New Zealand ecoregions

a classification for use in stream conservation and management

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ABSTRACT

An ecoregion classification for New Zealand was developed based on mapped data on six macro-environmental variables: vegetative cover, bedrock geology, soils, relief, rainfall normals, and Meteorological Service Climatic Regions. Maps of these variables were merged, and a new composite ecoregion map generated. Twenty-five ecoregions are proposed, 13 in the North Island and 12 in the South Island. Systematic sampling of 100 headwater streams within 10 of the South Island ecoregions was undertaken subsequently to evaluate their distinctiveness with respect to water chemistry and their benthic invertebrate faunas. Most ecoregions could be recognised by characteristic assemblages of invertebrates. `Pristine' forested ecoregions of Westland Forest, North-west Nelson Forest, North-east Nelson Forest, and the South-east Forest had high taxonomic diversity, numerous endemic species, and faunas dominated numerically by Ephemeroptera and Plecoptera. In contrast, the highly modified pastoral ecoregions of the East Coast Plains, Central Otago, and the Southland Plains had low-gradient streams with very similar invertebrate assemblages, low taxonomic diversities and a predominance of gastropod molluscs, oligochaete worms and Diptera. Regional invertebrate assemblages appear to be strongly influenced by past biogeographical events, climatic conditions and present-day vegetative cover/land use. Water chemistry varied considerably between and among ecoregions, however, South-east Forest and North-east Nelson streams in particular, were distinctive. Our findings point to the presence of some areas of high endemism that may be worthy of conservation.

1. INTRODUCTION

To be fully effective, a nationwide river classification based on biotic communities needs to incorporate a regional perspective so that its usefulness to local planners, conservators and river managers will be maximised. An ecoregion classification based on lanscape criteria such as climate, geology, vegetation and soils can be expected to provide an objective basis for such a regional classification of running waters. Site-specific studies on water quality, and the effects of land use on aquatic environments, can then be assessed against appropriate regional criteria and representative reference sites.

The few freshwater classifications proposed for New Zealand have been used for defining the hydrological properties of streams and rivers for descriptive and predictive purposes. Toebes and Palmer (1969) divided the country into 90 hydrological regions on the basis of rainfall, bedrock geology and slope, whereas Beable and McKercher (1982) suggested nine flood frequency regions using mean flow data.

The first river classification incorporating a wide range of abiotic and biotic criteria resulted from a nationwide survey by Biggs *et al.* (1990) and included flow variability, water quality, periphyton and faunal data. Biggs *et* al. (1990) proposed dividing New Zealand into five ecoregions, with the South Island provisionally representing a single region. However, large areas of the South Island, including the West Coast, Fiordland, Banks Peninsula, eastern Southland

and Stewart Island, could not be included in their study because of a lack of hydrological data.

Recent North American river classification systems have acknowledged strong associations between terrestrial and aquatic ecosystems, and as a consequence considerable emphasis has been placed on geographical features that influence catchment conditions (Likens and Bormann 1974, Hynes 1975).

A major strategy adopted to identify aquatic ecoregions is to define them by correlating macro-environmental factors with appropriate biotic data (Lotspeich 1980). Fundamental to this approach is the assumption that ecosystems and their components show regional patterns that are reflected in combinations of different biogeographical conditions (Larsen *et al.* 1986, Omernik 1987). In North America, soil, climate, water availability, vegetation type and land use criteria have been used to identify Land Resource Regions and Major Resource Areas in the United States (USDA Soil Conservation Service 1981). The same technique was adopted by Bailey (1976) to develop an ecoregion map of the USA, and Omernik (1987) who produced ecoregion maps of the Pacific Northwest and the entire United States by integrating mapped data on soil, land-surface form, potential natural vegetation, and land use. Similarly, in New Zealand the Land Resource Inventory categorises areas on the basis of soil type, geology, vegetation and slope (NWASCO 1975-79).

The ecoregions proposed by Bailey (1976) and Omernik (1987) have been tested extensively using diverse data sets, and validated within several States across the U.S.A. (Olson *et al.* 1982, Larsen *et al.* 1986, Heiskary *et al.* 1987, Hughes *et al.* 1987, Rohm *et al.* 1987, Whittier *et al.* 1988).

We have developed an ecoregion classification applicable to New Zealand stream systems based on a range of climatic and geomorphological factors considered likely to be important in influencing the distribution and abundance of stream biota. The distinctiveness of 10 of our South Island ecoregions was evaluated by surveying the water chemistry and benthic communities of 100 representative streams.

2. ECOREGIONS

2.1 Identification of ecoregions

Ecoregions were defined by comparing climatic and geomorphological parameters that on the basis of past experience were considered likely to influence stream biota (Biggs *et al.* 1990, Quinn and Hickey 1990). Lotspeich (1980) suggested that stream communities evolve in response to climatic conditions acting on the geological landscape. Biggs *et al.* (1990) proposed that climate, vegetation, geology and human activities all influence the structure and functioning of river ecosystems; and their hierarchical model with the addition of a biogeographical component was used as the basis of our classification (Fig. 1). The primary tenets of the Biggs *et al.* model are that geology, relief, climate and biogeographic conditions are the `driving' factors that influence vegetation, and land use; and that all of these factors, both directly and indirectly, influence water chemistry, stream hydrology and biota.

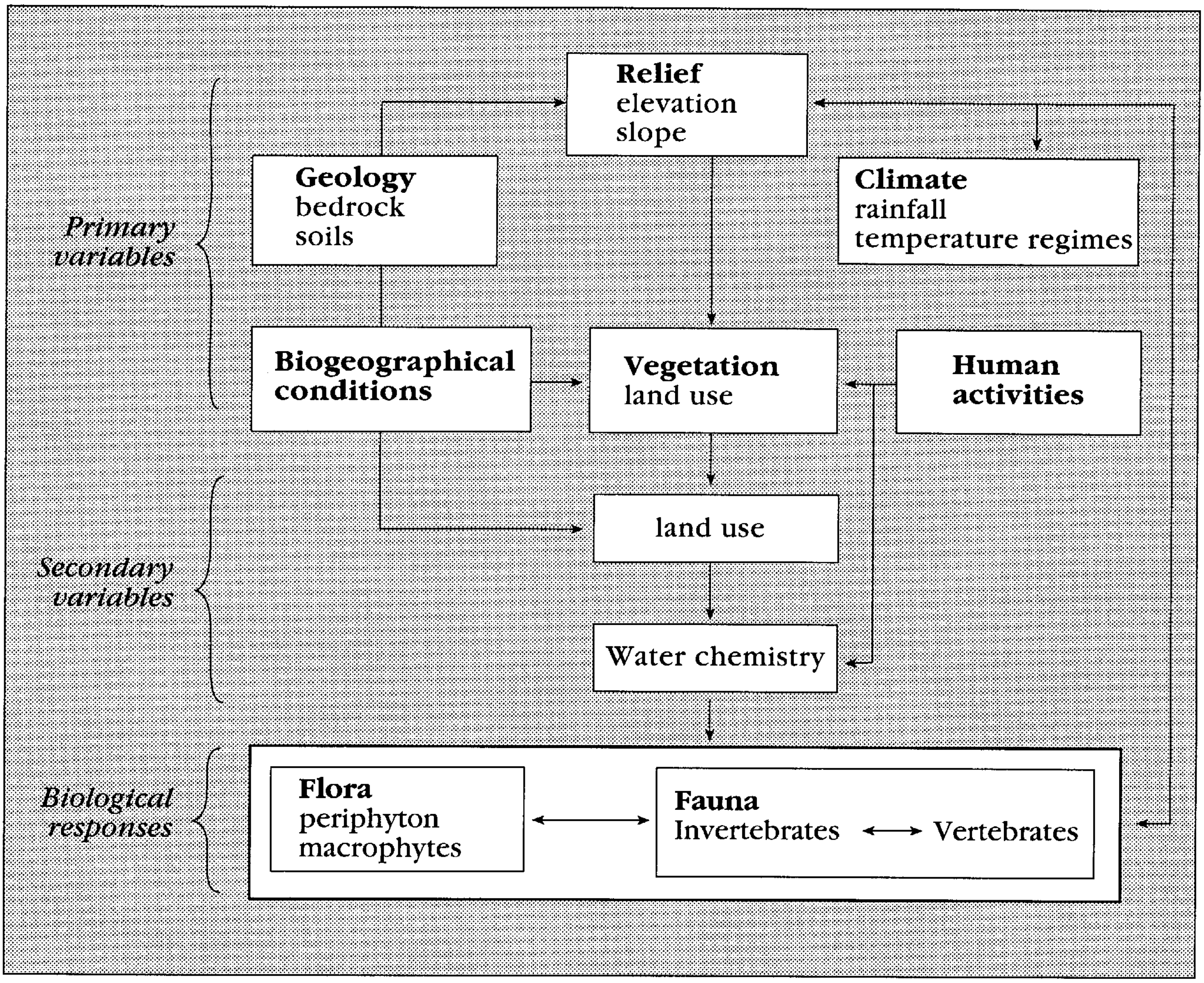


FIGURE 1. A HIERARCHICAL MODEL OF THE MAJOR VARIABLES INFLUENCING THE WATER CHEMISTRY, FLORA AND FAUNA OF STREAMS, AND THE LINKAGES BETWEEN THEM (MODIFIED AFTER BIGGS ET AL. 1990).

We used six variables to identify ecoregions and establish their boundaries. They were: New Zealand Meteorological Climatic Regions, rainfall, relief, vegetation, soils, and geology. New Zealand Climatic Regions were developed by the NZ Meteorological Service (1983), and were used to provide an indication of comparable hydrological, temperature, and climatic conditions across the country. Rainfall normals (1951-80) representing the mean annual rainfall averaged over a 30 year period were included to indicate potential differences in stream flows between streams in each ecoregion (NZ Meteorological Service 1985). Vegetative cover (Newsome 1987) was used as an indicator of current land use patterns, and soil type was included to give a perspective of past regional climate, topography (relief and slope), vegetation and bedrock material, as well as to indicate potential groundwater chemistry. Bedrock geology and soils (NZ Geological Survey 1972a,b; 1973a,b) were measured because of their effects on water chemistry, and on catchment and channel morphology. Lastly, relief (NZ Lands & Survey 1989) was considered as a surrogate of temperature (particularly seasonal extremes).

The South Island ecoregion map was constructed using the Geographic Information System (GIS) package TERRASOFT (Digital Resources 1987). TERRASOFT was used to overlay digitised linework from 1:1,000,000 and 1:2,000,000 maps of the six variables. As databases containing map linework of these variables did not exist, the linework was digitised into the computer by hand. Firstly, six GIS `layers' were created corresponding to the climatic and geomorphological variables. Each of these variables was divided into broad classes: e.g., vegetative cover was divided into forest, scrub, tussock and improved grasses. These layers were then merged and integrated, and areas of less than 1000 hectares were removed. The same procedure was used for the North Island, however, instead of using GIS, the six maps were merged by hand. The North Island is not as geologically complex as the South Island, and areas of native forest, exotic forest and grassland are more clearly defined in the North. There was probably only a minor loss of accuracy in integrating and generalising linework by hand rather than using GIS.

Changes in vegetation and altitude are often associated with changes in rainfall isohyets. Because these two variables accounted for half of the component map data, they provided the most frequent indicators of ecoregion boundaries.

Ecoregions were identified by means of a name/descriptor and a two letter code. Descriptors and codes are indicative of the general geographical area of the ecoregion; e.g., Southland Plains (SL).

2.2 The ecoregions

The North Island was divided into 13 ecoregions (Fig. 2) and the South Island into twelve (Fig. 3). The ecoregions range in size from about 900 to 12 000 km^2, and in the case of High Country (HC), Southern Alps (SA) and Westland Forest (WD) includes small non-contiguous components. Stewart Island forms part of the Westland Forest and South-east Forest ecoregions. Each ecoregion is characterised by a suite of `representative' conditions associated with the six climatic and geomorphological variables (Tables 1 and 2). In general, vegetation was the best delineator of regions as it was often associated with changes in altitude, rainfall, and to a lesser extent soil type. Some ecoregions may be subdivisible on the basis of differences in vegetation, climate and soils. For example, much of the High Country ecoregion is dominated by short tussock (*Festuca* and *Poa* spp.) and snow tussock (*Chionochloa* spp.), although extensive beech forests (*Nothofagus* spp.) occur along the Puketeraki, Poulter, and Dampier Ranges in the headwaters of the Waimakariri and Ashley Rivers. These forested areas also have higher rainfall and higher mean temperatures than the more southern parts of the High Country ecoregion (e.g., the Hokonui and Taringatura Hills), and it can be argued that they represent a subecoregion. Several regions are clearly distinguishable by their uniformity of characteristics, e.g., East Coast Plains of the South Island (EC), and Mt Taranaki (TK), whereas others are less distinctive and included complex combinations of vegetation, geology and soils, e.g., Northern Hill country of the North Island (ND), and North-east Nelson Forest (NE).

3. STREAM ENVIRONMENTS AND STREAM FAUNAS OF SOUTH ISLAND ECOREGIONS

To be useful entities for ecologists, biogeographers, conservation biologists and resource managers, ecoregions need to incorporate distinctive, identifiable environments, and in the present context, characteristic stream communities. The greatest likelihood of finding distinctive running water communities reflecting features of local geography is in low-order streams (headwater tributaries) where the strongest functional relationships between aquatic and adjacent terrestrial ecosystems can be expected to occur. In fact, in such situations the boundaries between the two nominal ecosystem types can be distinctly blurred.

As a first step towards evaluating the validity of the ecoregions defined above we carried out biological and chemical surveys on 10 small (<1.5 m wide) streams in each of 10 South Island ecoregions. No field validation has been undertaken in the Marlborough Plains (MP) and Nelson Plains (NP) ecoregions, or in the North Island. The streams used were identified on topographical and other maps, and had to conform with the principal vegetational, geological, and other catchment criteria most typical of the ecoregion.

This did not mean they were all located in pristine unmodified environments, although this was the case (or closely approximated the situation) in the five predominantly forested, or upland regions. Where the characteristic environment of an ecoregion is now pasture, streams were located there.

3.1 Methods

Physico-chemical and biological surveys were carried out in the 100 headwater streams in the summers of 1993 and 1994. In each stream, sampling was confined to a reach about 10 m long, selected on the basis of visual criteria as being representative of the stream. Physical measurements made in each reach were stream width, water depth and water velocity. The substrate index of Jowett and Richardson (1990) was calculated to provide a comparative measure of average particle size of bed materials. A water sample was taken from each stream for chemical analysis and five benthic invertebrate samples were taken with a Surber sampler (0.11 m^2, 0.25 mm mesh). Full details of sampling, analytical and statistical procedures used are given in Harding (1994).

3.2 The ecoregions

Locations of the 10 sampling sites in each of the 10 South Island ecoregions surveyed in the field are shown in Fig. 4. Summary data for physical characteristics of the streams in each ecoregion are given in Appendix 1 and Appendix 2 shows the total number of macroinvertebrate taxa, and the numbers of taxa belonging to major taxonomic groups in each ecoregion. A list of those taxa collected in at least six streams within an ecoregion is given in Appendix 3, and Appendix 4 lists the five most abundant taxa recorded in each ecoregion. Appendix 5 provides a comparative summary of stream water chemistry.

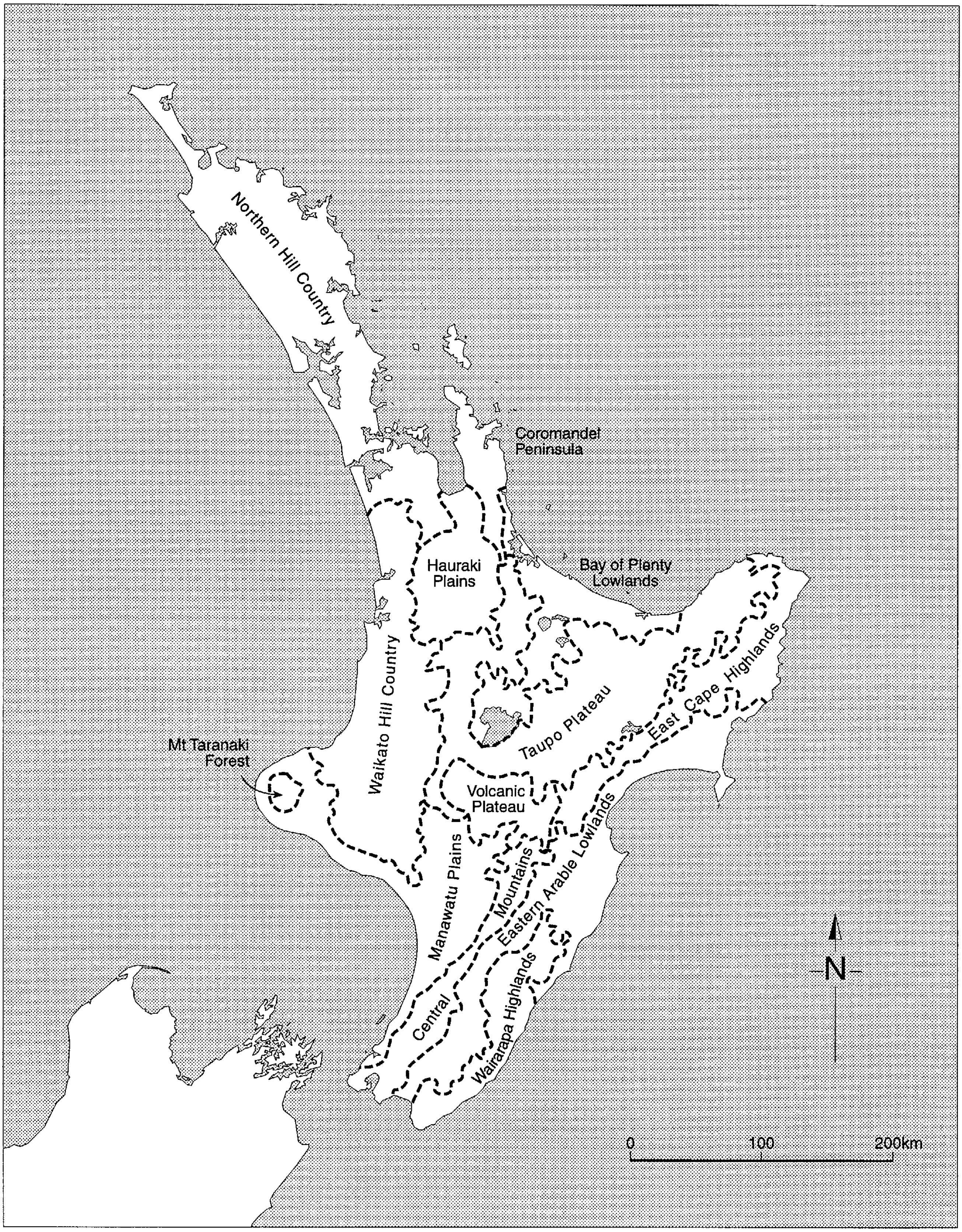


FIGURE 2. THE ECOREGIONS PROPOSED FOR THE NORTH ISLAND, NEW ZEALAND.

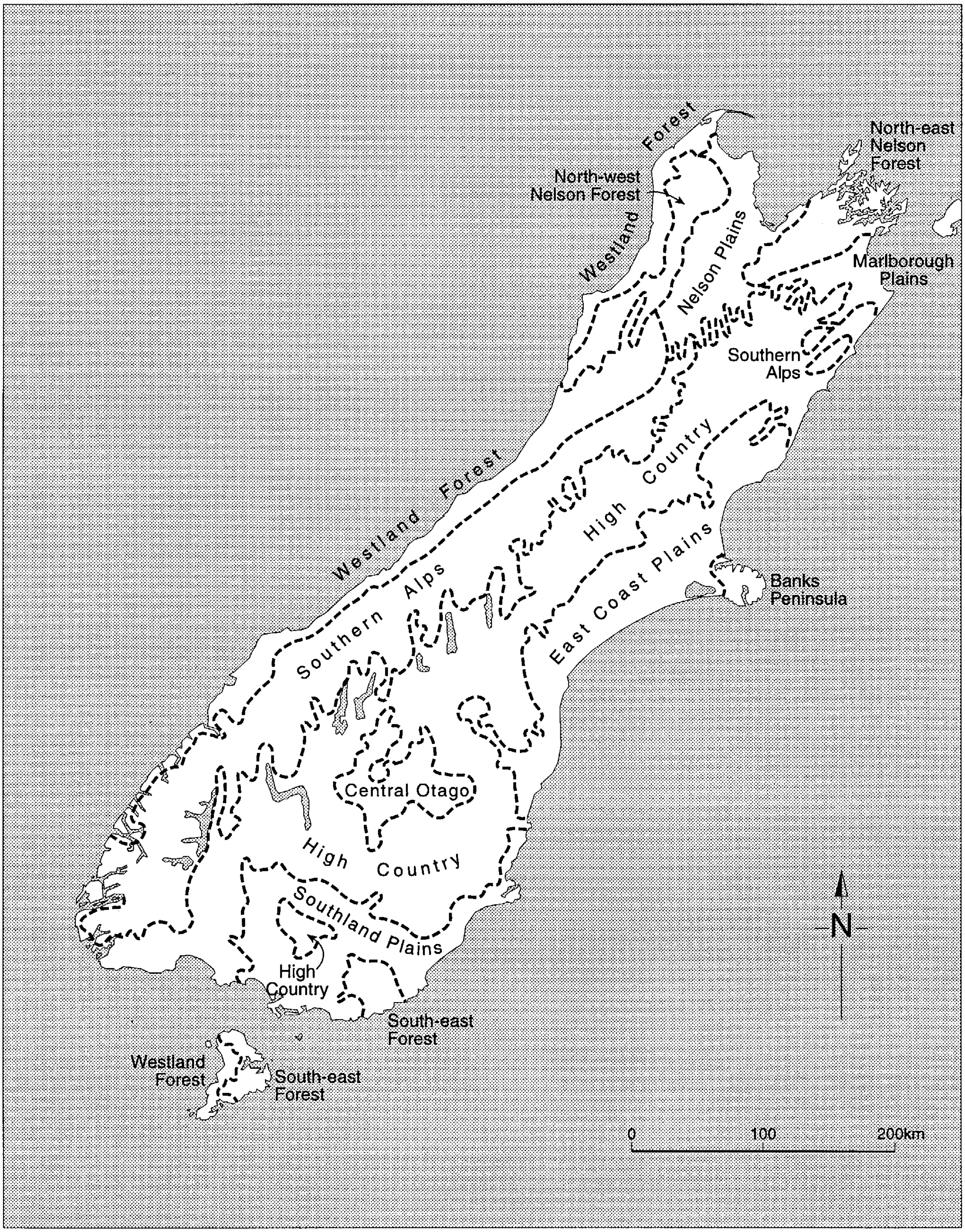


FIGURE 3. THE ECOREGIONS PROPOSED FOR THE SOUTH ISLAND, NEW ZEALAND.

TABLE 1. THE 13 NORTH ISLAND ECOREGIONS. CHARACTERISTIC FEATURES OF THE SIX CLIMATIC AND GEOMORPHOLOGICAL VARIABLES USED TO DIFFERENTIATE THE ECOREGIONS.

CODE	ECOREGION	CLIMATIC REGION	RAINFALL (mm)	RELIEF (m)	VEGETATION	SOILS	GEOLOGY
North	Island						
ND	Northern Hill Country	Al/A2	800-2400	0-300	Mixed forest, grassland	Yellow-brown earths	Sandstone, siltstone
CL	Coromandel Peninsula	A2	1600-3200	0-600	Podocarp/broadleaf forest & exotic forests	Brown-granular loams & yellow-brown pumice	Andesite
HP	Hauraki Plains	A1	800-1600	0-300	Improved pasture	Gley, yellow-brown loams	Alluvium, swamp & peat deposits
BP	Bay of Plenty Lowlands	B1/B2	1200-2400	0-600	Improved pasture, exotic forests	Yellow-brown pumice recent volcanic soils	Alluvium
WO	Waikato Hill Country	A2	1200-3200	300-600	Pasture, podocarp-broadleaf forest	Yellow-brown earths	Sandstone, siltstone
TO	Taupo Plateau	M/B2	1200-4800	300-1000	Exotic, podocarp-broadleaf & beech forest	Yellow-brown pumice	Sandstone, siltstone, ignimbrite
EH	East Cape Highlands	C3	1200-2400	300-600	Grassland, scrub	Yellow-brown earths & pumice	Sandstone, siltstone
EL	Eastern Arable Lowlands	CI/C2	800-1600	0-300	Improved pasture	Yellow grey earths	Marine gravel, sandstone, siltstone
VP	Volcanic Plateau	M	2400-6400	600-2000	Alpine scrub, tussock	Bare rock, recent volcanic soils	Andesite, laharic colluvium
TK	Mt. Taranaki Forest	M	2400-6400	600-2000	Podocarp-broadleaf-beech forests	Bare rock, yellow-brown loams	Andesite, laharic colluvium .
CM	Central Mountains	M/D1	1600-6400	300-1000	Podocarp-broadleaf-beech forests	Yellow-brown earths	Sandstone, siltstone
MN	Manawatu Plains	D1	800-1200	0-300	Improved forest	Yellow-brown sands & yellow grey earths	Alluvium, marine sandstone, siltstone
WA	Wairarapa Highlands	C3/C1	1600-3200	300-600	Grassland, scrub	Yellow-brown & yellow-grey earths	Sandstone, siltstone

TABLE 2. THE 12 SOUTH ISLAND ECOREGIONS. CHARACTERISTIC FEATURES OF THE SIX CLIMATIC AND GEOMORPHOLOGICAL VARIABLES USED TO DIFFERENTIATE THE ECOREGIONS.

CODE	ECOREGION	CLIMATIC REGION	RAINFALL (mm)	RELIEF (m)	VEGETATION	SOILS	GEOLOGY
South	Island						
NN	North west Nelson Forest	M	2400-9600	300-2000	Beech/podocarp	Gleyed podzols	Greywacke, granite
NF	Nelson Plains	B1	0-2400	0-1500	Beech, Exotic, Horticulture	Assorted earths	Gravels, limestone, greywacke
NE	North east Nelson Forest	C1/D2	1200-4800	0-2000	Beech/lowland podocarp	Podzols	Greywacke, argillite
MP	Marlborough Plains	C2	600-1200	0-300	Improved pasture	Yellow-grey earths, recent	Gravel, marine sandstone, siltstone
WD	Westland Forest	E1	2400-4800	0-300	Podocarp	Podzols, recent	Greywacke, glacial gravels
SA	Southern Alps	M	<4800	<1000	Alpine scrub, rock	Podzols, earths, rock	Greywacke, schist
HC	High Country	F2	600-2400	300-2000	Tussock, grassland, scrub	Yellow-brown/grey earths	Greywacke, argillite
EC	East Coast Plains	F1	400-1200	0-300	Improved grasses	Yellow-grey earths, recent	Glacial gravels
PE	Banks Peninsula	C1	1200-2400	300-1000	Grassland, scrub	Brown granular loams & clays	Volcanic basal flows
CO	Central Otago	F3	0-600	0-300	Pasture, tussock	Brown-grey & yellow-brown earths	Alluvial gravels, schists
SL	Southern Plains	G1/G2	600-1200	0-300	Improved grasses	Yellow-grey/brown earths	Aggraded gravels, greywacke
SE	South-east Forest	F2/Gl/G2	1200-2400	0-800	Lowland podocarp, limited beech	Yellow-brown earths, organic, podzols	Sandstone, siltstone

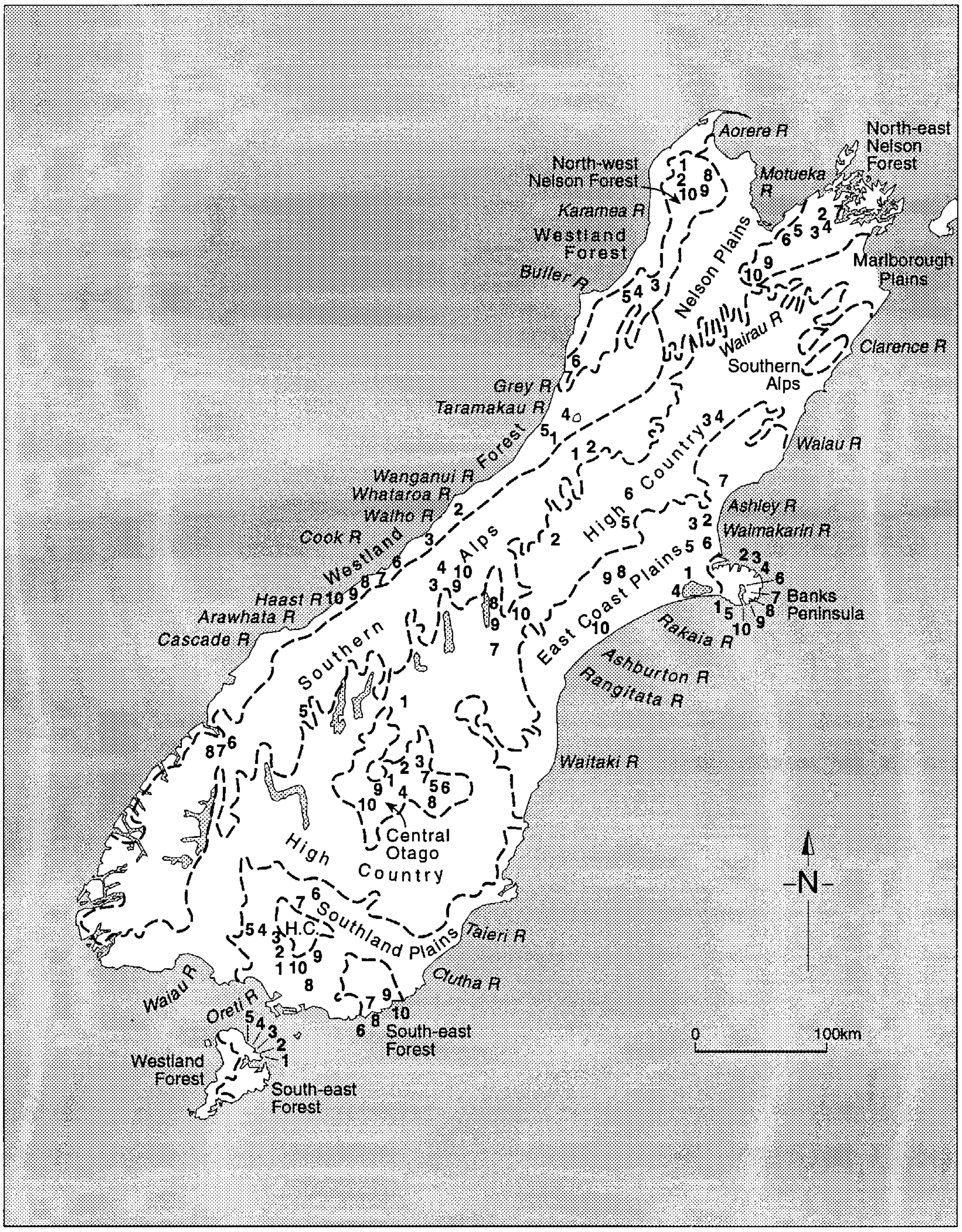
Westland Forest
1 Lake Kaniere tr
2 Noone Ck
3 Fox Stm
4 Nr Donegals tr
5 Kaniere R tr
6 Nr Makawhio tr
7 Ruera tr
8 Fox 59km tr
9 Fox 72km tr
10 Windbag Ck tr

South-east Forest
1 Ryans Ck
2 Fern Gully Ck
3 Horseshoe Bay Ck
4 South Maori R tr
5 Port William Ck
6 Bush Cone tr
7 Longbeach tr
8 Chaslands tr
9 Cathedral tr
10 Florence Stm

NW Nelson Forest
1 Fossil Ck
2 Brown R tr
3 Buller tr 1
4 Flat Ford Ck
5 Nr Lyell Stm
6 Ten Mile Ck tr
7 Taylorville Ck
8 Drummonds Ck
9 Mt Peel Ck
10 Galatea Stm tr

NE Nelson Forest
1 Whangamoa tr 1
2 Whangamoa tr 2
3 Pelorus tr 1
4 Elvy tr
5 The Brook tr
6 Maitai Valley Stm
7 Ronga Saddle Ck
8 Okiwi Valley tr
9 Six Mile Ck
10 Nr Rotoiti tr

East Coast Plains
1 Wildon dr
2 Upper Cam R
3 Upper Ohoka R
4 Lakeside dr
5 Aylesbury wt
6 Amberley Stm
7 Styx R
8 Bar Hill wt
9 B & Vaughan wt
10 Ashburton wt



High Country
1 Longslip Ck
2 Clent Hill Ck
3 Gabriels Gully
4 Camp Stm
5 Coach Stm
6 Dry Stm
7 Bullocky Ck
8 Mossy Stm
9 Ohau tr
10 Paddys Market Stm

Banks Peninsula
1 Kinloch tr
2 Te Kawa tr
3 Holmes Ck
4 Upper Pawsons tr
5 Okuti tr
6 Tautamata Ck
7 Grehan Ck
8 Balgueri Stm
9 Wainui Ck
10 Waiheke Ck

Central Otago
1 Lauder Stm
2 Becks Ck
3 Gorge Ck
4 Spain Ck
5 Wetherburn Stm
6 Eweburn Stm
7 Idaburn Stm
8 Hills Ck
9 Young Hill Ck
10 Waikerike Stm

Southern Alps
1 Upper Otira tr
2 Lake Mavis inflow
3 Stocking Stm tr
4 Stocking Stm tr
5 Treble Cone Ck
6 Marion tr 1
7 Marion tr 2
8 Homer Tunnel tr
9 Wakefield Stm
10 Tussock Ck

Southland Plains
1 Ryal Bush Ck
2 Swales Ck
3 Nr Roe Burn
4 Roy Stm
5 Bonds Ck
6 Larnach Stm
7 McGregor Stm
8 Roslyn Bush Stm
9 Waikiwi Stm
10 Blue tr

FIGURE 4. MAP OF THE SOUTH ISLAND SHOWING THE 12 ECOREGIONS AND THE LOCATIONS OF THE 100 STREAMS SAMPLED DURING THE SUMMERS OF 1993-94. MAJOR RIVERS GENERALLY INDICATED BY SITES OF RIVER MOUTHS. ABBREVIATIONS: tr = TRIBUTARY, Ck = CREEK, Stm = STREAM, R = RIVER, dr = DRAIN, wt = WATER RACE.

The descriptions of individual ecoregions that follow focus on major features of stream catchments, water chemistry and benthic fauna composition. For further details the reader should refer to the Appendices.

North-west Nelson Forest (NN)

The sampled streams drained catchments supporting beech (*Nothofagus* spp.) and mixed lowland/highland podocarp-broadleaf forest. Common components of the latter were rimu *(Dacrydium cupressinum),* kamahi *(Weinmannia racemosa),* tawa *(Beilschmiedia tarairi)* and Hall's totara *(Podocarpus hallii).* Streams were very small and had brown waters and cobble-dominated beds with conspicuous growths of mosses and liverworts. Stream slopes were 3-5°.

Water chemistry of the streams was highly variable (Appendix 5), reflecting the heterogeneous geology of the area. Thus, stream water pH ranged from 6.2 to 7.8, conductivity 28-179 FS cm1, and the concentrations of sodium, calcium and chloride spanned a wide range.

Seventy-five invertebrate taxa were recorded from the 10 streams, the third most of any ecoregion. Species richness was greatest for Trichoptera (caddisflies), Diptera (two-winged flies) and Plecoptera (stoneflies). The most abundant taxa were mayflies *Deleatidium* spp., a small oligochaete worm *Nais* sp., the chironomid midge genus *Paucispinigera,* and stoneflies belonging to the *Zelandobius furcillatus* and Z. *confusus* species groups.

North-east Nelson Forest (NE)

The vegetation of headwater catchments sampled consisted mainly of beech forest, podocarp forest (rimu, miro *(Prumnopitys ferruginea),* totara *(Podocarpus totara)* and kamahi), with ferns, broadleaf shrubs and flax *(Phormium* spp.*)* common in riparian zones. Stream bed materials were predominantly boulders and cobbles, and stream courses were generally steeper (about 5°) than in the North-west Nelson Forest ecoregion.

Stream waters were of circumneutral pH (6.9-7.7) and moderate conductivity (x = 90 FS cm1). Sodium was the dominant cation.

Eighty species of benthic invertebrates were found in the 10 streams sampled, the second highest total of any ecoregion. Species richness was greatest for Trichoptera, Diptera and Plecoptera as in North-west Nelson. The most abundant taxa were *Deleatidium, Zelandobius,* a net-spinning caddisfly *Diplectrona zelandensis,* a mayfly *Coloburiscus humeralis* and the oligochaete genus *Nais.* Of particular note is the presence and abundance of *D. zelandensis* which was found only in the two Nelson ecoregions.

Westland Forest (WD)

The predominant vegetation in the headwater catchments where sampling sites were located was rimu, miro and totara, with an understorey of *Coprosma* species and ferns. Streams were small with variably brown water, and cobble and pebble beds. Mosses and liverworts were common on compacted cobbles, boulders and logs. Stream bed slope was generally low (<3°) and few signs of bank undercutting were evident despite the high rainfall of the region.

Streams were quite well defined chemically with low conductivity (x =41 mS cm'), and low concentrations of sodium and calcium. Stream water pH varied considerably, however, (4.7-7.5), the lower pH streams having brown waters with high concentrations of organic acids.

Ninety-six invertebrate taxa were recorded from the 10 streams, the most recorded in any ecoregion. Species richness was greatest for the Trichoptera, Diptera and Plecoptera, the presence of 16 stonefly species being a distinctive feature of the ecoregion. The most abundant taxa were the mayflies *Deleatidium* spp. and *Coloburiscus humeralis,* a stonefly *Austroperla cyrene,* a midge *Polypedilum* sp., and the caddisfly *Rakiura vernale.*

Southern Alps (SA)

Terrestrial vegetation of the alpine stream catchments was dominated by snow tussock *(Chionochloa* spp.*)* above about 1000 m, and alpine scrub and herbfields above about 1600 m. Stream beds were steep (>5°), and consisted mainly of loose boulders and cobbles devoid of mosses and liverworts.

Streams were well defined chemically with low concentrations of all ions and therefore low conductivity (x = 28 pS cm"'). Calcium was the dominant cation. The dilute nature of alpine streams is a consequence of the high rainfall in the mountains, rapid runoff, thin soils and greywacke bedrock.

Benthic invertebrate faunas were species poor, only 39 taxa being found in the 10 sampled streams. This was the lowest number obtained in any ecoregion. Species richness was greatest for Diptera. *Deleatidium* was the most abundant taxon followed by two chironomid midges *(Eukiefferiella* and *Maoridiamesa),* *Zelandobius* and a small oligochaete *Telmatodrilus multiprostatus.* A notable absentee was the large megalopteran *Archichauliodes diversus.*

High country (HC)

Snow tussock provided the principal vegetative cover in the 10 high country catchments, with pockets of indigenous scrub *(Dracophyllum* spp., *Hebe* spp., *Podocarpus nivalis, Phyllocladus alpinus, Discaria toumatou)* common. Vegetation bordering streams was mainly tussock and introduced plants including broom *(Cytisus scoparius),* gorse *(Ulex europaeus)* and assorted grasses. Sampled stream reaches were of moderately low gradient (3 °) and commonly contained well defined pools alternating with riffles or runs. Dominant bed materials were boulders and cobbles which often supported obvious algal films but few mosses or liverworts.

High country streams had the highest pHs recorded in the 10 ecoregions (x = 7.8) and moderate-low conductivity (X = 68 pS cm·'). Calcium was the dominant cation.

The fourth highest number of species was recorded in this ecoregion (71), with species richness being greatest for Diptera, Trichoptera and Plecoptera. *Deleatidium* was the most abundant taxon followed by two caddisflies *(Aoteapsyche colonica* and *Olinga feredayi)* and two dipterans, the midge *Maoridiamesa* and blackfly (= sandfly) larvae (Simuliidae).

East Coast Plains (EC)

The East Coast Plains ecoregion represents a highly modified landscape in which pastoral farming is the major land use activity. Catchments incorporated in the study supported introduced perennial and short-rotation ryegrasses *(Lolium* spp.*)* and clovers *(Trifolium* spp.*).* Streams draining the catchments were of three types: natural channels, farm drains (mostly natural streams that had been straightened and channelised), and irrigation channels (water races). Natural streams and farm drains were generally slow-flowing, whereas irrigation channels were swifter. Bed materials were mainly pebbles and cobbles that typically supported thick mats of algae. Rooted aquatic macrophytes were also common.

The pH of stream and channel water ranged from 6.3 to 7.7 and the conductivity of some streams was high (X = 142 FS cm1) reflecting moderately high sodium, calcium and chloride concentrations (Appendix 5). Elevated concentrations of nitrate and phosphate were also found in some East Coast streams (Harding 1994).

Forty-nine benthic invertebrate species were recorded from the 10 streams in this ecoregion, the seventh highest total. Species richness was greatest for Trichoptera and Diptera, but only one ephemeropteran taxon was found *(Deleatidium),* and no Plecoptera or Megaloptera were recorded. These heavily modified, low-gradient streams were dominated numerically by the snail *Potamopyrgus antipodarum,* two oligochaete worms and an amphipod *ParacaMope fluviatilis.* The small bivalve *Sphaerium novaezelandiae* was also common.

Banks Peninsula (PE)

Vegetation of the sampled catchments was primarily tussock and other grasses *(Festuca* and *Poa* species), mixed indigenous scrub including mahoe *(Melicytus ramiflorus)* and fuchsia *(Fuchsia excorticata),* and bracken fern *(Pteridium esculentum).* Stream channels were moderately steep (3-5°) and generally consisted of alternating riffles, pools and cascades. Dominant bed materials were boulders and cobbles that were colonised by mosses, liverworts and algae.

The Banks Peninsula streams were chemically more alike than than those of any other ecoregion, not surprisingly perhaps given the area's small size and physical homogeneity. The streams had a narrow pH range (7.0-7.5) and moderately uniform but high conductivity (116-184 pS cm1). High sodium and chloride concentrations reflected the coastal location of the sampled streams.

Sixty-two taxa were recorded from the Banks Peninsula streams, the fifth largest total. Species richness was greatest for Diptera and Trichoptera. The mayflies *Deleatidium* spp. and *Coloburiscus humeralis* were the most abundant taxa followed by two chironomids (Macropelopiini and *Eukiefferiella)* and the snail *Potamopyrgus antipodarum.* A distinctive component of the stream fauna is the net-winged midge *Neocurupira chiltoni* (Blephariceridae) which is endemic to this ecoregion.

Central Otago (CO)

Streams selected for sampling in Central Otago were in tussock and improved grassland catchments. They were low gradient streams (<3 °) consisting mainly of riffles and runs. Bed materials were predominantly loose cobbles, gravels and silt which formed prominent bars on the insides of bends. Sheep were often found in streambeds.

Central Otago streams were quite variable chemically, although total ion concentrations were quite low (x conductivity = 62 mS cm"'). Calcium was the major cation and pH averaged 7.3.

Only 45 taxa were recorded from the 10 Central Otago streams, the eighth largest total. Species richness was greatest for Diptera and Trichoptera. Distinctive features of the Central Otago stream fauna were the presence of only one mayfly taxon *(Deleatidium)* and an unusual combination of abundant taxa. In descending order the top five were an oligochaete worm *Stylodrilus* sp., Simuliidae, *Potamopyrgus antipodarum,* a species of Elmidae (Coleoptera) and *Deleatidium*. The presence of abundant fine sediments probably explains the high relative abundance of oligochaetes and Elmidae in particular.

Southland Plains (SL)

Streams sampled were located in catchments where the predominant land use was intensive grassland farming. Streams had low gradients (1-3 °) and were composed of alternating riffles and runs. Some streams had been straightened and channelised to act as drains as in the East Coast Plains ecoregion and their banks (often as high as 1 m) were frequently eroded by livestock. Dominant stream bed materials were loose cobbles and gravels.

Stream water chemistry was highly variable and some very high sodium and chloride values were recorded (Appendix 5). Mean conductivity (168 PS cm-1) was higher in this and the adjacent South-east forest (SE) ecoregion than in any other, and SL7 had the highest pH (8.5) we recorded.

The second lowest number of taxa (40) was recorded from the 10 Southland Plains streams. Species richness was greatest for Diptera and Trichoptera but only single species of Ephemeroptera, Plecoptera and Coleoptera were found. These low-gradient streams were dominated by the snail *Potamopyrgus antipodarum,* with a second gastropod, the introduced *Physa acuta* also one of the five most abundant species. An oligochaete *(Stylodrilus* sp.*),* a chironomid *(Eukiefferiella* sp.*)* and Elmidae, all of which are associated with fine sediments, were the other most abundant taxa.

South-east Forest (SE)

Rimu, kamahi and miro dominated the forested catchments in which the sampled streams were located. Streams had low gradients (<3 °) and brown waters and were heavily shaded by canopy trees and streamside plants including ferns and epiphytes. Riffles had cobble and pebble-dominated beds and were separated by sandy pools.

Streams were chemically well defined and characterised by high conductivity (X = 187 pS cm1) and high concentrations of sodium and chloride, reflecting the coastal location of the streams and the presence of soft sedimentary bedrock. Calcium concentration was uniformly low in all streams (x = 3.7 mg 1"1).

Fifty-four invertebrate taxa were recorded from the 10 South-east Forest streams, the sixth greatest total. Species richness was greatest for Diptera and Trichoptera. *Deleatidium* was the most abundant taxon, while the occurrence of two amphipods - *Paracalliope* sp. and *Paraleptamphopus subterraneus* - in the list of five most abundant taxa was a distinguishing feature of this ecoregion's fauna.

3.3 Distinctiveness of the proposed ecoregions

Ecoregions were defined on the basis of climatic, geographical and vegetational characteristics, and those examined in the South Island were variably distinctive in terms of their small stream environments and benthic invertebrate faunas.

A TWINSPAN classification of the 100 streams based on presence and absence of invertebrate taxa (Harding 1994) initially separated closed-canopied stream sites (all streams in Westland Forest, South-east Forest, both Nelson ecoregions, and six streams on Banks Peninsula) from exposed or open-canopied sites in Central Otago, Southland Plains, East Coast Plains, High Country, the Southern Alps, and the four remaining 'Banks Peninsula streams. The group of open streams were subsequently divided into two High Country clusters, Southern Alps streams, and the remainder which could not be differentiated along ecoregion lines.

In contrast, South-east Forest streams were separated as a group from the other closed-canopy streams. Subsequent divisions separated most of the other streams on an ecoregion basis. This analysis provides support for the validity of the proposed ecoregions as a basis for classifying aquatic communities since the more pristine and/or climatically harsh ecoregions of the west, north and south-east of the South Island were distinguishable based on the taxonomic composition of their stream faunas. However, as the extent of anthropogenic influences (i.e., deforestation, farming) and the harshness of the climate increase, the distinctiveness of regional stream faunal assemblages declines. Land use clearly is a major factor influencing the diversity and composition of benthic invertebrate faunas in South Island streams, and has the capacity to override regional differences that might otherwise be seen.

In contrast to the fauna, stream water chemistry was less able to discriminate among ecoregions. Several ecoregions contained streams that differed considerably across the spectrum of chemical variables measured, and in no ecoregion did the suite of 10 sites fall out together and alone when subjected to cluster analysis or multivariate ordination (Harding 1994). Catchment level differences in geology, soils, vegetation, rainfall and catchment slope ensure that the water chemistry of streams within an ecoregion is not uniform. Nevertheless, the water chemistry of many streams within individual ecoregions (North-east Nelson Forest, Westland Forest, Southern Alps, High Country, Banks Peninsula, Southland Plains, and South-east Forest) was sufficiently similar that they clustered together on an ecoregional basis.

4. RELEVANCE FOR WATER MANAGERS

An ecoregion classification has the potential to be a useful tool for water managers in several ways:

1. For extrapolating the results of site-specific studies to a broader regional or national scale.
2. To help predict changes in water quality and biological communities in relation to changes in land use activities.
3. For the selection of representative biological monitoring sites.
4. For establishing regionally based management protocols and criteria, for example by providing an appropriate basis for the application of objective stream monitoring techniques such as the Index of Biotic Integrity (Plafkin et al. 1989, Rosenberg and Resh 1993) which assess `degree of impairment' relative to reference sites.

Our surveys undertaken in 10 headwater streams within each of 10 South Island ecoregions provided fundamental information on the composition of benthic faunas of streams within each ecoregion. The relatively high degree of similarity of stream faunas within individual ecoregions, and the finding of regional differences especially in forested ecoregions is particularly encouraging, and suggests that the faunal lists given in Appendix 3 should provide appropriate baseline information for comparative purposes.

Caution is needed however, in using these lists which apply specifically to the faunas of small streams (width < 1.5 m) within particular landscapes as clearly defined within this report. Larger streams and rivers can be expected to differ in their faunal composition, and at least partly because their terrestrial/aquatic linkages are weaker, regional (inter-ecoregion) differences among river faunas can be expected to be less apparent.

Further field research is needed to evaluate the distinctiveness of the proposed North Island ecoregions and the two South Island ecoregions (Nelson Plains and Marlborough Plains) not included in our field programme, and to strengthen understanding of the links between aquatic and terrestrial ecosystems and their biological communities. Only in this way can our ecoregion classification be evaluated rigorously, as a tool for environmental managers.

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7. APPENDICES

Appendix 1

Mean values for physical characteristics of streams surveyed in the 10 South Island ecoregions
(±1SE, n = 10 per ecoregion).

ECOREGION	ALTITUDE (m)	DEPTH (m)	WIDTH (m)	VELOCITY (ms")	SUBSTRATE INDEX
NN	353±92	0.07±0.09	0.7±0.1	0.2±0.01	5.1±0.1
NE	301±68	0.09±0.12	1.1±0.2	0.2±0.20	5.4±0.1
WD	87±23	0.07±0.05	0.9±0.2	0.2±0.02	5.0±0.1
SA	1068±85	0.07±0.09	0.8±0.1	0.2±0.01	5.6±o.1
HC	687±61	0.11±0.13	1.3±0.2	0.3±0.02	5.2±0.1
EC	90±33	0.18±0.23	1.1±0.2	0.3±0.04	4.7±0.1
PE	150±36	0.11±0.10	0.9±0.1	0.2±0.01	5.4±0.1
CO	426±46	0.14±0.18	1.1±0.1	0.3±0.2	4.6±0.1
SL	119±32	0.12±0.15	1.3±0.1	0.2±0.02	4.7±0.2
SE	114±24	0.06±0.03	0.6±0.1	0.2±0.01	5.0±0.3

Appendix 2

Total number of macroinvertebrate taxa collected from all 10 streams in each ecoregion.

	NN	NE	WD	SA	HC	EC	PE	CO	SL	SE
Ephemeroptera	6	9	7	2	5	1	5	1	1	5
Plecoptera	14	13	16	8	11	0	7	2	1	8
Trichoptera	26	22	30	9	19	11	15	11	9	11
Megaloptera	1	1	1	0	1	0	1	1	1	0
Coleoptera	4	4	6	2	2	2	3	1	1	3
Diptera	16	20	25	12	21	18	18	13	12	16
Mollusca	1	2	3	1	3	4	2	6	4	1
Others	7	9	8	5	9	14	13	10	11	10
Total	75	80	96	39	71	49	62	45	40	54

Appendix 3

List of taxa collected in at least 6 streams within an ecoregion.

	EC	SL	CO	SA	HC	PE	NE	NN	SE	WD
PLATYHELMINTHES										
Neppia montana	+	+			+	+	+			+
ANNELIDA										
Lumbriculus variegatus										+
Telmatodrilus multiprostatus				+						
Stylodrilus sp.	+	+	+						+	
Nais sp.							+	+		
MOLLUSCA										
Potamopyrgus antipodarum	+	+	+		+	+	+		+	
Physa acuta	+	+								
Sphaerium novaezelandiae	+	+								
CRUSTACEA										
Paracalliope sp.	+								+	
INSECTA										
EPHEMEROPTERA										
Coloburiscus humeralis					+	+	+			+
Nesameletus sp.						+	+	+		
Ameletopsis perscitus										+
Neozephlebia scita						+	+			
Zephlebia dentata							+	+		
Deleatidium spp.	+		+	+	+	+	+	+	+	+
Austroclima jollyae										+
PLECOPTERA										
Stenoperla prasina							+	+	+	+
Austroperla cyrene						+	+	+	+	+
Zelandoperla decorata					+	+	+	+	+	
Zelandobius confusus - group							+		+	
Zelandobius furcillatus - group						+		+		+
Cristaperla fimbria							+	+		
Megaleptoperla diminuta									+	
MEGALOPTERA										
Amhichauliodes diversus					+	+				
COLEOPTERA										
Elmidae	+	+	+		+		+	+		
DIPTERA										
Eriopterini sp.		+						+	+	
Nothodixa sp.									+	
Eukiefferiella spp.		+	+	+	+	+				
Paucispinigera approximata								+		
Polypedilum spp.							+			
Macropelopiini sp.						+				
Diamesinae indet.									+	
Maoridiamesa sp.					+	+				
Cricotopus spp.			+							
Simuliidae	+	+	+		+	+	+		+	+
Tanyderidae						+				
Empididae sp. A					+	+				
Empididae sp. B (hairy)									+	
Muscidae		+								
Paralimnophila skusei									+	
Aphrophila neozelandica					+					

	EC	SL	CO	SA	HC	PE	NE	NN	SE	WD
TRICHOPTERA										
Diplectrona zelandensis							+	+		
Aoteapsyche colonica			+		+	+	+			
Hydrobiosella stenocerca							+	+	+	
Hydrobiosis silvicola										+
Hydrobiosis parumbripennis	+	+	+		+	+				
Psilochorema nemorale	+	+			+		+		+	+
Olinga feredayi					+	+	+			
Helicopsyche spp.					+	+	+			
Rakiura vernale								+		+
Pycnocentria evecta	+		+		+		+			
Pycnocentrodesspp.	+				+					
Hudsonema amabilis	+		+							
Oxeythira albiceps	+	+								

Appendix 4

The five most abundant taxa in order of frequency of abundance in streams of each ecoregion (n = 10 streams per ecoregion).

	ORDER OF ABUNDANCE				
	1	2	3	4	5
NN	*Deleatidium spp.*	*Nais sp.*	*Paucispinigera sp.*	*Zelandobius furcillatus - gp*	*Zelandobius confusus*
NE	*Deleatidium spp.*	*Zelandobius confusus - gp*	*Diplectrona zelandensis*	*Coloburiscus bumeralis*	*Nais sp.*
WD	*Deleatidium spp.*	*Coloburiscus humeralis*	*Austroperla cyrene*	*Polypedilum sp.*	*Rakiura vernale*
SA	*Deleatidium spp.*	*Eukiefferiella sp.*	*Zelandobius furcillatus - gp*	*Maoridiamesa sp.*	*Telmatodrilus multiprostatus*
HC	*Deleatidium spp.*	*Aoteapsyche colonica*	*Olinga feredayi*	*Maoridiamesa sp.*	Simuliidae
EC	*Potamopyrgus antipodarum*	*Paracalliope sp.*	*Limnodrilus sp.*	*Stylodrilus sp.*	*Sphaerium novaezelandiae*
PE	*Deleatidium spp.*	*Coloburiscus bumeralis*	Macropelopiini	*Potamopyrgus antipodarum*	*Eukiefferiella sp.*
CO	*Stylodrilus sp.*	Simuliidae	*Potamopyrgus antipodarum*	Elmidae	*Delealidium*
SL	*Potamopyrgus antipodarum*	*Stylodrilus sp.*	Elmidae	*Eukiefferiella sp.*	*Physa acuta*
SE	*Deleatidium spp.*	*Paracalliope spp.*	*Stylodrilus sp.*	*Paraleptamphopus subterraneus*	*Hydrobiosella stenocerca*

Appendix 5

Means and ranges of values for pH, conductivity and six major cations and anions for streams in 10 South Island ecoregions. Units are mg 1 -' except pH, and conductivity (IASctri' at 25°C).

	NN	NE	WD	SA	HC	EC	PE	CO	SL*	SE
pH	6.9	7.4	6.0	6.9	7.8	6.9	7.2	7.3	7.2	7.1
	(6.2-7.8)	(6.9-7.7)	(4.7-7.5)	(6.0-7.9)	(7.6-8.1)	(6.3-7.7)	(7.0-7.5)	(6.8-7.8)	(6.4-8.5)	(6.8-7.5)
Conductivity	76	90	41	28	68	142	133	62	168	187
	(28-179)	(43-149)	(19-88)	(5-43)	(32-175)	(57-237)	(116-184)	(33-96)	(68-299)	(16o-237)
Na	6.2	6.8	2.9	2.4	5.2	11.3	15.5	6.2	20.2	32.3
	(2.5-24.1)	(2.7-8.3)	(1.6-6.1)	(0.5-13)	(2.5-9.9)	(1.9-30.2)	(10.1-22.2)	(2.9-16.6)	(7.5-47.5)	(24.2-44.2)
K	0.6	0.8	0.9	0.5	1.1	1.8	0.9	1.1	1.4	2.6
	(0.2-1.5)	(0.6-1.4)	(0.2-2.1)	(0.3-0.7)	(0.5-3.0)	(0.4-2.9)	0.8-1.3)	(0.3-3.6)	(0.4-2.8)	(1.8-3.5)
Ca	9.3	2.6	2.4	6.6	10.8	10.5	4.0	9.5	9.7	3.7
	(1.4-54)	(1.2-3.9)	(0.2-5.8)	(0.8-14)	(5.3-18.3)	(4.0-16.7)	(2.7-6.4)	(5.4-13.6)	(5.5-21.4)	(2.9-4.4)
Mg	2.0	1.7	0.6	0.4	1.8	3.0	2.1	1.7	5.5	4.6
	(0.6-3.6)	(0.5-3.1)	(0.2-1.9)	(0.1-0.8)	(0.8-3.6)	(0.7-6.5)	(1.8-2.7)	(0.9-2.4)	(2.7-8.4)	(3.8-5.9)
Cl	54	15	4	1.6	8	13	28	11	26	56
	(2-61)	(2-32)	(0.5-13)	(0.4-4.4)	(1.2-20)	(0.5-39)	(18-52)	(5-15)	(1.4-65)	(43-84)
S04	2.5	3.8	0.4	1.7	2.0	1.4	1.4	1.6	2.9	3.3
	(0.8-6.0)	(1.7-9.7)	(0.1-1.2)	(0.2-2.6)	(0-2.9)	(0.7-2.7)	(0.8-4.6)	(0.5-2.1)	(0.6-4.5)	(2.7-3.8)

*Site SL10 had an excessively high conductivity of 466 pScm""" and is omitted from calculations.