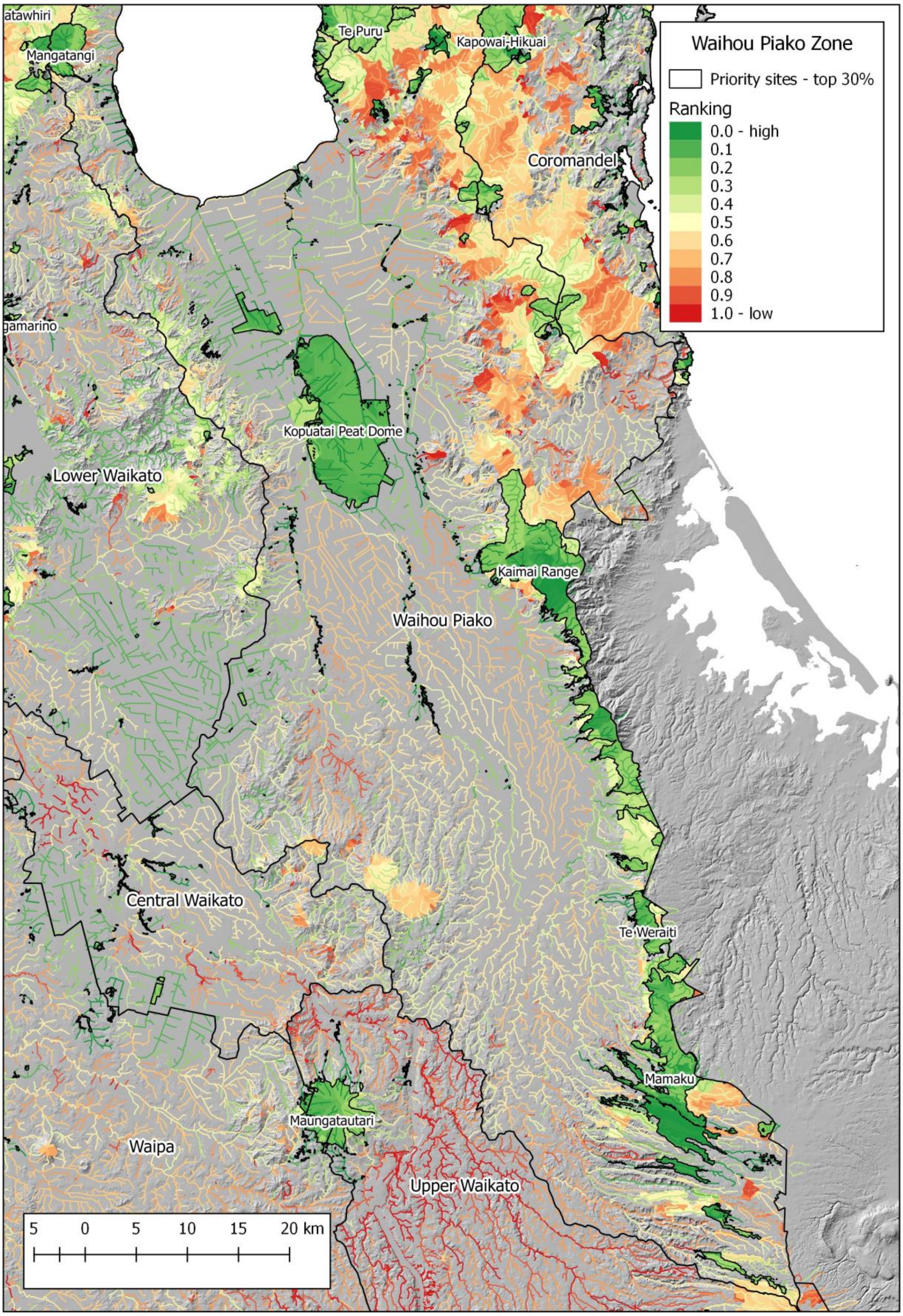
Map 3 - West Coast Zone



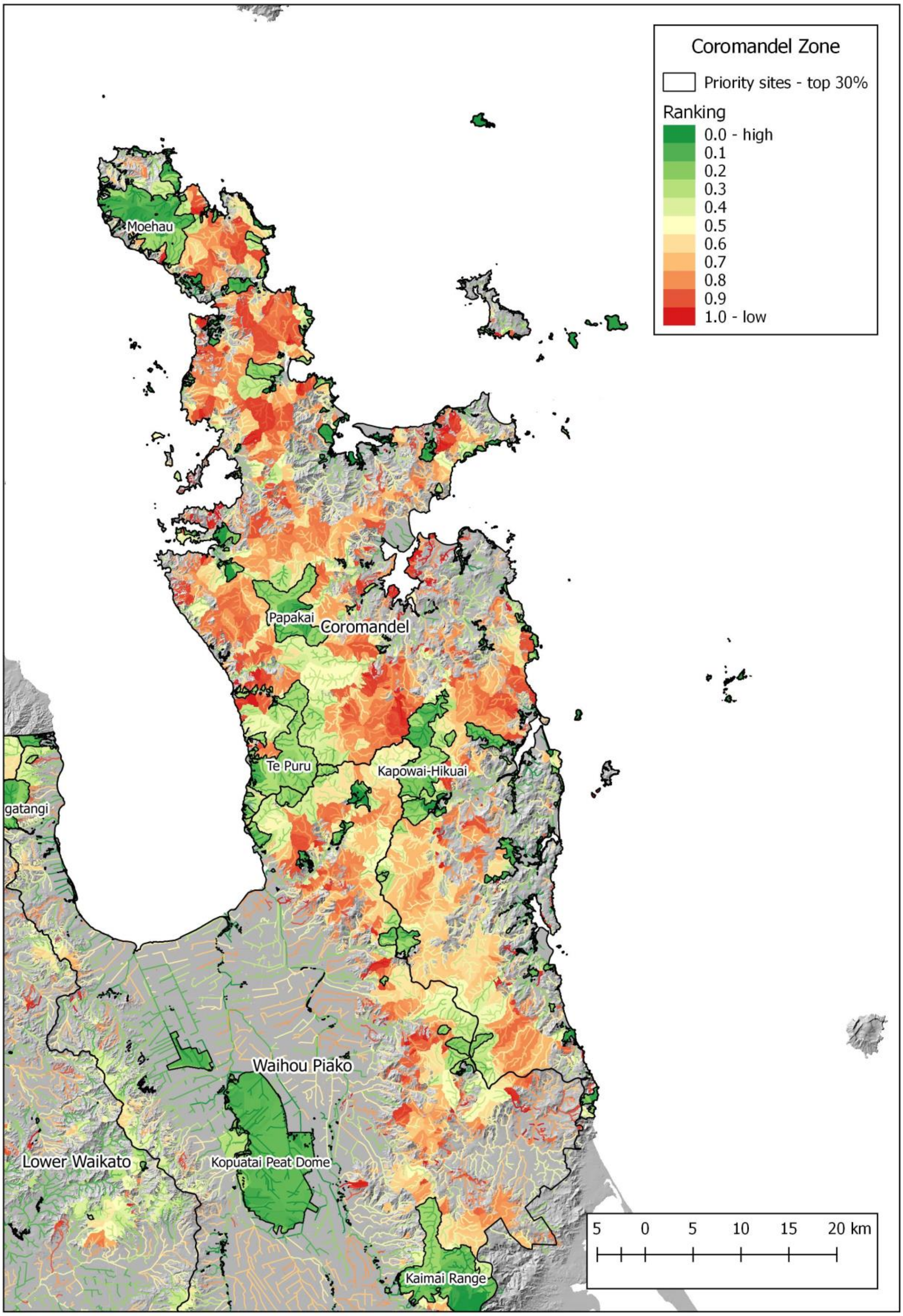
Map 4 - Central Waikato Zone



Map 5 - Lower Waikato Zone



Map 6 - Waihou Piako Zone



Map 7 - Coromandel Zone