Identifying freshwater ecosystems of national importance for biodiversity

Criteria, methods, and candidate list of nationally important rivers

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Disclaimer: This discussion document was prepared specifically for the Waters of National Importance sub-project of The Sustainable Development Programme of Action for Freshwater (or 'Water Programme of Action'). It is a working draft that presents a proposed methodology and a preliminary list of candidate rivers of national importance based on their biodiversity values. This list needs to be further refined, firstly because some data quality and systems problems could not be resolved within reporting time frames; and secondly following the public consultation and peer review during 2005. The report does not define waters of regional or local importance, so should not be interpreted at those scales. The authors should be consulted prior to formal citation of, or reliance on, this report.

Cover: A highly natural brown-water stream on Stewart Island, showing intact riparian linkages and a diversity of in-stream habitat. *(Photo by L. Chadderton.)*

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EXECUTIVE SUMMARY

Conservation management of freshwater is a complex activity. The responsibility is fragmented across different agencies, and no single agency is accountable for the overall condition of freshwater natural heritage. However, pressures on New Zealand freshwater ecosystems are intensifying: water is increasingly in demand for irrigation and energy generation; water quality is declining as a result of increasing nutrient loading associated with changes in land use; and with the continued spread of introduced pest species. The Sustainable Development Programme of Action for Freshwater was established by Government to reconcile the competing demands for freshwater. A sub-project involves identifying Waters of National Importance (WONI) for tourism, irrigation, energy generation, industrial uses, recreation, natural heritage and cultural heritage. The Department of Conservation (DOC) was given the task to identify a candidate list of nationally important aquatic systems for freshwater natural heritage (natural heritage being divided into physical and biological diversity). This candidate list may assist decision making about the use and allocation of freshwater resources.

The present report describes the results and process used to identify the minimum set of catchment units that best represent the *full range of indigenous biodiversity*, in New Zealand's freshwater riverine ecosystems. Our assessment caters for two contrasting objectives:

- Maintenance of viable populations of all indigenous freshwater species and subspecies.
- Protection of a full range of remaining natural freshwater habitats and ecosystems.

Our analysis was based on river catchment units as defined by the river catchment network, developed as part of the River Environment Classification (REC)*. A total of 4706 river catchment units were defined at five hierarchical levels, representing catchments or major tributaries nested within larger catchments. The candidate list of Waters of National Importance was drawn from this set of 4706 river catchment units.

Because the data describing the distribution of freshwater species and communities (i.e. actual biodiversity) are inadequate, an assessment based primarily on biotic databases was not possible. Instead, we derived surrogate biodiversity information from environmental, biogeographic and human disturbance information: these are known to determine much of the spatial pattern in the distribution of native biodiversity. Thus our candidate list is founded on the assumption that biogeographic, environmental, and disturbance patterns collectively predict ecological variation.

We characterised environmental pattern by first dividing New Zealand into 29 biogeographic units based around catchment boundaries: 15 in the North Island, and 13 in the South Island plus Stewart Island. Our decision to separate areas into biogeographic units was made on the basis that variation in the

* REC was published in 2002 by T.H. Snelder and B.J.F. Biggs in the *Journal of the American Water Resources Association 38*: 1225–1240.

character of freshwater ecosystems reflects both the responses of individual species to contemporary environments, and the effects of historic disturbance and recolonisation events. Glaciation, sea level change and volcanic eruptions are known to be major determinants of biological distributions, particularly of species with limited dispersal ability (comprising many freshwater organisms). The biogeographic framework identifies geographic units that are likely to have experienced similar physical disturbance regimes, and have shared source populations and pathways for recolonisation, or geographic barriers to the dispersal of freshwater biota.

We then used river classes defined within REC to characterise environmental variance within river catchments. These river classes represent finer-scale environmental variation, known to influence freshwater community composition. Hence each river class should contain unique elements of biodiversity (i.e. distinctive communities or species assemblages): capturing a full range of environments (river classes) should therefore ensure representation of a full range of biological diversity.

Catchment units were then ranked according to the degree of human-induced disturbance pressure, on the basis that the least disturbed systems have retained most indigenous biodiversity and are therefore the highest priorities for protection. Human disturbance pressure was calculated by combining seven pressure measures:

- percentage natural land cover
- urbanisation
- land use intensity
- fish passage
- downstream dam effects
- exotic fish
- point source pollution.

We developed a single natural heritage score for each catchment unit by combining:

- measures of environmental representativeness, and pressure

with

- information on the presence of threatened species

and

- connectivity to nationally important wetlands, estuaries or lakes.

This index of natural heritage value was used to rank each catchment unit within its biogeographic unit.

Conservation of at least the one catchment unit of greatest natural heritage value (large, diverse and little-modified) within each of these 29 biogeographic units is one conceptually simple and moderately efficient way to sustain a range of New Zealand's natural freshwater biological diversity. However, this approach was tested and found to be inadequate because it accounted for an average of 32% of the environmental and ecological variance (indicated by the number of river classes represented) within a biogeographic unit.

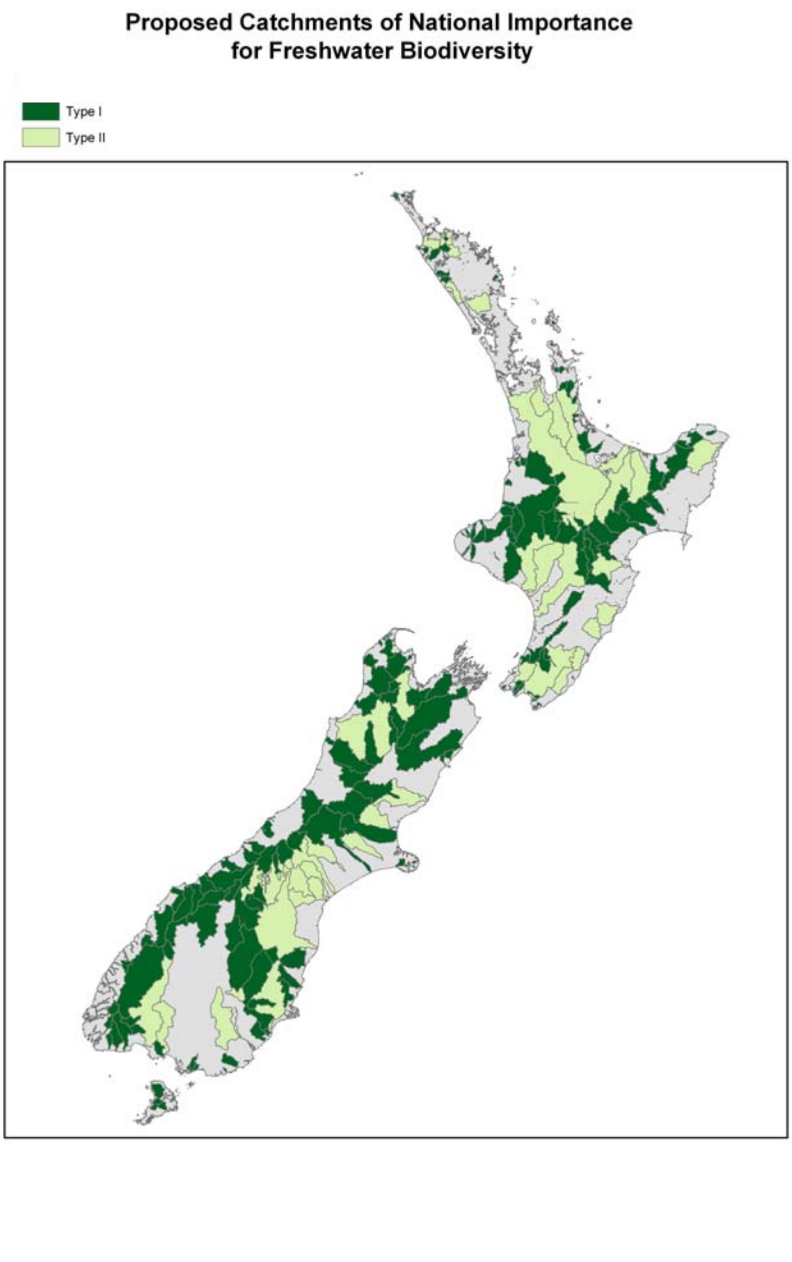
In order to make the candidate list more representative, we developed a list of the minimum set of least disturbed catchments within each biogeographic unit required to protect the full range of river classes. We compared this with a second list of the top ten systems within each biogeographic unit ranked by natural heritage value score, and a third list of catchments ranked by their combined threatened species scores. From these comparisons, a final candidate list of catchment units was derived on the basis of one or both of two rules:

1. The site was listed in the minimum set required for representation of 100% of the river classes, and listed among the top ten sites ranked by natural heritage value within the biogeographic unit;

and/or:

2. The site contained special features (i.e threatened species, floodplain forests), or was connected to a nationally important wetland, lake or estuary.

This procedure resulted in selection of 177 whole catchments and 57 sub-catchment units (Type I) as being among the most valuable rivers for sustaining New Zealand's freshwater biodiversity. These catchments units (see map) represent just over 5% of the 4706 catchment units assessed and accounted for an average of 76% of the range of river classes present in New Zealand. An additional 46 catchments (Type II) were identified as containing sections of river, special features, or populations of threatened species that were also of national significance.



We conclude that integrated and rigorous conservation action in these catchment units will help secure examples of freshwater biodiversity, but will not halt the decline in New Zealand's freshwater biodiversity. Decline can only be halted if restoration and recovery fully compensates for continued degradation elsewhere. Furthermore, protection of these catchments alone would represent a high-risk strategy, because much of the biodiversity would be extremely vulnerable to extinction following a single large natural or human-induced catastrophic disturbance or invasion. This risk is compounded by the longitudinal connectivity of river systems: catastrophic events in headwaters have consequences all the way downstream to the coast.

Our project represents a first attempt to prioritise catchments on the basis of their contribution to New

Zealand freshwater biodiversity. It will continue to be refined as data sets and systems are improved, for example by developing analyses undertaken at the scale of reaches (where each reach is part of a fully defined network) rather than at the scale of whole catchments arranged in a fixed hierarchy. The present approach is a precursor to the Natural Heritage Management Systems (NHMS) that the Department of Conservation (DOC) is developing to support and prioritise its conservation management and advocacy functions. These tools are being developed as part of a broader government agency partnership between DOC, the Ministry for the Environment (MfE), regional councils, and iwi.

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1. Introduction

1.1 NEW ZEALAND'S NATURAL HERITAGE

The New Zealand landscape is geologically diverse, tectonically and volcanically active, and subject to climatic extremes. It has also experienced biological isolation from other large landmasses for 80 million years. These factors combine to produce a diverse and distinctive biota occupying mountainous terrain, dissected by an abundance of streams and rivers, lakes, wetlands, ground waters, geothermal features and estuaries—these comprise New Zealand's freshwater natural heritage. Our natural heritage can be divided into abiotic or physical diversity (i.e. geological and environmental) and biological diversity. Abiotic diversity represents the physical attributes that characterise New Zealand's landscape, and include internationally renowned features such as the volcanic geysers and mud fields of Rotorua, braided shingle rivers of the South Island, Canterbury glacial lakes, Pupu Springs, cave and karst systems of Northwest Nelson-Paparoa, and Waitomo.

The 1992 Convention on Biological Diversity defined biological diversity as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within and between species and of ecosystems." New Zealand's freshwater biological diversity is less well known than its terrestrial counterpart, but it is just as ecologically and internationally significant. Isolation over geological time, during which our rich and dynamic landscapes developed, has led to high levels of endemism, as well as the persistence of many rare and several primitive groups (Boothroyd 2000). Strong affinities to South America and Australia at genus and family levels reflect historic Gondwanaland connections. Divergence of localised endemics is common: these species are native only to New Zealand, and are restricted to small localised areas measured in tens of kilometres, (e.g. Banks Peninsula). Divergence partly also reflects New Zealand's turbulent geological history and the numerous catastrophic disturbance events (e.g. the Taupo eruption) that have further isolated communities.

Freshwater rivers provide habitat for over 38 species of native freshwater fish, for 38 native aquatic plant species, and for hundreds of aquatic and semi-aquatic invertebrate species. In addition, there are over 160 species of water birds, including five endemic species that spend all or crucial parts of their lifecycles on our rivers (O'Donnell in press).

For many New Zealanders, these places, and the creatures that live in them, are taken for granted as part of our national life. However, most of New Zealand's freshwater ecosystems have already been degraded to some degree (Winterbourn 1995) and are under increasing pressure from land use intensification, demand for water and invasion by exotic species. The majority of these iconic freshwater systems exist today because they are actively protected, either through the Resource Management Act (1991) or because they are part of the public conservation estate. Loss or degradation of any of them diminishes both the natural biodiversity of our archipelago, and the quality of our lives as New Zealanders.

1.2 POLICY CONTEXT (BACKGROUND)

New Zealand government departments are developing an integrated approach to freshwater resources management as part the Government's "Sustainable Development Programme of Action for Freshwater" (Department of Prime Minister and Cabinet, January 2003). The programme covers three themes: Water Quality, Water Quantity, and Waters of National Importance (WONI). The WONI project requires several government departments to identify Waters of National Importance in respect to their values for natural heritage conservation, recreation, culture and heritage, irrigation, energy generation, industrial use and tourism. This project assumes that nationally important values need to be secured at a place in order to achieve a nationally agreed policy goal (expressed in legislation or Cabinet-approved policy) and recognises the competing demands for water use in New Zealand.

The main aim of the WONI project is to develop candidate lists of water bodies that can contribute to a process seeking to sustain national important freshwater assets. The Department of Conservation was given the task to identify aquatic systems of national importance for freshwater natural heritage, specifically indigenous biological and physical diversity. For biological diversity, the aim is to protect the full range of remaining biodiversity (species, natural habitats and ecosystems) and maintain viable populations of all indigenous species and subspecies. This goal is derived from, and consistent with, the requirements of the New Zealand Biodiversity Strategy (Anonymous 2000), and Reserves Act 1977. The latter requires "the preservation of representative samples of all classes of natural ecosystems and landscapes which in the aggregate gave New Zealand its own recognisable character".

This report[1] addresses the biodiversity component of the WONI project. It focuses on river systems as this was the most immediate priority within the multi-agency WONI working party; limited resources and short time frames precluded an analysis of other freshwater ecosystems.

1.3 PROCESS FOR IDENTIFYING WATERS OF NATIONAL IMPORTANCE (WONI)

The conservation of biodiversity requires avoidance of biological information loss, from any of three mutually exclusive categories of information, namely:

- Properties or Components: equivalent to inter-species and intra-species genetic diversity

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1 The outputs of this WONI project are the first step in a larger programme of work by the Department of Conservation, called the Natural Heritage Management Systems. This NHMS programme, in conjunction with the Freshwater Heritage Strategy, will help direct and prioritise the Department's freshwater management and advocacy functions. The freshwater component of NHMS will be developed as a broader government agency partnership between DOC, MfE, regional councils, and iwi. The databases and results presented in this report will therefore continue to be refined as data sets, models, and the spatial resolution are refined.

- Patterns: equivalent to the interactions between components (or the *relationships among biota and between the biota and their environment)*, which in combination, yield biological pattern
- Processes: ecological system dynamics and resultant ecosystem structure (Richmond 1999).

Waters of national significance for biodiversity can be identified through consensus of opinion, or by technical assessment based on data, criteria and models.

Consensus approaches achieve buy-in through participation and hence broad-based ownership of the result. They are also relatively quick, technically straightforward and cheap. The disadvantages are:

- Absence of transparency in what attributes of the resource lead to its recognition
- Inability to easily repeat the assessment given different assumptions, and with new or improved information
- Whether or how to weight opinions from people with variable values, expertise and credibility
- Limited or biased geographic knowledge of participants.

Thus major and irresolvable credibility may be a major problem.

The alternative is to make technical assessments. Such approaches combine verifiable resource data, explicit models and criteria based on transparent and testable assumptions. A well designed technical approach is fully repeatable, allowing the impact of new data or different assumptions to be explored. Thus technical approaches offer the basis for addressing credibility issues, learning and continual refinement. The disadvantages lie in the data volumes, mathematical models and the complexities of interacting assumptions. They may render the process leading to the results inaccessible to people who do not engage with the technical nature of the methodology. This is compounded by the fact that resource data can rarely offer more than a partial and biased description of the resource. Moreover, the models and criteria used are inevitably incomplete, simplistic and generalised depictions of real relationships and interactions. Acceptance of results may therefore be compromised, and some people may be inclined to reject the overall result on the basis of one particular flaw.

We chose to adopt a technical approach as it offered a comprehensive assessment, greater consistency and objectivity; and also because it presents opportunities for future learning, improvement and exploration of alternative assumptions.

Prior to the WONI project the Department undertook an extensive review of current literature, classifications, and criteria with a view of developing a process for identifing a minimum set of nationally important freshwater ecosystems that would encompass the full range of New Zealand's biodiversity (Collier et al. 2003). The review concluded that any framework or process should account for variability at the local environment scale (river reach) that is known to determine aquatic community composition (Vinson & Hawkins 1998; Stephens et al. 2002), and historic (biogeographic) processes that are known to have influenced large-scale biotic patterns (McDowall 1996; Leathwick et al. 2003; Harding & Winterbourn 1997; Townsend et al. 2003).

Here we identify the set of nationally important water bodies for biodiversity protection by combining environmental and biogeographic frameworks with information about the distribution of threatened species, and communities, and a range of human pressure variables that collectively indicate the naturalness of the system. If representative and ecologically viable units of the full range of environments and species within each biogeographic units are protected, then it should be possible to conserve a full range of what remains of New Zealand's freshwater biodiversity for future generations. Successful conservation of this range will at least set a base level at which the decline in our natural freshwater biodiversity will be halted.

Our approach is based on the following principles:

- The least disturbed waters have retained most natural biodiversity and are therefore the highest priorities for protection if further loss is to be minimised.
- All river environment types or hydro-classes must be represented among those protected, in order to retain the full range of natural habitat and ecosystems.
- Remaining threatened native species or community types where known also need to be protected, so that viable populations of all indigenous species and subspecies can be maintained.

2. Methods

2.1 BIOGEOGRAPHIC FRAMEWORK

Existing spatially explicit freshwater classifications (e.g. REC—Snelder & Biggs 2002; Lotic Ecoregions—Harding & Winterbourn 1997) do not account for historic determinants of contemporary biodiversity patterns (Harding & Winterbourn 1997). These determinants include large-scale disturbance events like glaciation, and volcanic eruptions that devastate biological communities; and the presence of colonisation pathways and barriers (e.g. alpine ridgelines, coastal straits) that have affected the ability of surviving taxa to reoccupy former or habitable ranges. A biogeographic framework was therefore developed to delineate areas likely to contain similar freshwater assemblages as a result of shared large-scale historic events (both temporal and spatial) that have shaped freshwater community compositions (Leathwick et al. 2003).

We used data describing the history of major disturbances (principally the last glacial maximum and/or volcanic deposition), and the presence of geographic barriers to recolonisation or dispersal pathways, to define a series of the biogeographic units. Four sources of evidence were used:

- Distributions of aquatic biota as recorded in a range of databases, with particular emphasis on the distributions of non-diadromous fish as recorded in the New Zealand Freshwater Fish Database.
- Evidence of genetic similarity between different populations of various freshwater species, as determined from analyses using molecular genetics tools.
- Evidence of physical disturbances affecting New Zealand's landscapes with particular emphasis on the Last Glacial Maximum, volcanic eruptions in the central North Island, and seismic activity (particularly in mountainous parts of the South Island).
- Presence of regional-scale barriers or pathways to dispersal including contiguous multi-catchments' alpine ridgelines, areas of nearshore deep marine water (> 120 m), straits and shared flow plains.

The final biogeographic framework was derived from consensus among a panel of freshwater scientists with representation from most of New Zealand's freshwater science providers (see Leathwick et al. 2003). It represents a first rapid attempt to classify New Zealand freshwater ecosystems according to their biogeographic history. The biogeographic units are conservative, and based on either biological evidence or inferred from physical evidence of isolation or catastrophic disturbance. There are good biotic data to support the separation of biogeographic units over most of the South Island. Biological evidence for separation of some North Island units is limited, despite strong physical evidence of isolation and/or catastrophic disturbance. This is because we have limited genetic and distributional data for obligate freshwater species (e.g. non-diadromous fish and crustaceans, molluscs) whose entire life cycle is spent in freshwater. Such species provide the best surrogate measures of the minimum spatial scales required for conservation of entire freshwater ecosystems (Abell et al. 2000) as their distribution patterns more closely correspond to catchments. Geographic evidence of isolation and catastrophic disturbance was therefore a stronger driver in the development of some North Island units. Even at the scale of our biogeographic classification, it must be noted, that some groups of poor-dispersing species (crustaceans and molluscs) can vary at finer spatial scales that correspond to first-order catchment units, or even to springs within a unit (Ponder et al. 1996). Thus our biogeographic classification resolution is more likely to under-estimate than over-estimate actual biological variation.

2.2 SCALE OF WONI ASSESSMENT

The WONI assessment was undertaken at the river catchment unit scale. Catchment units were based upon the River Environment Classification (Snelder & Biggs 2002) modified to define whole-river catchments (i.e., headwater to river mouth).

- Sub-catchments greater than approximately 2000 hectares entering a major regulated lake were split at the point where they entered the lake (major lakes included, roughly from north to south: Taupo, Ohakuri, Atiamuri, Whakamaru, Maraetai, Arapuni, Karapiro, Waikaremoana, Tekapo, Pukaki, Ohau, Benmore, Aviemore, Waitaki, Dunstan, Roxburgh, Te Anau, Manapouri).
- Sub-catchments greater than approximately 100,000 hectares were split at points where major tributaries entered the mainstem river.
- Sub-catchments were further broken where tributary catchments still exceeded approximately 100 000 hectares.

The boundaries of the underlying whole catchment were preserved so that each new sub-catchment was a polygon overlying a portion of the underlying parent polygon. This created a nested hierarchy in which generations of sub-catchments overlay each other, producing a total of 284 sub-catchments (including all generations of sub-catchments) for the three main islands of New Zealand (for further detail see Norton et al. 2004). Each river system or sub-catchment was given its own unique identifier.

Rivers with catchment size under 100 ha were excluded from the assessment to reduce the data set from over 10,000 possible catchments to a more tractable 4706 catchments. We assumed that catchments <100 ha would not be considered nationally important in other WONI assessments (particularly irrigation, energy generation or industrial use) and hence they would not be relevant to the WONI ranking process. We note however, that some of these smaller catchments will contain nationally important natural heritage values.

The WONI analysis included all large inshore islands but did not consider the Chatham or Kermadec Islands, or the New Zealand sub-antarctic islands.

2.3 CALCULATING NATURAL HERITAGE VALUE SCORES

To determine a candidate list of rivers and lakes we need to cater for two contrasting objectives:

1. Maintenance of viable populations of all indigenous species and subspecies.

2. Protection of a full range of remaining natural habitats and ecosystems.

The first objective requires that rivers are ranked according to their overall "natural heritage value" and to the vulnerability of key natural features to loss. The second objective requires construction of a list of catchments ranked according to the cumulative contribution each progressively makes to the full range of New Zealand's freshwater-dependent natural heritage. The two tasks differ in that the first is concerned primarily with catchment naturalness, whereas the latter is context-dependent: it is determined by how much new biodiversity a catchment unit contributes to that represented in the set of catchments already selected for the list.

The information required to develop this list includes data describing:

- A classification of river reaches to indicate what each catchment contributes to the range of environments represented (i.e. the river reach classification within the River Environment Classification).
- The quantity of biodiversity likely to be present (catchment area, number of river reach types present, catchment distinctiveness).
- The degradation pressure on the catchment as a surrogate for naturalness (land clearance; land use intensity; discharges; dams; exotic fish).
- The vulnerable natural features present (threatened species; natural floodplain forest; national or internationally significant features).

Variables describing the quantity, degradation and vulnerability of biodiversity present were transformed to explicitly depict the relationship that each was thought to have with natural heritage value. The characteristics of each relationship were defined by expert judgement; then a function was chosen to describe these characteristics and transform each variable. The input variables, assumptions about relationships with natural heritage, and the transformations applied are listed in Table 3. All variables (except catchment area) were similarly (but not identically) scaled so that all values were > 0 and only outliers were > 1.

A correlation analysis of all transformed variables was undertaken to identify redundant variables. If one variable was both highly correlated with another and the functional connection was well understood (e.g. catchment area and number of reach types present), then one was not included in the multiplicative index of natural heritage value. If high correlation was more likely a consequence of a shared driver (e.g. nitrogen levels and the number of major discharges; or threatened species of plant, bird and fish), the variables were combined to reflect the assumed nature of the interaction. Thus the form of the function defining the index of natural heritage value (NHV) was primarily multiplicative, with special features combined additively; then a minor additive adjustment was made for connection to nationally significant water bodies. This additive adjustment reflects the reality that a system may have no significant inherent natural heritage values, but still provide a nationally important buffering or connectivity function for a nationally important wetland, lake or estuarine feature (Collier et al. 2003). The national heritage value is therefore calculated from the equation:

$$NHV = (Area^{0.27} \times Unq \times Int \times Cov \times N \times Exotic \times [Fish + BDuck + Birds + Plants + FF]) + Conn$$

Variables are listed and described in Table 3 (p. 20).

2.4 CHARACTERISING ENVIRONMENT

River reach types were classified using the River Environment Classification, REC (Snelder & Biggs 2002). Source of Flow, Geology, Network Position and Valley Landform variables of REC were combined to generate a physical typology. Climate variables were removed because they were unlikely to add further discriminatory power. (Climate is relatively homogenous within each biogeographic unit and would increase the number of potential river types six-fold, creating unnecessary complexity.) Contemporary land cover data was also excluded, because this reflects human disturbance over much of New Zealand's land area (> 80%) and so is not a good surrogate for underlying environmental conditions. For example, pasture and plantation forest occur in both Southland and Northland despite very different environments. Also, inclusion of land cover data would have increased the number of river types eight-fold, creating more unnecessary complexity.

The number of river environment classes (referred to as "river classes" hereafter) generated, reflects our assumption that river type is an adequate surrogate for biological variance. Although this assumption requires further testing, we believe that the scale chosen is likely to reflect variation in species assemblages. The number of river classes generated from the four levels of REC used (Geology, Source of Flow, Valley Landform, and Network Position: Snelder & Biggs 2002) is similar to the number that would be generated from a combination of Rosgen's (1994) classification of natural rivers based on their morphology (7–9 types) and the inclusion of source of flow, stream size and catchment geology. These physical factors are known to have significant influences on biotic pattern (Harding 1992; Harding et al. 1997; Vinson & Hawkins 1998). The use of both regional and local or reach variables is also consistent with the findings of recent studies (see Vinson & Hawkins 1998; Duggan et al. 2002; Death & Joy 2004) and the principle that physical complexity should promote biological richness (Vinson & Hawkins 1998). Thus we believe the river environment class resolution used for this analysis will prove to be a reasonable surrogate description of biological pattern.

2.5 DETERMINING ANTHROPOGENIC PRESSURE

Much of New Zealand's landscape outside a few offshore islands, and the alpine, subalpine, and forested montaine regions is highly modified (Winterbourn 1995). Land clearance, pastoral development, urbanisation, industrial point source discharges, water abstraction, flow alterations, artificial barriers and introduced species have resulted in marked changes to biological characteristics of freshwater ecosystems (Winterbourn 1995, see also reviews in Collier & Winterbourn 2000). These anthropogenic factors can be viewed as disturbance pressures affecting natural heritage. Measurement of pressure provides an indication of the intensity of various human-induced disturbances affecting the condition of native biota (Stephens et al. 2002). Hence those systems with least human-induced disturbance pressure are likely to be of the highest natural condition. That is, they should have retained most of their natural biodiversity content.

A total of seven pressure variables were derived (Table 1). These represent the impacts on biodiversity of changes in land use and land cover, point-source and non-point source pollution, loss of fish passage, alterations in flow and sediment transport, and introduced fish species.

Data were derived from a range of sources (Table 2) including existing national databases such as the Land Cover database (LCDB) and the Freshwater Fish database (FFDB—Norton et al. 2004). They were supplemented with information from Territorial Local Authority consent databases, and information from Fish & Game and local Department of Conservation conservancy staff. Most of these layers were developed by National Institute of Water and Atmospheric Research and methods are described in Norton et al. (2004).

Some of our models and criteria are simplistic depictions of actual situations (a consequence of deficiencies in the data available). For instance, point source discharges are represented using simple presence/absence data without differentiating the size or nature of either the discharge or receiving waters. Hence the discharges from the Kawerau pulp and paper mill into the Tarawera River have almost no effect on national heritage value score in the WONI database. Yet in reality they have a major detrimental ecological impact along much of the lower Tarawera River (C. Richmond pers. comm.). In contrast, the ecological effects of numerous sewerage discharges into the Clutha River are almost undetectable (L. Chadderton pers. obs.).

Another example of overly simplistic depiction is the use of presence/absence data for introduced fish. Presence/absence data do not differentiate between catchments containing abundant populations of exotic fish, and those dominated by native fish with an occasional trout present in deep pools. The latter presence is unlikely to have widespread effects upon native biodiversity.

TABLE 1. ANTHROPOGENIC PRESSURE MEASURES DEVELOPED FOR WATERS OF NATIONAL IMPORTANCE.

VARIABLE	IMPACT	REFERENCES
Catchment cover	Loss of native vegetation, riparian vegetation and in-stream cover; increased sedimentation and stream temperature; decreased bank stability and terrestrial drift; modifications to hydrological function	Quinn 2000; Boothroyd 2000
Urbanisation	Changes in hydrological function (flashy streams), increased levels of heavy metals, sedimentation, and channelisation; loss of riparian cover and connectivity; lowered water table	Suren 2000
Land use intensity	Increasing levels of nutrient, sedimentation and pesticides; correlated with increased channelisation, loss of cover, riparian connectivity and shade; changes in hydrological functioning.	Quinn 2000
Fish passage	Barrier to fish passage for diadromous fish (> 50% of native fish species are diadromous)	McDowall 1990
Downstream dam	Impeded sediment transport, armouring, and alterations in flow and fine sediment deposition rates, decreased bed area, and loss of habitat	Jowett 2000; Ward & Stanford 1979
Exotic fish	Predation and competition with native communities, trophic cascades, altering physical habitat, and water quality	McIntosh 2000; Champion et al. 2002
Major point source discharges	Changes in DO, pH, nutrients, increases in toxic heavy metal levels, biological oxygen demand, pesticides, flocculants, biocides and hydrocarbons; increasing water temperatures	Hickey 2000

TABLE 2. FORMAT AND SOURCE DATA USED TO PRODUCE PRESSURE MEASURES.

VARIABLE	DATA SOURCE	FORMAT	NOTES
Catchment cover	LCDB natural land cover types, modified with an overlay developed from Agribase farm type records (S. Thompson pers. comm.)	% cover of all natural cover types	See Norton et al. (2004)
Urbanisation	Urban land cover (LCDB)	% cover	See Norton et al. (2004)
Land use intensity	Derived from MAF Agribase land use types. Total nitrogen yield was assigned to land use types	Simple ordinal scale, from 0 = natural cover to 40 = highly intensive land use	Yields derived from Wilcock et al. (1999) and expert opinion
Fish passage	New Zealand Dam Inventory supplemented with records from council database records (n = 498 structures)	% catchment affected by dam for fish passage	All dams > 3 m height, or > 20,000 m^3 capacity
Downstream dam	New Zealand Dam Inventory supplemented with records from Council database records (n = 498 structures)	% downstream of total river length affected by a dam	All dams > 3 m height, or > 20,000 m^3 capacity
Exotic fish	Freshwater Fish database records, supplemented with local information from Fish & Game and DOC staff	Presence/absence data, for koi carp, brown and rainbow trout, gambusia, rudd and perch	Priority invasive fish species listed in Chadderton et al. (2003a)
Major point source discharges	Council consent database records	Presence/absence data summed for each catchment	Discharge types were: pulp and paper mills, meat works, large sewerage discharges (> 5000 people), dairy factories or any industrial discharges of similar magnitude

2.6 SPECIAL FEATURES

The distributions of threatened species and communities are often not strongly correlated with the most natural ecosystems. Their vulnerability has often arisen because their habitats have been subject to much loss and degradation. Hence identification of just the most natural systems will not cater for many threatened components of New Zealand's biodiversity. To protect a full range of biodiversity, it is therefore also necessary to identify remaining viable populations of threatened native species or community types.

Threatened species rankings were derived from threatened species classifications listed in Molloy et al. (2002), Hitchmough (2002) and de Lange et al. (in press). Comprehensive spatially explicit distribution information was available for a few threatened aquatic species principally within Bioweb (threatened plants, blue duck, brown teal, Hochstetter's frog) and Freshwater Fish database (Fish). BioWeb is a web-based database system managed by DOC that holds presence/absence data about a range of New Zealand's natural and historic heritage of importance for conservation. The Freshwater Fish database is managed by NIWA, and holds presence/absence records of all freshwater fish species across New Zealand. Threatened invertebrate data were not considered in the analysis because distribution information and sampling efforts are insufficiently consistent across the country.

The special features recognised were threatened bird, plant and fish species, as well as flood forests (Collier et al. 2003). All threatened species were recorded as presence/absence data and then weighted by their threat classification (Molloy et al. 2002); a weighted threat score was calculated based on the inverse of the DOC threatened rank as follows:

THREAT CLASSIFICATION	THREAT NUMBER	WEIGHTED THREAT
Nationally critical	1	6
Nationally endangered	2	5
Nationally vulnerable	3	4
Serious decline	4	3
Gradual decline	5	2
Data deficient	5	2
(Sparse)	(6)	(1)

For threatened plants, all available presence/absence data were compiled for each species from records currently held in, or due to be migrated into, Bioweb (5981 records). A total threatened-plant score was then compiled for each catchment by summing the product of presence data multiplied by threat scores.

For threatened fish only species in “gradual decline” or “data deficient” ranking or above were considerd, because populations of “sparse” or “range restricted” fish (e.g. *Galaxias fasciatus*) were likely to be provided for within the most natural coastal water bodies, or catchments containing other threatened fish. Again we generated a presence/absence data set of nationally important fish populations. For non-migratory fish species the 15 most important populations identified within recovery plans was used. For migratory species, the country was divided into 4 coastal regions and the 15 largest populations that covered the geographic range of the region were identified (R. Allibone pers. comm.). Criteria for selection aim to preserve large populations in order to maintain the geographic range, genetic and biological diversity of each fish species and key scientific sites. A threatened-fish score was then compiled for each catchment by summing the product of presence data multiplied by threat scores. Multiple records for a species were treated as a single occurrence.

The presence of populations of blue duck, brown teal and Hochstetter’s frog were compiled from all records Bioweb. For blue duck only those records post 1990 were used; recently extinct populations were removed from the data set prior to analysis. Each catchment containing these species was assigned an overall threat score based on the sum of their individually weighted threat scores.

There are no current, spatially explicit population and distribution data for all other aquatic threatened birds species. Therefore a presence/absence database of all other “nationally threatened” bird species was developed for all rivers > 30 000 ha catchment size. Data for Canterbury were derived from O’Donnell (2000) whereas all other river data were compiled from conservancy records and published records. Presence records were converted to a weighted threatened-species score, summed for each catchment or sub-catchment and

TABLE 3. VARIABLES DESCRIBING THE NATURAL HERITAGE VALUE INDEX (NHV). +ve = positive, –ve = negative.

VARIABLE	INFLUENCE ON NHV	TRANSFORMATION
Catchment area (ha)	+ve as richness increases with area but at a diminishing rate (0.15)	Root function (0.15) to maximize the linearity of the relationship with catchment richness (**Area**)
Uniqueness within biogeographic unit	–ve as representativeness increases at low values but +ve as distinctiveness increases at high values	U-shaped function with maximum NHV (0.675) at both high and low values with minimum NHV (0.26) at intermediate values (**Unq**)
Catchment richness (number of REC types present)	+ve as more biodiversity is present with greater richness	Variable not used as strongly correlated with catchment area
Portion of catchment upstream of dam	–ve as NHV declines with increasing proportion affected	Variables summed to index the integrity of catchment flow regime (**Int**)
Portion of catchment downstream of dam	–ve as NHV declines with increasing proportion affected	
% natural cover	–ve as NHV declines with loss of natural cover and conversion to exotic vegetation.	Variables combined in a sigmoidal function that shifts to the right with increasing urbanization. NHV tends toward zero with extreme conversion (> 90% urban) (**Cov**)
% urban	–ve as NHV declines with urbanisation	
Land use intensity (total dissolved nitrogen yield)	–ve as NHV declines with increasing N enrichment	Variables combined in a reverse sigmoid function of N levels that shifts to the left with increasing numbers of point source discharges. NHV tends toward zero with extreme pollution (N > 30) (**N**)
Number of major point source discharges	–ve as NHV declines with increasing pollution	
Number of exotic fish species present	–ve as NHV declines at a diminishing rate with increasing numbers of exotic species	Inverse function of exotic species richness with NHV tending to 0.1 at the maximum of 8 spp. present. Assumes each additional exotic sp. present has less impact than the preceding one (**Exotic**)
Weighted threatened fish	+ve as both NHV and vulnerability increase with numbers of threatened species	Number of threatened species weighted by threat status scaled to range from 0.05 (none present) up to 2 (**Fish**)
Blue duck, brown teal, Hochstetters frog	+ve as both NHV and vulnerability increase with presence of these threatened species	Threat status scaled as for threatened fish with absence set to 0.05 (**BDuck**)
Threatened birds	+ve as both NHV and vulnerability increase with numbers of threatened species	Summed weighted threat status scores based on presence/absence in catchments > 30,000 ha. Absence set to 0.05 (**Birds**)
Threatened freshwater-dependent plants	+ve as both NHV and vulnerability increase with numbers of freshwater-dependent threatened plants	Summed weighted threat scores scaled as for threatened fish with absence set to 0.05 (**Plants**)
Floodplain forest	+ve as both NHV and vulnerability increase rapidly with area of remnant floodplain forest	Steeply rising exponential function that reached half of maximum value at 100 ha and rapidly flattens out towards a maximum as floodplain area reaches 5000 ha. Assumes that even very small remnants are important, but bigger is better (**FF**)
Connectivity	+ve as NHV, particularly of low NHV catchments increases with connection to a nationally significant lake, wetland or estuary	0.001 added for each connected nationally significant (Cromarty & Scott 1996) water body present in the catchment (**Conn**)

then multiplied by the product of Area (raised to power of 0.15) as a surrogate estimate of abundance. This function is based on species richness/area relationships (see Stephens et al. 2002 for further explanation). The rankings produced by this approach compared favourably with those produced by O'Donnell (2000) from a semi-quantitative data set that assessed a range of criteria including population size, diversity, and viability measures (Spearman rank correlation R^2 was 0.84).

The amount of riverine floodplain forest was quantified on GIS by selecting all areas of native forest from the Land Cover Data Base present on riverine basins with a catchment slope less than one degree, and within a 110-metre buffer of a river line in the REC network.

2.7 CONNECTIVITY/BUFFERING FUNCTION

This variable recognises that some systems have value because they provide a critical ecological buffer for, or connection to, other nationally important aquatic ecosystems (e.g. wetlands, estuaries, lakes: Collier et al. 2003). Loss of the hydrological connection or corridor provided by the river or lake would significantly lower the value of these nationally important systems. Nationally important non-riverine and lacustrine freshwater/estuarine systems were identified to include:

1. Wetlands of International Importance (Cromarty & Scott 1996).
2. Estuaries of International Importance (Cromarty & Scott 1996).
3. Areas of Significant Conservation Value (ASCVs) listed by conservancy experts as part of DOC's submissions to regional coastal plans.
4. The least human-disturbed lake in a biogreographic unit, or any lake containing nationally significant bird populations.

A value equivalent to the lower 10-percentile of all heritage value scores (0.001) was then added to the natural heritage value score of each catchment that contained a nationally or internationally important wetland, estuary or lake.

2.8 DEVELOPING A CANDIDATE LIST

Our procedure was designed to ensure that the list of Waters of National Importance identified catchment units with the highest natural heritage value score (NHV score), as well as those known to contain a range of special vulnerable features, distinctive river classes, or unique biological communities.

The candidate list was therefore developed to include where possible:

1. At least 70% of the environmental variance (as measured by the number of river classes captured) within each biogeographic unit.
2. Catchments with the highest NHV score within each biogeographic unit.
3. Known special features (threatened species or nationally important wetlands, lakes or estuaries).

The Sort function in MS Excel® was used to determine the minimum area and smallest set of sites within each biogeographic unit required to protect at least 70% of the full range of river classes. The sort was hierarchical, starting with a subset of sites that represented the smallest sub-catchments within any given river system (i.e. only those catchments and tributaries that did not contain sub-catchments nested within their catchment), sorting by highest NHV score. Thus a site was added to the candidate list only if it added new river classes to the combined pool of river classes already selected and was the smallest highest ranked (by NHV) sub-catchment that could provide the new addition. Consequently, the largest parent catchments (e.g. Waiau and Waikato), with many sub-catchments nested upstream, were included last so that they did not mask the analysis.

A separate list of the ten top-ranked (by NHV only) systems within each biogeographic unit was developed. Finally catchments were also ranked within each unit by total threatened species scores.

From these lists, a single list of candidate catchment units was then produced on the basis of two rules:

1. The site was both listed in the minimum set, and also listed among the top ten sites ranked by natural heritage value score within each biogeographic unit.
2. The site contained one or more special vulnerable features (threatened species; flood forest); or connected to a nationally important wetland, lake or estuary.

The catchment list derived by this process represented what we have termed **Type I** catchments, where the majority of the catchment is nationally significant. A second group of catchments, termed **Type II,** were selected on the basis that they contained special features of national significance, usually a wetland or nationally important population of a threatened species. Only sections of the Type II catchments are of national importance; the entire catchment would not require protection in order to conserve these values.

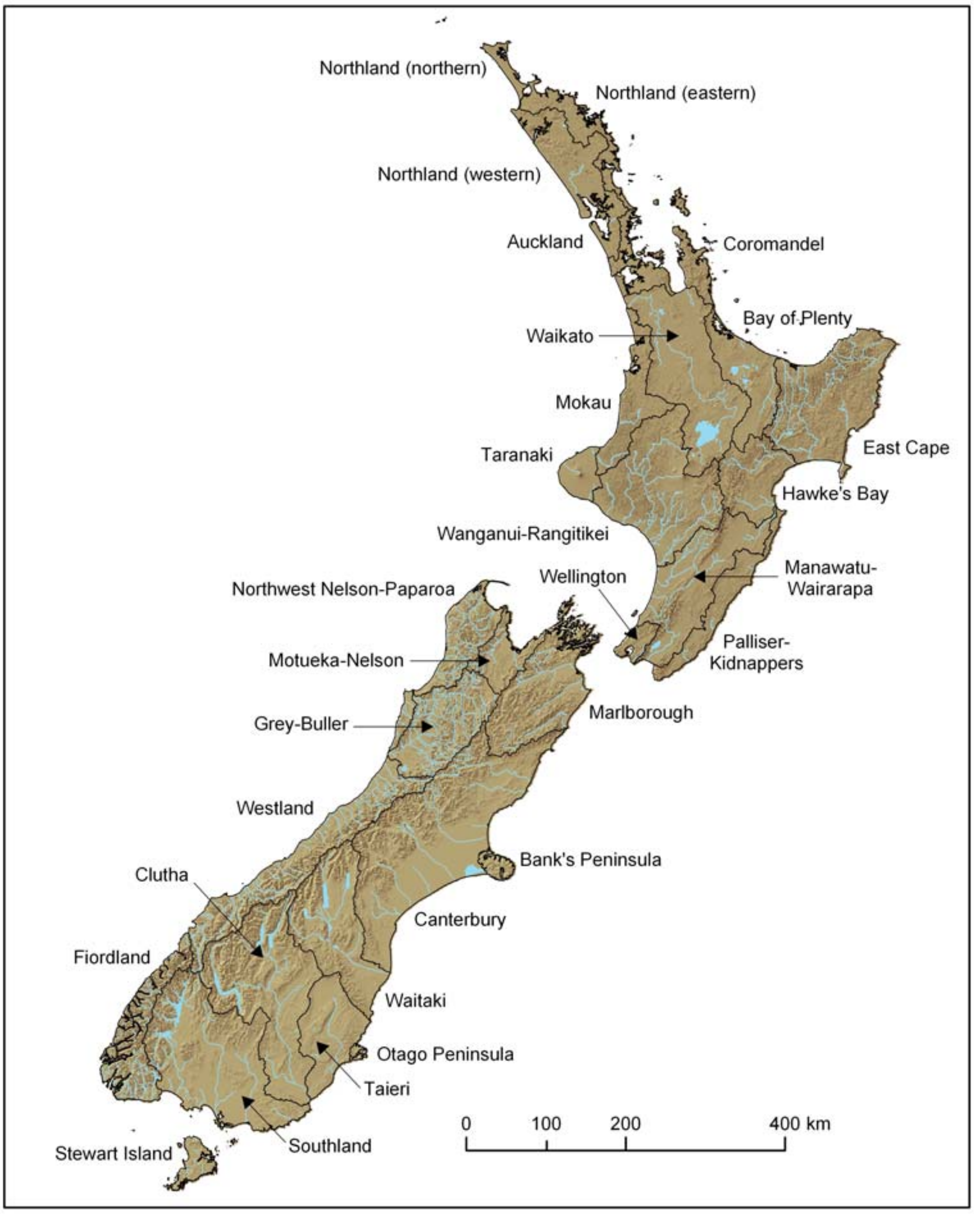
3. Results

3.1 COMPONENT VARIABLES

A total of 29 biogeographic units were defined by Leathwick et al. (2003). Stewart Island forms the most southern unit, there are 13 units defined in the South Island and 15 in the North Island (Fig. 1).

The river typology based on Source of Flow, Geology, Network Position and Valley Landform variables of REC resulted in 215 river classes in the South Island/Stewart Island and 154 classes in the North Island. Total numbers of classes per river was closely correlated to catchment area (Table 4; Fig. 2A; $R^2 = 0.89$). The total number of river classes was therefore not included separately in the index of heritage value.

Figure 1. Freshwater biogeographic units of New Zealand (after Leathwick et al. 2003).



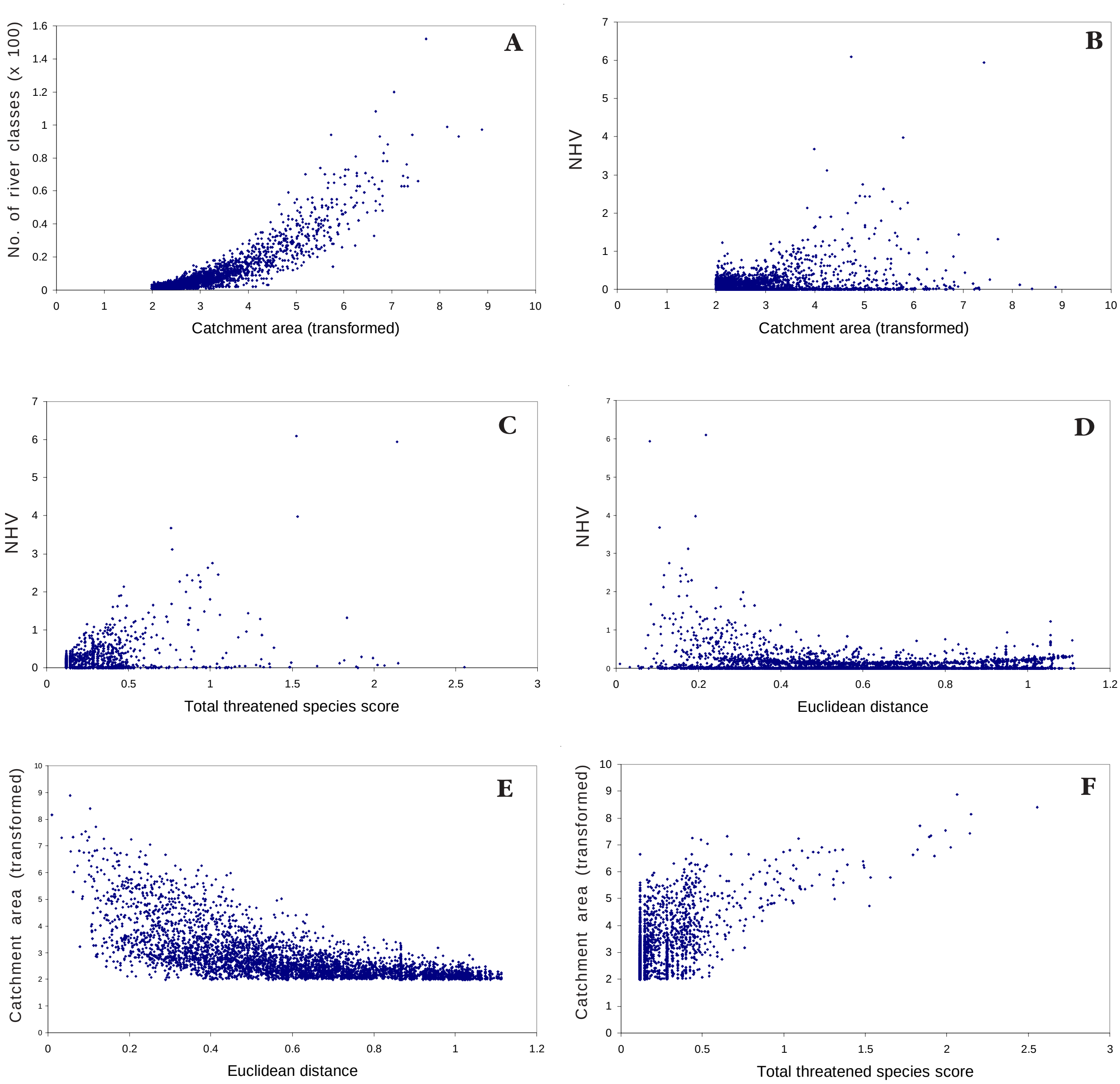


Figure 2. Relationships between Natural Heritage Variables. **A**, Number of river classes versus catchment area; **B**, NHV score versus catchment area; **C**, NHV score versus total threatened species score; **D**, NHV score versus Euclidean distance; **E**, Catchment area versus Euclidean distance; **F**, Total threatened species score versus catchment area. The variable Area (in ha) was transformed mathematically (raised to power 0.15, refer Table 3 on p. 20).

The relationship between NHV score and threatened species (Fig. 2C) demonstrates that some sites with high threatened-species scores do not have correspondingly high heritage value scores. This is because threatened species are still present in some degraded environments. Inclusion of sites on heritage value score alone would not adequately provide for threatened species.

The relationship between Euclidean distance and NHV score (Fig. 2D) reveals that the highest heritage scores apply to catchments that are also the most representative of the range of river types present in a biogeographic unit. This correlation reflects the relationship between catchment size and the number of river types, and hence representativeness (as measured by Euclidean distance: Fig. 2E). However, there are a number of small catchments with highly

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