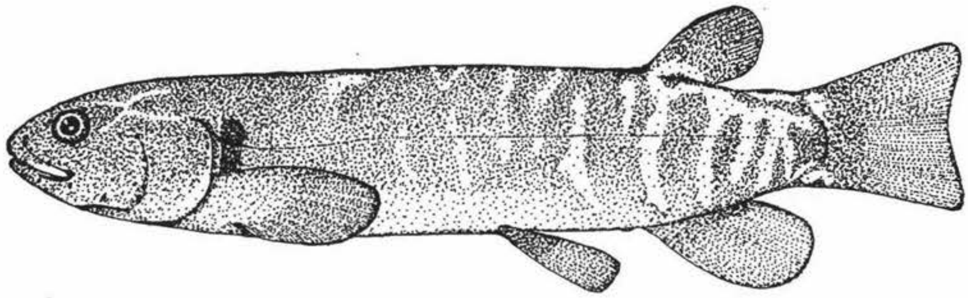
FRESHWATER FISH COMMUNITY STRUCTURE IN TARANAKI: DAMS, DIADROMY OR HABITAT QUALITY?



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ABSTRACT

The relationships between freshwater fish community structure and habitat characteristics including dams were examined at 85 sites on 38 waterways draining Mount Taranaki during the summer of 1997/98. Thirteen native and two exotic fish species were captured. Four groupings were identified based on species composition. The first two were high elevation site groups: one dominated by the diadromous Galaxiids: shortjawed kokopu, banded kokopu and koaro, the other dominated by longfin eels. The third group of sites was a mid-elevation group dominated by redfin bullies and longfin eels while the fourth group was made up of low elevation sites dominated by redfin bullies and shortfin eels. Discriminant analysis revealed that distance from the sea, site elevation and the presence of dams were the environmental variables most strongly associated with fish distribution patterns.

Data from the New Zealand freshwater fish database (NZFFD) were used to examine the influence of dams and other environmental variables on the fish communities. The sites listed in the NZFFD as having free migratory access were used as reference sites for the construction of a predictive model of fish community assemblage. The species found at test sites were compared with the predicted assemblage and an observed over predicted ratio (O/P) produced for each test site in order to evaluate the relative impact of migratory barriers. The 85 sites from the 1997/98 survey, which were independent of the reference sites used in the model, were used as a test of the model. The O/P ratios were significantly lower for sites above barriers when compared with sites with free access. To demonstrate the use of the model, the impact of the Motukawa dam on fish communities was analysed by comparing the O/P ratios for sites above and below the dam. The resulting ratios were significantly lower above the dam, indicating that the dam was having a negative impact on fish communities.

Distinctive trajectories of occurrence were detected for 13 species from the Taranaki ring plain. The diadromous species were ranked based on their ability to penetrate inland to enable comparison with other regions. The Taranaki rankings were consistent with rankings for the same species from the West Coast of the South Island.

The high proportion of diadromous species in the Taranaki fauna means that access is of primary importance in structuring the fish communities and the large number of dams in the region has had a discernable negative effect on freshwater fish communities.

EXPLANATION OF TEXT

This thesis is a combination of three individual papers. This has resulted in some repetition in introductions, methods and site descriptions between chapters. Chapter two has been submitted to Ecological Applications and Chapter three to the New Zealand Journal of Marine and Freshwater Research. The model outlined in Chapter 3 has been made into a Windows based computer program called Redfin version 1.1. The program has been installed and used by the Taranaki Regional Council, Department of Conservation Wanganui and the consulting firm Resource and Environment (New Plymouth).

The fish sampling methods used in this project have been sanctioned by the Massey University Ethics Committee.

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Finally, I want to dedicate this thesis to my sister Bernice Hawken and to my partners' mother Peggy Hewitt who both died during the writing of this thesis.

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Chapter 1: General Introduction

The New Zealand freshwater fish fauna is unique in that more than half the fauna is migratory and of those migratory species an unusually high proportion are either amphidromous[1] or catadromous[2] (McDowall 1998). In contrast, in most other fish faunas worldwide, migratory species are rare and among those migratory species, anadromy[3] predominates while amphidromy is virtually absent. The predominance of migratory species is even more pronounced in the Taranaki fauna with 15 migratory species from a total of 21 species (71%), 12 of these migratory species are catadromous or amphidromous (80%), while the rest are anadromous (Table 1.1). These differences in the ratio of migratory to non-migratory species and types of diadromy have important ramifications when assessing the way communities are assembled and structured. Most studies of riverine fish communities have taken place in continental USA and Europe and have related community structure to intrinsic biotic community processes and/or proximal habitat variables. However, communities with a high proportion of diadromous species are constantly modified by the influx of migratory species. This means that they may be more influenced by factors related to site access than habitat or biotic interactions and this will limit the applicability of such studies to New Zealand.

The high proportion of diadromous species in the New Zealand fauna is also important to the understanding of patterns of distribution, assemblage structure and the resilience of fish communities. McDowall (1996 a) highlighted the importance of considering whether a community is open (i.e., continually being invaded from outside the community) or closed (minor migratory component). This distinction is important because the relative significance of proximal and historical influences will differ markedly between open and closed communities. Attempts at establishing links between fish communities and habitat or biotic relationships in New Zealand have been frustrated by the overwhelming influence of diadromy (Hayes et al. 1989;

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[1] Amphidromy is migration between freshwater and sea not related to spawning.

[2] Catadromy is migration from freshwater by adult fish to spawn at sea.

[3] Anadromy is migration upstream from the sea by adult fish to spawn.

Hanchett 1990; Jowett et al. 1996; Jowett & Richardson 1996). Thus, fish communities made up of predominantly diadromous species are structured by the available species pool after the influence of access (McDowall 1996 a) rather than by evolutionary/historical factors (Gorman 1991; Bayley & Li 1992). In addition, these communities are potentially more resilient to short duration disturbance as species which become locally extinct can be replaced by migration (McDowall 1998). Access then becomes the important factor structuring communities and may become more important than proximal biotic and abiotic factors.

Table 1.1. Taranaki ring plain freshwater fish species, familial associations and type of diadromy for species captured during 1997/98 survey and historical records from the New Zealand Freshwater Fish Database (NZFFD).

Family	Scientific name	Common name	Type of diadromy
Anguillidae	*Anguilla australis* Richardson	Shortfin eel	Catadromy
	Anguilla dieffenbachii Gray	Longfin eel	Catadromy
Cyprinidae	*Cyprinus carpio* Linnaeus	European carp	non-migratory
	Scardinius erythrophthalmus Linnaeus	Rudd	non-migratory
Retropinnidae	*Retropinna retropinna* (Richardson)	Common smelt	Anadromy
Galaxiidae	*Galaxias maculatus* (Jenyns)	Inanga	Catadromy
	G. argenteus (Gmelin)	Giant kokopu	Amphidromy
	G. fasciatus Gray	Banded kokopu	Amphidromy
	G. postvectis Clarke	Shortjaw kokopu	Amphidromy
	G. brevippinis Günther	Koaro	Amphidromy
Geotriidae	*Geotria australis* Gray	Lamprey	Anadromy
Percidae	*Perca fluviatilis* Linnaeus	Perch	non-migratory
Pinguipedidae	*Cheimarrichthys fosteri* Haast	Torrentfish	Amphidromy
Eleotridae	*Gobiomorphus huttoni* (Ogilby)	Redfin bully	Amphidromy
	G. gobioides Valenciennes	Giant bully	Amphidromy
	G. hubbsi Stokell	Bluegill bully	Amphidromy
	G. cotidianus McDowall	Common bully	Amphidromy
	G. basalis Gray	Crans bully	non-migratory
	G. breviceps Stokell	Upland bully	non-migratory
Mugilidae	*Aldrichetta forsteri* Valenciennes	Yelloweyed mullet	Anadromy
Salmonidae	*Salmo trutta* Linnaeus	Brown trout	non-migratory

Scale is another important consideration when looking at the influences on community structure (Levin 1992; Pickett 1995). In many studies, the habitat features implicated in structuring fish communities appear to depend on the scale used in the study. In continental Africa, America and Europe, most freshwater fish studies have related different habitat factors to communities using community descriptors such as diversity or species number. On very large scales, such as biogeographical areas, fish species richness is attributed to climatic or geographical events (Mahon 1984; Moyle & Hebold 1987; Hugueny & Leveque 1994). At regional or single catchment scales species richness is mainly explained by catchment area (Livingston et al. 1982; Hugueny 1989; Welcomme 1990) and river discharge (Oberdorff et al. 1995). At even smaller scales such as stream reaches the physical factors related to species richness are usually habitat size or volume (Angermeir & Schlosser 1989), habitat diversity (Gorman & Karr 1978; Angermeir & Schlosser 1989), and distance from the sea (Lyons & Schneider 1990; Reyes-Gavilan, 1996). Similarly, the factors associated with fish community structure in New Zealand differ with scale. Most New Zealand studies of fresh water fish have taken place in confined geographical areas and have related the communities to land use (Hanchett 1990; Swales & West 1991; Graynoth 1979; Taylor 1988; Jowett et al. 1996), competition/predation (Cadwallader 1975; Sagar & Eldon 1983; Townsend and Crowl 1991) or disturbance (Glova et al. 1985). At larger scales, when waterways are considered over an elevational range (Hayes et al. 1989; Jowett et al. 1996) or over the country as a whole (Minns 1990; McDowall 1996 b; Jowett & Richardson 1996) then diadromy is proposed as the main influence on fish assemblage.

One of the most widespread human disturbances of the stream environment both in New Zealand and worldwide is flow modification (Fraser 1972; Ward & Stanford 1979; Stanford & Ward 1983). Man made dams have existed for centuries world wide and there is little doubt that they have a dramatic impact on the ecology, flora and fauna of these waterways. Many studies suggest that the changes to the stream environment caused by a dam have long-term deleterious effects both above and below the dam (Neel 1963; Ridley & Steel 1975; Baxter 1977; Reyes-Gavilan 1996). Dams, regardless of function will have major impacts on freshwater fish in many ways. Fish habitat is impacted by flow alteration with modification of the aquatic habitat from lotic to lentic, yielding changes in physical habitat availability, water chemistry, temperature and nutrient cycling (Burt & Mundie 1986; Bain et al. 1988; McDowall 1996 a). However, the most obvious and important (especially in New

Zealand) consequence of dams on freshwater fish is the blocking of migration. Dams potentially block both upstream and downstream passage to spawning grounds and habitat in general. Furthermore, the spawning or habitat areas migratory fish are seeking may have been rendered unsuitable by the dam as a result of inundation, change in flow regime, substrate, temperature or water chemistry.

Given the importance of diadromy in the structuring of fish communities in New Zealand it follows that the dams in New Zealand will have an even greater impact on fish distribution than they would elsewhere in the world. More than 50 dams are known in the Taranaki region (Taranaki Regional Council 1995); many are disused water supply dams for now defunct dairy factories (Hicks 1983). Several of these dams have fish passes installed although most passes are considered totally inadequate for the purpose (Mitchell 1993).

To quantify the effect of barriers on fish communities, the communities found in the absence of a barrier must be compared with those separated from the sea by a barrier. One of the most effective ways to make comparisons using fish communities is with the reference condition approach as illustrated by Zampella and Bunnell (1998). This approach is based on comparing biological conditions at a test site to that at a range of communities observed at a set of unimpacted sites (reference sites) (Hughes et al.1986). To assess a test site; its deviation from the reference condition is made based on habitat and environmental information. If a set of habitat or environmental measures explains a substantial amount of the variation in the communities, then the observed values of these measures enables prediction of the community that would be expected if the site were unimpacted. In this study, the method used to apply this process was initially based on the procedure used with benthic macroinvertebrates by Wright et al. (1984) and Reynoldson et al. (1995) to quantify water quality. In this case however, the reference sites are those with free migratory access. Observed values are compared with predicted values to measure the effect of dams on fish communities and to quantify the effectiveness of fish passes where they are installed.

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Chapter 2: Control of Freshwater Fish Community Structure in Taranaki: Dams, Diadromy or Habitat Quality?

ABSTRACT

The relationships between freshwater fish community structure and habitat characteristics including dams were examined in 38 waterways draining Mount Taranaki, North Island, New Zealand. During the summer of 1997/98 thirteen native and two exotic fish species were captured at a range of elevations in a survey of 85 sites. Sites were grouped based on their species composition using TWINSPAN analysis. Four groups were identified. The first was a high elevation site group dominated by the diadromous Galaxiids: shortjaw kokopu, banded kokopu and koaro; whereas in the second group, also a high elevation group, longfin eels dominated. The next group of sites was a mid-elevation group dominated by redfin bullies and longfin eels while the fourth group was made up of low elevation sites dominated by redfin bullies and shortfin eels. Discriminant analysis showed that distance from the sea, site elevation and the presence of dams were the environmental variables most strongly associated with fish distribution patterns.

Keywords: Diadromy, freshwater fishes, Taranaki, dams, multivariate analysis

INTRODUCTION

A number of factors are implicated in controlling the distribution of stream fish species and the regulation of fish community structuring worldwide. Biotic interactions, mainly competition and predation have been proposed as major influences on fish community organisation (Werner & Gillian 1984; Ross 1986; Gillian et al. 1993). However, other studies have proposed abiotic factors as predominant influences on fish communities. The abiotic factors include physical habitat features such as substrate composition, width, depth, temperature and current velocity (Huet 1959; Gorman & Karr 1978; Burt 1989; Angermeier & Schlosser 1989; Rahel & Hubert 1991) stream size, gradient, stream order and catchment area

(Sheldon 1968; Horowitz 1978; Eadie et al. 1986; Beecher et al. 1988). Biotic and abiotic factors have been combined along upstream-downstream gradients with the River Continuum Concept (RCC) (Cummins 1979; Vannote et al. 1980; Cushing et al. 1983; Minshall et al. 1985; Schlosser 1990) and integrated into synthetic models (Zalewsky & Naiman 1985; Zalewsky et al. 1990; Schlosser 1987). In contrast to deterministic views of community organisation, stochastic events mainly related to flow variability have also been proposed as important influences on fish communities (Moyle & Li 1979; Grossman et al. 1982, 1985, 1990; Ross et al. 1985), although assemblages may be stable even in extreme flow variations (Matthews 1986; Meffe & Berra 1988; Meador & Matthews 1992).

Regardless of the processes implied in regulation of stream fish communities, an increase in diversity is found in a downstream direction almost universally. In North America and Europe this pattern is generally attributed to increased habitat diversity, habitat volume and more stable conditions in the lower reaches of a waterway (Sheldon 1968; Lotrich 1973; Rahel & Hubert 1991). In New Zealand however, this increase in species richness downstream has been attributed to the fact that the fauna is dominated by diadromous species (Hayes et al. 1989; McDowall 1993, 1996, 1998; Jowett & Richardson 1996). No other fish fauna with the same or higher number of species has such a high proportion of diadromous species (McDowall 1988, 1995, 1997). As a consequence, establishing links between species diversity and such factors as land use, habitat and/or biotic relationships in New Zealand is frustrated by the overwhelming and variable influence of diadromy (Hayes et al. 1989; Hanchet 1990; Jowett et al. 1996; Jowett & Richardson 1996).

Because of their marine life-stage, diadromous fish have distributions influenced by upstream and downstream migrations. These distributions are analogous to diffusion from a source (the ocean) to the limit of their upstream penetration, governed by the interaction of variables such as their swimming ability, barrier effects, distance upstream and instinctive migratory drive (Smogor et al. 1995). Caution is therefore required when associating habitat characteristics with fish distribution, as the observed distribution may not be the result of habitat suitability, but rather access. A fauna with such a high proportion of diadromous species has an enormous potential to be affected by barriers to migration. Dams, regardless of the reason for their existence, are likely to impact on fish habitat in a number of ways (Sale 1985; Bain et al.1988; Kanehl 1997); however, the most obvious negative effect is the impediment of migration (Davis & Teirney 1987; Jowett 1987; Lusk 1995; Reyes-Gavilan 1996).

In this study, we examine changes in fish assemblage structure along an elevational gradient in 38 Taranaki ring plain streams (a number of which have barriers to migration) to identify whether species distribution is associated with migratory barriers (dams) or some other habitat features.

METHODS

Study area and sampling methods

Mt. Taranaki is an andesitic volcano, symmetrical in shape and has intact native forest down to an altitude of c. 400-m a.s.l. This results in streams having similar gradients and all emerge at similar altitudes from native forest into farmland. The predominant land-use of the farmland is dairying. Fish were collected from 85 sites on 38 streams draining Mount Taranaki during summer 1997/98. Thirty-two of these sites are known to be above a man made barrier; however, none of these appear to be total barriers to migration for all species and some have fish-passes installed to permit passage.

Two sampling methods were used, electro-fishing and night spotlighting. Electro-fishing was carried out using a battery powered pulsed DC backpack electro-fishing machine (EFM300; NIWA Instrument Systems). Fish stunned when electro-fishing, and those caught in nets when spotlighting, were identified to species then returned to the water. Fish observed and positively identified to species before or during electro-fishing and/or night spotlighting were also recorded. The area fished at each site ranged between 50 and 200m^2. Fish densities are expressed as the number of fish per 100 m^2

Altitude and distance from the sea was estimated for each site from NZMS 1:50,000 topographic maps. The predominant riparian vegetation, substrate composition, water surface character and overhead cover were visually assessed over the area fished.

Diversity measures

Three measures of fish diversity were calculated for each site, they were:

(1) Species number (S).

(2) Shannon-Weaver index (H'):

$$H' = -\sum p_i \ln p_i$$

Where p_i is the proportion of individuals in the ith species (Shannon & Weaver 1949)

(3) Evenness (E): H'/ln S (Pielou 1969).

Data analysis

Data were analysed using the regression and Spearman rank correlation procedures of SAS (1995). Spearman rank correlation was used to identify relationships between fish density or diversity and environmental variables. Differences in species diversity for sites above and below dams were evaluated by analysis of covariance with elevation as a covariate (REG procedure of SAS: 1995). Habitat data from sites without migratory barriers were included in a linear regression analysis to yield a predictive equation for species richness. Using this equation species richness was predicted for sites above barriers. The residuals were compared for sites with and without barriers using a T test under the null hypothesis of barriers having no effect on species richness. Comparisons of mean density and diversity measures for sites above and below dams were made with the non-parametric Kruskal-Wallis test (NPAR1WAY procedure of SAS: 1995). Significance was accepted at $P < 0.05$.

The relationship between fish communities and the physical characteristics found at sites was examined by first identifying groups of sites that contained similar fish assemblages using TWINSPAN (PC-ORD; McCune & Mefford 1995). The TWINSPAN analysis (to two levels) was achieved using five pseudospecies cut levels 0, 2, 5, 10 and 20 fish per 100 m^2. Relationships between environmental measures and groups classified by TWINSPAN were examined using linear discriminant analysis. The models were then used to test the performance of the environmental variables in separating sites into their respective TWINSPAN groups (classification success) and by considering the posterior probability error rate estimates of the classification results (DISCRIM CROSSVALIDATE procedure of SAS: 1995).

Canonical discriminant analysis was then performed to evaluate the importance of each of the environmental variables in discriminating between the Twinspan groups (CANDISC procedure of SAS: 1995). The coefficients of canonical variables can be biased by correlated variables (Williams 1983). To mitigate this effect the canonical variables were also interpreted by examining their correlation with each of the variables (CORR procedure of SAS: 1995). To highlight the differences between mean diversity and environmental measures between TWINSPAN groups the non-parametric analysis of variance Kruskal-Wallis test was used (NPAR1WAY procedure of SAS: 1995). To indicate which of the four TWINSPAN groups were different comparisons of means were made with Duncan's multiple range tests with the significance level set at 5%.

To test for differences between fish communities with and without migratory barriers and between TWINSPAN groups the multi-response permutation procedure (MRPP) was used (PC-ORD; McCune & Mefford 1995). MRPP is a non-parametric procedure for testing the hypothesis of no differences between two or more groups of entities and has an advantage over analysis of variance as it is not reliant on multivariate normality and/or homogeneity of data (Berry et al. 1983). Euclidean distance measures were used.

RESULTS

Species composition

Fifteen fish species were captured from 85 sites around Mount Taranaki, 13 of which were native, and two exotic (common names are used throughout; for scientific names and familial associations see Table 2.1). The large decapod crustacean *Paranephrops planifrons*, koura was also recorded. The density of fish captured ranged between 1 and 85 fish/100 m^2 with a mean of 24 fish/100 m^2. The longfin eel and redfin bully were the most widely distributed occurring at 92% and 63% of the sites respectively (Table 2.1). The longfin eel made up 32% of the total catch followed by the redfin bully (19.8%). The next most widespread and abundant species were brown trout, koaro and shortfin eel. The remaining ten species: shortjaw kokopu, Crans bully, inanga, banded kokopu, common bully, torrentfish, yelloweyed mullet, common smelt, perch and lamprey were uncommon and occurred at less than 12% of the sites and 10% of the catch (Table 2.1).

The number of species was negatively correlated with reach elevation (r_s = -0.33, P = 0.002) and distance from the sea (r_s = -0.29, P = 0.007). Fish density showed a similar pattern with density negatively correlated with altitude (r_s = -0.42, $P < 0.001$) and distance from the sea (r_s = -0.29, P = 0.006). Similarly there was a reduction in Shannon diversity with reach elevation (r_s = -0.24, P = 0.03), however, the relationship between diversity and distance from the sea was not significant (r_s = -0.14, P = 0.21). Species evenness showed no significant linear relationship with elevation or distance inland (r_s = -0.09, P = 0.39; r_s = -0.06, P = 0.58 respectively).

Table 2.1. Frequency of occurrence and species scientific, common names and familial assignments of fish and Crustacean species captured from 85 sites sampled over summer 1997/98 in Taranaki ring plain streams. (* Denotes exotic species)

			Occurrence (sites)		Species composition (fish)	
Family	Scientific name	Common name	No. of sites	% of total	No. of fish	% of total
Anguillidae	*Anguilla dieffenbachii* Gray	longfin eel	79	93	1115	32
Parastacidae	*Paranephrops planifrons*	koura	54	64	645	18.5
Eleotridae	*Gobiomorphus huttoni* Ogilby	redfin bully	34	40	691	19.8
Salmonidae	*Salmo trutta* Linnaeus	brown trout *	33	38	203	5.8
Galaxiidae	*Galaxias brevipinnis* Günther	koaro	19	22	127	3.6
Anguillidae	*A. australis* Richardson	shortfin eel	13	15	91	2.6
Galaxiidae	*G. postvectis* Clarke	shortjaw kokopu	12	14	145	4.2
Eleotridae	*G. basalis* Gray	Crans bully	10	11	222	6.4
Galaxiidae	*G. fasciatus* Gray	banded kokopu	10	11	44	1.3
Galaxiidae	*G. maculatus* Jenyns	inanga	5	5	93	2.7
Eleotridae	*G. cotidianus* McDowall	common bully	4	4	25	0.7
Mugiloididae	*Cheimarrichthys fosteri* Haast	torrentfish	3	3	33	0.9
Mugilidae	*Aldrichetta forsteri* Valenciennes	yellow eyed mullet	2	2	45	1.3
Retropinnidae	*Retropinna retropinna* Richardson	common smelt	1	1	1	0.0
Percidae	*Perca fluviatilis* Linnaeus	perch *	1	1	1	0.0
Geotriidae	*Geotria australis* Gray	lamprey	1	1	2	0.1
		Total	85		3483	100

Fish density was negatively correlated with percentage of native riparian vegetation (r_s = -0.27, P = 0.01) and positively correlated with increasing percentage of grass riparian vegetation (r_s = 0.37, $P < 0.001$). Diversity and species richness were not correlated with either of these two vegetation types. Native riparian vegetation was positively correlated with both altitude and overhead cover (r_s = 0.62, $P < 0.001$ and r_s = 0.65, $P < 0.001$ respectively) and a negative correlation was revealed between altitude and grass riparian cover (r_s = -0.56, $P < 0.001$). Altitude and the percentage of sand substrate were negatively correlated (r_s = -0.42, $P < 0.001$), as were mean width and depth negatively correlated with altitude (r_s = -0.44, $P < 0.001$; r_s = -0.38, $P < 0.001$ respectively). None of the stream surface character measures showed any significant correlations with density or diversity measures.

Migratory barriers

Thirty-two sites had known potential migratory barriers and 53 sites were thought to have no barrier. There were differences in the fish assemblages of the two groups with a number of species absent from the sites above barriers (Table 2.2). Species richness was lower above dams (Spearman rank correlation r_s = -0.36, $P < 0.001$). The barrier effect on diversity was significant even when elevation was employed as a covariate ($F_{2, 82}$ = 7.54, P = 0.04) but not with distance from the sea ($F_{2, 82}$ = 1.15, P = 0.21). Species richness was lower above migratory barriers even when altitude or distance inland were employed as the covariate ($F_{2, 82}$ = 9.10, P = 0.003; and $F_{2, 82}$ = 5.68, P = 0.02 respectively). Multi-response permutation procedures showed a significant difference in fish community composition at sites with and without migratory barriers (T = -7.43, $P < 0.0001$).

Altitude and distance from the sea were used to construct linear regression models for species richness using the 53 sites without migratory barriers. The model for inland distance explained 16% of the variance ($F_{2, 50}$ = 9.63, $P < 0.05$) and yielded the following equation: Species richness = 5.11 - 1.11 log distance inland. The model for altitude explained 17% of the variation ($F_{2, 50}$ = 10.77, $P < 0.05$) and yielded the equation: Species richness = 5.73 - 0.93 log altitude. The 32 sites with barriers were examined with the predictive equations and the residuals were compared with those from sites having no barriers. The majority of sites with barriers (24 of the 32) had residuals lower than expected from the above equations (distance inland T_{31} =1.99, P = 0.08; altitude T_{31} =1.99, P = 0.05; Fig 2.1a & b).

Table 2.2. Frequency of occurrence of fish species for sites above and below dams sampled over summer 1997/98 on the Taranaki ring plain. Mean diversity and density measures (± SE) and Kruskal-Wallis values evaluating differences between sites above dams and those with free access. ($P < 0.05$*; $P < 0.001$**)

	No dam (53)			Dam (32)		
Species	No. of fish	No. of sites	% of total no. of fish	No. of fish	No. of sites	% of total no. of fish
Longfin eel	752	51	31.0	363	28	34.4
Redfin bully	625	29	25.7	66	5	6.3
Brown trout	315	30	13.0	330	24	31.3
Shortjaw kokopu	144	11	5.9	1	1	0.1
Koaro	106	12	4.4	21	7	2.0
Inanga	93	5	3.8	0	0	0.0
Shortfin eel	85	11	3.5	6	2	0.6
Crans bully	82	5	3.4	140	5	13.3
Koura	76	18	3.1	127	15	12.0
Yelloweyed mullet	45	2	1.9	0	0	0.0
Banded kokopu	44	10	1.8	0	0	0.0
Torrentfish	33	3	1.4	0	0	0.0
Common bully	25	4	1.0	0	0	0.0
Lamprey	2	1	0.1	0	0	0.0
Common smelt	1	1	0.0	0	0	0.0
Perch	1	1	0.0	0	0	0.0
Diversity & Density						
Richness **		3.68 ± 0.16			2.72 ± 0.18	
Density		25.87 ± 2.54			23.23 ± 3.35	
Evenness		0.78 ± 0.02			0.67 ±0.06	
Diversity *		0.96 ± 0.04			0.71 ±0.07	

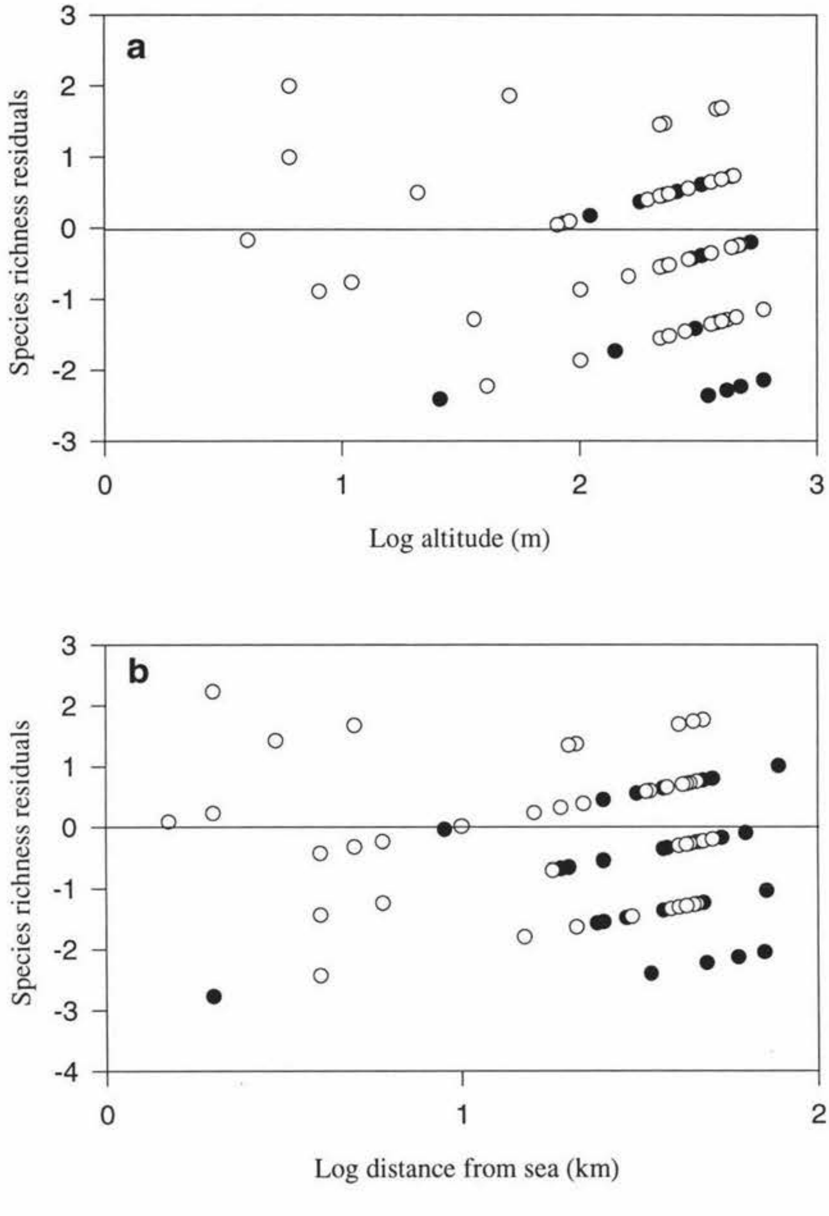

Fig. 2.1 **(a)** residuals of species richness (observed species richness minus predicted for log altitude against log altitude for 53 sites located below dams (open symbols) and 32 sites above dams (filled symbols). **(b)** residuals of species richness (observed species richness minus predicted for log distance from the sea) against log distance from the sea for 53 sites located below dams (open symbols) and 32 sites above dams (filled symbols).

TWINSPAN classification and fish assemblages

Four fish assemblages were identified from the TWINSPAN analysis at level two (Fig. 2.2). The eighteen sites in group 1 were dominated by shortjaw kokopu, koaro, koura, redfin bully, banded kokopu and longfin eel, with trout present but rare (Table 2.3). The fifty sites making up group 2 were dominated by longfin eels, koura, and Crans and redfin bullies. Group 3 contained twelve sites and had a simple fish assemblage dominated by redfin bullies, longfin eels and to a lesser extent, inanga and trout. Banded kokopu and inanga were more common in this group than in any other. The most abundant taxa at the five sites in group 4 were the redfin bully followed by short and longfin eels, then yelloweyed mullet. The classification of the sites from the species associations revealed mean elevation reduced from groups 1 to 4 (Table 2.4). Parallel with this the percentages of native riparian vegetation reduced, and stream size and percentage of grass riparian vegetation increased. Multi-response permutation procedures revealed a significant difference between fish communities in the TWINSPAN groups (T = -12.38, P < 0.001) and using all possible pairwise and three group combinations all were significant at P < 0.0001 except groups 3 and 4 (T = - 1.39, P = 0.093). The environmental variables for the four groups were also significantly different (T = -12.50, P < 0.001).

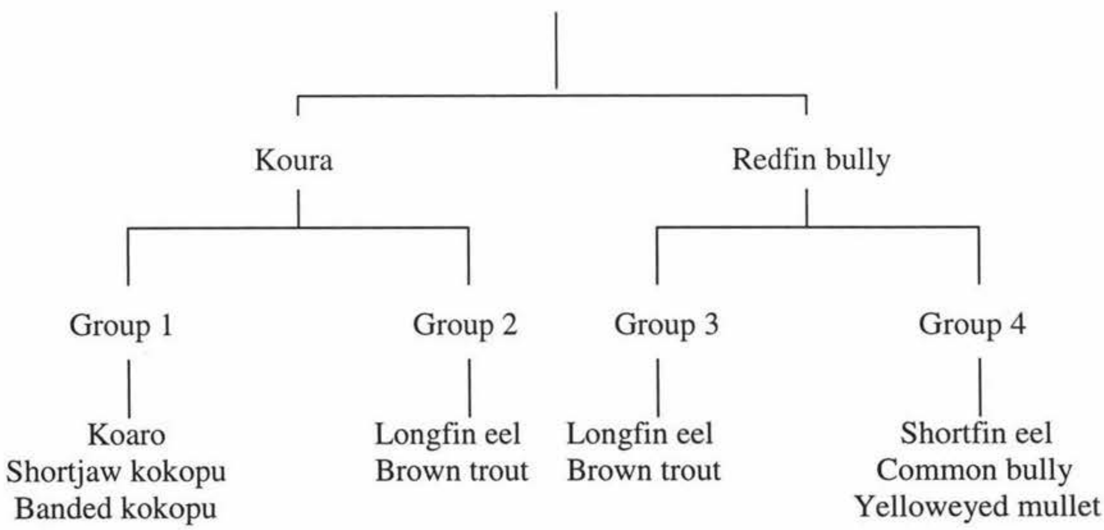

Fig. 2.2 Dendrogram of TWINSPAN classification of fish species and groups formed.

Table 2.3. Percentage occurrence of fish species in each of the Twinspan groups, indicator species in bold.

	Twinspan group and indicator species			
Species	Group 1 (N =18)	Group 2 (N = 50)	Group 3 (N = 12)	Group 4 (N = 5)
Mullet				**12.9**
Redfin bully	08.7	11.9	46.2	34.5
Common smelt				0.3
Longfin eel	16.6	**38.5**	**32.6**	17.5
Koura	21.3	26.9		
Trout	0.6	**08.4**	**5.4**	
Crans bully		11.2		
Shortjaw Kokopu	**26.4**	0.3		
Shortfin eel		0.5	3.3	**17.5**
Perch				0.3
Torrentfish		0.1	0.2	8.6
Inanga		01.5	9.6	0.9
Banded kokopu	**6.6**	0.5		
Common bully		0.1		**6.9**
Lamprey				0.6
Koaro	**20.0**	0.2	2.7	

Group 1 sites were at the highest altitude, had the most native riparian vegetation and overhead cover. Group 2 sites occurred at lower elevations but mean distance from the sea was greater, the sites were on average wider, deeper and had a higher percentage of grass riparian vegetation (Table 2.4). The group 3 sites were on average deeper, wider and had finer substrates; had less native but more grass riparian vegetation, and less overhead cover than groups 1 and 2. Group 4 sites were all less than 6-m a.s.l with no overhead cover and a high percentage of grass riparian vegetation. Diversity and density of fish also varied between the TWINSPAN groups. Groups 1 and 2 were similar and only group 4 had significantly higher density and diversity than the other three (Table 2.4).

Table 2.4. Mean site characteristics and community descriptors (± 1 SE) for 85 sites on the Taranaki ring plain over the summer of 1997/98. Significant differences between TWINSPAN groups from species abundance data using the non-parametric Kruskal-Wallis test are also given ($P < 0.05$ *; $P < 0.01$ **; $P < 0.001$ ***). Groups in first column underlined are not significantly different at $P < 0.05$ level using Duncan's multiple range test.

	TWINSPAN groups			
Variable and Duncan's test	Group 1 (N = 18)	Group 2 (N = 50)	Group 3 (N = 12)	Group 4 (N = 5)
Altitude *** 12 3 4	396.67 ± 31.03	285.48 ± 16.21	145.45 ± 33.17	5.00 ± 0.63
Inland *** 12 3 4	27.11 ± 3.64	36.94 ± 2.20	15.77 ± 4.69	1.75 ± 0.37
Mean width * 1 234	2.63 ± 0.25	3.97 ± 0.38	4.36 ± 0.54	7.88 ± 1.65
Mean depth * 1 2 34	0.61 ± 0.11	0.94 ± 0.10	1.42 ± 0.23	1.23 ± 0.14
Reach fished				
% pool	29.17 ± 4.84	40.10 ± 3.11	30.00 ± 8.42	15.00 ± 5.29
% run	32.22 ± 3.41	34.13 ± 2.30	47.73 ± 7.72	58.75 ± 10.07
% riffle	28.89 ± 3.25	23.37 ± 1.88	20.91 ± 4.30	26.25 ± 5.34
% rapid	7.50 ± 2.78	1.92 ± 0.69	1.36 ± 0.64	0.00 ± 0.00
Substrate composition				
% mud	0.00 ± 0.00	1.35 ± 1.00	0.00 ± 0.00	0.00 ± 0.00
% sand	6.39 ± 5.18	7.50 ± 1.25	14.09 ± 4.88	3.75 ± 2.91
% fine gravel	4.72 ± 1.33	9.33 ± 1.61	10.00 ± 3.94	3.75 ± 0.97
% coarse gravel	12.78 ± 1.89	9.13 ± 1.43	5.45 ± 2.50	11.25 ± 4.85
% cobble	40.83 ± 3.97	39.25 ± 2.83	35.91 ± 6.96	55.00 ± 5.29
% boulder	35.28 ± 4.59	30.38 ± 2.94	33.64 ± 25.94	18.75 ± 3.31
% bedrock	0.00 ± 0.00	1.35 ± 1.17	0.00 ± 0.00	0.00 ± 0.00
Riparian vegetation.				
% native *** 12 34	94.44 ± 5.40	60.19 ± 5.51	30.00 ± 12.01	10.00 ± 7.76
% exotic	0.00 ± 0.00	1.92 ± 1.36	0.00 ± 0.00	0.00 ± 0.00
% grass *** 1 2 34	5.56 ± 5.40	29.42 ± 5.04	62.73 ± 12.26	77.50 ± 10.21
% scrub	0.00 ± 0.00	8.46 ± 2.84	7.27 ± 4.28	12.50 ± 9.70
% overhead cover *** 12 34	57.22 ± 7.93	47.12 ± 4.33	19.55 ± 7.85	0.00 ± 0.00
% of sites above barrier*** 123 4	20%	52%	10%	0%
Community descriptor				
Richness *123 4	3.33 ± 0.30	3.20 ± 0.15	3.00 ± 0.31	5.20 ± 0.52
Density *123 4	22.30 ± 4.46	22.40 ± 2.23	28.83 ± 6.13	49.47 ± 0.00
Evenness	0.73 ± 0.03	0.75 ± 0.03	0.69 ± 0.07	0.82 ± 0.07
Diversity *123 4	0.86 ± 0.05	0.86 ± 0.05	0.73 ± 0.09	1.31 ± 0.12

Discriminant analysis

Site elevation was the most important environmental factor discriminating between TWINSPAN groups (Table 2.5). A discriminant model with this factor alone correctly predicted group membership of 66% of the sites. Adding distance inland increased the prediction rate to 73%. Including all 11 variables from the likelihood ratio criterion analysis ($P < 0.05$) increased the predictive ability of the model to 80% (Table 2.6). Correlations between the discriminant factors and the environmental variables revealed that the first canonical variate, accounting for 85% of the separation between the groups, was positively correlated with altitude, distance inland, native riparian vegetation and overhead cover (Table 2.7). Canonical variate 1 was negatively correlated with width, depth, and grass riparian vegetation. The second canonical variate accounting for 11% of the separation between the groups was positively correlated with distance inland, percentage pool, percentage sand-fine gravel substrate, and percentage grass riparian vegetation and negatively correlated with percentage rapid.

Table 2.5. Ability of the 11 environmental variables to discriminate between groups significant at < 0.05% level as measured by partial correlation (R^2) and Wilks Lambda, and the likelihood ratio criterion (F).

Environmental variable	R^2	F Statistic	Prob. > F
Altitude	0.69	59.05	0.0001
Distance from the sea	0.42	19.06	0.0001
% Pool	0.23	8.03	0.0001
Mean Width	0.21	6.4	0.0006
% Sand	0.15	4.4	0.006
% Grass riparian vegetation	0.13	3.6	0.02
Mean depth	0.12	3.5	0.02
% Riffle	0.12	3.4	0.02
% Native riparian vegetation	0.12	3.4	0.02
% Mud substrate	0.11	3.3	0.02
% Bedrock	0.10	2.8	0.04

Table 2.6. The number and percentage of fish communities at 85 sites on the Taranaki ring plain surveyed over the summer of 1997/98 classified into each of the four Twinspan groups by linear discriminant analysis using the concurrently recorded environmental measures.

Group (from group)	No. of sites	Predicted group membership (to group)				% of sites correctly predicted
		1	2	3	4	
1	18	**15**	2	1		83%
2	50	2	**39**	6	3	78%
3	12	1	4	**7**		58%
4	5				**5**	100%
Totals	85	18	50	12	5	80 %

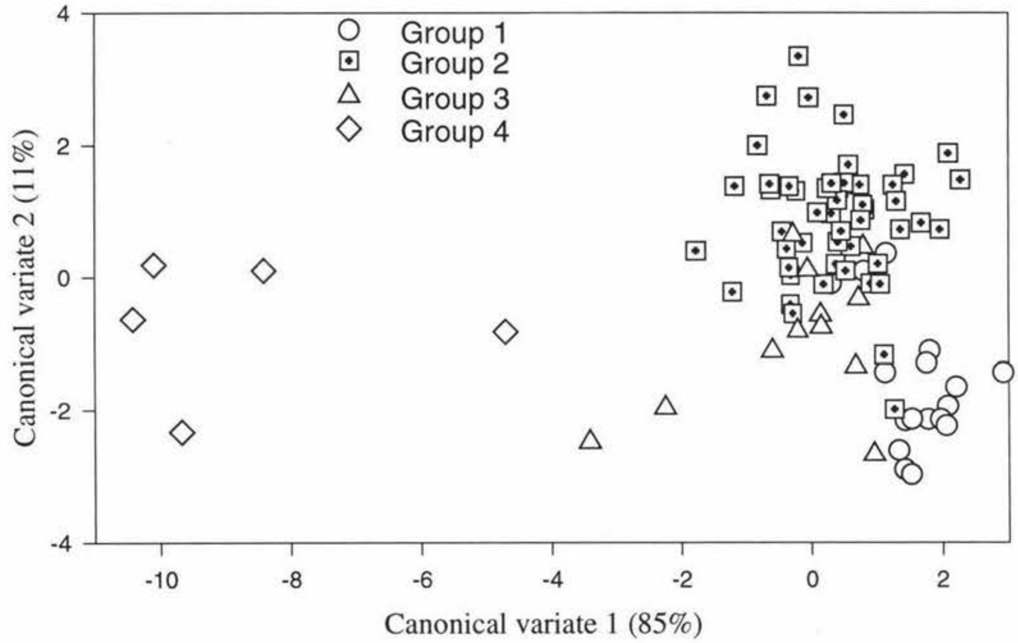

Fig. 2.3. Position of the 85 sites in discriminant space obtained by canonical variate analysis on the eleven environmental variables listed in Table 2.5

To illustrate the separation of the groups by the discriminant analysis the sites are shown in discriminant space in Fig. 2.3. Canonical variate one (Can 1) shows the separation of groups one, three and four. Canonical variate two (Can 2) separates group one from group two.

Table 2.7. Canonical coefficients and correlation coefficients for environmental variables with the first two axes of a canonical discriminant analysis ($P < 0.05$ *; $P < 0.01$ **; $P < 0.001$ ***). Environmental measures made at 85 sites surveyed over the summer of 1997/98 on the Taranaki ring plain.

	Coefficients		Correlations	
Variable	Can 1	Can 2	Can 1	Can 2
Altitude	3.245	-0.541	0.858***	0.166
Inland	2.128	1.043	0.599***	0.488***
Mean width	0.524	-0.095	-0.309**	0.073
Mean depth	0.482	-0.007	-0.231*	0.087
Reach fished				
% pool	0.522	0.342	0.150	0.356**
% run	-0.241	0.083	-0.200	0.060
% riffle	-0.512	0.528	-0.022	-0.067
% rapid	0.299	-0.009	0.196	-0.257*
Substrate composition				
% mud	0.953	0.179	0.030	0.194
% sand	0.514	0.580	-0.018	0.316**
% fine gravel	0.149	0.610	-0.001	0.265*
% coarse gravel	0.017	-0.032	0.012	-0.191
% cobble	0.180	0.276	-0.087	-0.006
% boulder	0.306	0.090	0.066	-0.077
% bedrock	-0.229	0.309	0.025	0.157
Riparian vegetation				
% native	0.934	0.410	0.412***	-0.016
% exotic	0.006	0.199	0.025	0.162
% grass	-0.894	0.776	-0.413***	0.225*
% scrub	0.160	0.354	-0.139	0.201
% overhead cover	0.088	0.337	0.497***	0.178
Migratory barrier	-0.090	0.192	0.026	0.068

The group four sites, which are negative on Can 1, are low elevation, wide, deep sites with a high proportion of grass riparian vegetation. At the opposite end of Can 1 are the group one sites which are the high elevation, shallow, narrow sites with a high proportion of native riparian cover and overhead shade. Thus, the influences of the environmental variables on Can 1 moving from negative to positive are increasing elevation, distance from the sea, native riparian vegetation and overhead shade. Moving in a positive direction along Can 2 the correlations are reducing elevation and percentage rapid, increasing distance inland, percentage pool and percentage grass vegetation.

DISCUSSION

As with many other New Zealand West Coast waterways, the Taranaki ring plain fish fauna was dominated by the longfin eel and redfin bully (Main et al. 1985; Taylor & Main 1987; Hayes et al. 1989; Hanchett 1990). The thirteen native fish species found in this survey exceeded that found in similar surveys of North Island waterways, ranging between 8 and 11 (Rowe 1981; Hicks & Watson 1985; Strickland 1985; Cudby & Strickland 1986; Hayes et al. 1989; Hanchett 1990). Species richness and diversity increased with downstream gradients of depth, width, reducing native vegetation and increasing farmland, distance from the sea and elevation. Site elevation, distance from the sea and the presence of a migratory barrier were the variables most highly correlated with species richness and diversity and, although they are intercorrelated, their association with fish communities was at least partially independent. This was illustrated by the different communities found at similar altitudes in the short run streams on the western side of the mountain compared to the longer eastern waterways. Similar conclusions to these have been reached in a number of other studies and diadromy has been proposed by Hanchett et al. (1990) and McDowall (1990, 1993) as the most important factor influencing New Zealand freshwater communities.

In Taranaki, overall water-quality as measured by chemical analysis (Taranaki Catchment Commission 1984) and macroinvertebrate indices (Taranaki Regional Council 1998) improves with increasing elevation, as does the amount of overhead cover and native vegetation. In contrast, the trajectories of occurrence for most of the native fish reduce with elevation independent of water quality because of the influence of diadromy (McDowall 1996, 1998). These variables reflect decreasing human impacts on catchments with elevation and illustrate the influence of diadromy in structuring fish communities although differentiating between the two influences may not be possible. Thus, potentially the best water quality is unavailable to the majority of the species and in the lower elevations, where the largest potential species pool is available, water quality is generally lowest. This means that access then becomes the most important habitat quality attribute for New Zealand freshwater fish.

The increase in species richness moving downstream in waterways has in North American and European studies been attributed to increased habitat diversity, volume and more stable conditions (Gorman & Karr 1978; Schlosser 1982; Rahel & Hubert 1991). The river continuum concept (Cummins 1979; Vannote et al. 1980; Cushing et al. 1983; Minshall et al. 1985; Schlosser 1990) also predicts increasing species richness in an upstream-downstream gradient, driven by changes in resource availability and habitat characteristics. The patterns observed in this study may reflect those predictions, however, they may equally reflect the variability in penetrative ability of the predominantly diadromous species. If the latter is the case then there is a breakdown in the relationship between fish community structure and habitat characteristics because of the open nature of these communities. McDowall (1995) pointed out that open fish communities, i.e. communities dominated by diadromous species, are primarily structured by the influx of species from outside the community (from the sea). In contrast, closed communities are structured by proximate biotic and abiotic influences. Thus, when considering habitat quality for New Zealand freshwater fish, migratory access must be considered above all other factors. Although habitat quality can not be ruled out completely in the Taranaki it does appear that diadromy is the primary structuring force in these stream fish communities.

Migratory barriers

Given the importance of upstream access for the New Zealand fish fauna, dams are one of the most prominent devices that may act as potential barriers to up and downstream passage. Species richness and diversity were lower at sites above dams and remained significant even when the effect of elevation was removed. However, from the diadromy dominated patterns of species distribution it is apparent that the relative impact of a given dam on the fish fauna will depend on the altitude of the dam and the ability of the fish species to penetrate inland. The native fish species of New Zealand vary widely in their migratory abilities, migratory drive and in their ability to negotiate barriers (McDowall 1990, 1993), and consequently the dams vary in their barrier effect. Many species are limited to low elevations, for example, torrentfish, yelloweyed mullet, common smelt, common bully and lamprey did not occur above 100 m elevation in this study. As most of the dams are above this altitude their effect on these species would be minimal. Nevertheless, dams at low altitude or on low gradient waterways have the potential to have impacts that are more serious on fish communities than if they were at higher altitudes.

Biotic interactions are also considered important in structuring fish communities (Werner & Gillian 1984; Ross 1986; Gillian et al. 1993). In New Zealand predation has been recorded by eels on banded kokopu, (Mitchell & Penlington 1982) and bullies, smelt and small trout (McDowall 1990). Large eels were found at most sites in this study, and at upland sites, where large galaxiids were found, juvenile galaxiids were rare or absent. Predation may therefore be affecting species distributions. Trout were similarly absent from many upland sites where koaro, shortjaw and banded kokopu were found at high densities. Limitation of native fish abundance by predation from trout (Townsend & Crowl 1991) or through competition for food (Cadwallader 1975; Sagar and Eldon 1983) has been proposed and may also be having an effect here.

In conclusion, while freshwater fish species richness on the Taranaki ring plain is higher than that found in other North Island rivers, much of the fauna has a relatively restricted distribution. The region has a large number of dams and they have a strong negative effect on fish passage. Altitude, distance from the sea and whether or not the site is above a dam were the variables that had the biggest impact on fish community organisation. The overriding influence on the distribution of fish was however, the prevalence of diadromy with species varying in their ability to penetrate inland both naturally and because of the impediments to migration. As a number of variables covary with altitude and distance from the sea, it is difficult to isolate influential environmental factors on community structure from the effect of diadromy. The high proportion of diadromous species means that where dams are present, however, they become the most important influence on community structure.

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Chapter 3: The Development and Application of a Predictive Model of Riverine Fish Community Assemblages in the Taranaki Region

ABSTRACT

A predictive model of fish community composition using a reference condition approach is proposed for the Taranaki region. The model is used to quantify the effects of barriers on the migration of native fish in the region. Occurrence records of fish in streams without migratory barriers (reference sites) obtained from the New Zealand freshwater fish database were used to establish trajectories of occurrence for each of 13 fish species with altitude. The relative occurrence per site for each of the species was calculated and used as the probability of the presence of that species in that altitudinal range. Comparison of these probabilities with the fauna actually found at a test site expressed as an observed over predicted ratio (O/P) is then used to compare sites to quantify barrier effects on fish communities. In a similar way this process can be used to monitor the effectiveness of fish passes, where present on dams. Independent data from 85 sites sampled over the summer of 1997/98 were used to test the predictive model. As an example of a typical use of the methodology, the effect of a single hydrodam on fish communities is illustrated.

Keywords: Diadromy, freshwater fishes, predictive model, dams.

INTRODUCTION

The use of biological indicators to evaluate anthropogenic effects on running waters has been increasing worldwide in the last two decades. As fish are at or near the apex of food chains they integrate the ecological processes of streams and may therefore be well positioned to act as indicators of stress over large temporal and spatial scales (Hynes 1970). One of the most effective ways of using fish communities in bioassessment is with the reference condition approach (Harris 1995; Bailey et al. 1998). The reference condition approach is based on pre-established criteria that exist at a wide range of sites rather than one or a few control sites. The reference sites then serve as replicates rather than the multiple collections within sites traditionally used (Reynoldson et al. 1997). If a large number of reference sites are sampled then the variation among communities should represent the range of acceptable conditions. Furthermore, if a habitat descriptor or set of descriptors explains a substantial part of the variation among the reference communities, then using this descriptor to characterise a site will lead to a more precise prediction of communities at unimpaired sites.

In North America a multimetric reference site approach, the Index of Biotic Integrity (IBI), which uses a number of fish community attributes to assess biotic integrity based on unimpacted sites, has been shown to be sensitive to a wide range of stresses (Karr 1981, 1991; Fausch et al. 1984; Karr et al. 1986; Leonard & Orth 1986; Miller et al. 1988; Steedman 1988; Hoefs & Boyle 1992). The IBI has been adapted for use in many regions (Fauch et al. 1990; Karr 1994; Oberdorff & Hughes 1992). However, the low number of species and high incidence of diadromy in the New Zealand fauna means the effectiveness of this index is negated or at least substantially reduced. In Great Britain, North America and Australia a multivariate predictive model approach using reference sites has been used effectively with macroinvertebrates to assess water quality (Wright et al. 1984; Moss et al. 1987; Reynoldson et al. 1995; Norris 1996). Using a multivariate analysis to characterise invertebrate community structure Wright et al. (1984, 1995) and Reynoldson (1995) refined their expectations of community structure at test sites by first establishing groups of reference communities with cluster analysis then finding environmental descriptors that differed among those groups. Finally, they used the values for the environmental descriptors observed at a test site to predict which community type would be present if the test site was unimpaired. This reference condition predictive model approach has the potential to be adapted for use with fish.

As the requirement to move between the sea and freshwater is considered to be the most important factor influencing the distribution of native fish in New Zealand (Hayes 1989; McDowall 1990, 1993; Jowett & Richardson 1996; Jowett et al. 1996) any predictive model of fish occurrence must take migration into account. New Zealand freshwater fish differ in their instinctive drive and ability to migrate upstream and thus each species has a distinctive elevational trajectory of occurrence (Hayes 1989; McDowall 1990, 1993, 1996, 1998). Therefore, successful predictive models for describing the distribution of diadromous native fish in New Zealand must take into account large scale variables such as altitude, distance from the sea and the presence or absence of barriers to migration (McDowall 1993, 1996). These are properties not accounted for by the IBI.

The objective of this study was to apply a reference condition approach with freshwater fish assemblages to assess the effect of migratory barriers on those fish in the Taranaki region. To effect this a predictive model was applied using a habitat descriptor as a predictor to explain variation in the reference communities and to characterise the test sites. Using this predictive model of occurrence, comparisons can be made between the predictions and the fish assemblages found at test sites.

Study area

Mount Taranaki is a unique landform in New Zealand, a quiescent andesitic volcano rising to 2518 m with more than 140 significant waterways radiating from its slopes (Taranaki Catchment Commission, 1984). All streams emerge at a similar altitude from native forest into pastureland. Few of these Taranaki ring plain catchments have been unaffected by impoundments of some sort and at least 50 dams and weirs have been identified (Taranaki Regional Council, 1995).

METHODS

The Database

Historical records of freshwater fish occurrence for the streams draining the Taranaki ring plain were collated from the New Zealand Freshwater Fish Database (NZFFD McDowall & Richardson 1983; Richardson 1989). The Database contains 432 entries for the Taranaki ring plain region on 102 waterways but only 296 (68%) of these entries contain close to the full range of environmental information potentially available on the database form. The NZFFD represents the combined effort of many agencies and individuals, the majority of records (>90%) are from electro-fishing, while the remainder were obtained using alternative fishing methods such as trapping and night spotlighting. No attempt has been made to assess biases, which might result from these different sampling methods and/or operators. For each of the entries in the database the length of waterway sampled ranged from 350 m to 10 m, with a mean of 78 m (SE = 49). The sampling dates span the years between 1978 and 1997, with 157 entries before 1986 and 275 after. There are 25 species of fish and one crustacean recorded for the Taranaki region, 20 are native and 5 introduced. Common names for fish species are used throughout, for scientific names see Table 3.1.

Table 3.1. Summary of species found in the Taranaki region from the New Zealand Freshwater Fish Database (McDowall & Richardson 1983; Richardson 1989).

Species	**Scientific name**	**Number of sites present**	**Migratory**
Banded kokopu	*Galaxias fasciatus*	14	Yes
Bluegill bully Ψ	*Gobiomorphus hubbsi*	2	Yes
Brown mudfish Ψ	*Neochanna apoda*	8	No
Brown trout*	*Salmo trutta*	183	No
Carp *Ψ	*Cyprinus carpio*	1	No
Common bully	*Gobiomorphus cotidianus*	48	No
Common smelt	*Retropinna retropinna*	15	Yes
Crans bully	*Gobiomorphus basalis*	45	No
Giant bully Ψ	*Gobiomorphus gobioides*	3	Yes
Giant kokopu Ψ	*Galaxias argentus*	8	Yes
Goldfish* Ψ	*Carassiuus auratus*	2	No
Inanga	*Galaxias maculatus*	24	Yes
Koaro	*Galaxias brevipinnis*	23	Yes
Koura	*Paranephrops planifrons*	223	No
Lamprey Ψ	*Geotria australis*	18	Yes
Longfin eel	*Anguilla dieffenbachii*	342	Yes
Perch *Ψ	*Perca fluviatilis*	4	No
Rainbow trout*	*Oncorhynchus mykiss*	13	No
Redfin bully	*Gobiomorphus huttoni*	136	Yes
Rudd *Ψ	*Scardinus erythrophthalmus*	1	No
Shortfinned eel	*Anguilla australis*	97	Yes
Shortjawed kokopu Ψ	*Galaxias postvectis*	10	Yes
Torrentfish	*Cheimarrichthys fosteri*	36	Yes
Upland bully	*Gobiomorphus breviceps*	15	No
Yellowbelly flounderΨ	*Rhombosolea leporina*	1	Yes

* Introduced species
Ψ Present at < 5% of sites

The 432 entries contain information on fish species abundance and size, date and time of survey, stream name, map co-ordinates, survey method, altitude, distance inland, and whether the site is above a migratory barrier. Because of considerable variation in recording methods for abundance on database forms, the species occurrence records were converted to presence/absence data for each site. Species present in less than 5 percent (< 14 occurrences) of the possible sites were also removed from the dataset, to decrease the effect of rare species. This left 13 species for further analysis.

Table 3.2. Pearson correlation coefficients for three axes of a DECORANA ordination of Dataset A from the NZFFD sites (n = 394) and Dataset B (n = 296) in the Taranaki region

	Dataset A		
Environmental variable	**Axis 1**	**Axis 2**	**Axis 3**
Downstream blockage	-0.41**	0.27	0.17
Altitude	-0.53**	0.32**	0.01
Distance inland	-0.49**	0.39**	0.01
	Dataset B		
Width	-0.09	0.14	0.27*
Depth	-0.02	-0.00	0.05
Altitude	0.41**	-0.48**	0.36**
% still	0.16	-0.08	0.04
% backwater	0.17	-0.11	0.05
% pool	0.15	-0.07	0.02
% run	-0.13	0.09	0.18
% riffle	0.01	0.04	-0.04
% rapid	0.10	-0.01	-0.13
%cascade	0.19	0.05	-0.13
Down stream block	0.32**	-0.37**	-0.07
Distance Inland	0.39**	-0.51**	-0.17
% mud	-0.13	-0.08	0.02
% sand	-0.17	0.17	0.23*
% fine gravel	-0.08	0.06	-0.01
% coarse gravel	-0.03	0.04	-0.13
% cobble	0.10	-0.01	0.06
% boulder	0.12	-0.01	-0.08
% bedrock	0.10	-0.14	-0.07

* Denotes P < 0.01

** Denotes P< 0.001

The database was subdivided into three datasets A, B and C. Dataset A is the complete dataset with lotic sites and rare species removed. It has 394 sites, which includes 13 species and 3 environmental variables; altitude, distance inland and whether there is a downstream blockage. Dataset B includes only those sites from Dataset A that had a complete range of substrate and habitat data available. This set includes 296 sites, 13 species and 19 environmental variables (Table 3.2). Dataset B contained 199 sites listed on the database cards as having no migratory barriers. Dataset C, the reference sites for the construction of the predictive model, is the set of sites from dataset A recorded as having no migratory barriers. Dataset C had 232 sites, and included 13 species and 2 environmental variables; altitude and distance inland.

Statistical Analysis

Fish presence/absence data were analysed using detrended correspondence analysis (DECORANA), an eigen-analysis ordination technique, using the PC-ORD multivariate statistical package (McCune & Mefford 1997). This is a mathematical treatment of data designed to produce an objective arrangement of communities that reflects the similarity of their taxonomic composition. The presence/absence data was transformed using Beals Smoothing to reduce the problem of zero truncation (Beals 1984; McCune 1994). Pearson correlation coefficients between environmental measures and the DECORANA scores at the study sites were also calculated by PC-ORD and a Mantel test was applied to evaluate the relationship between the environmental variables and the species matrix. The Mantel method tests the significance of the correlation between the matrices by a permutation method, where the rows and columns are permutated using a randomization (Monte Carlo) test.

RESULTS

Ordination of Dataset A graded the sites from those above barriers to the sites without barriers (Fig 3.1). Axes 1 and 2 accounted for 59% and 15% of the total variance respectively. Taxa associated with the axes in general split the fish species between migratory and non-migratory species. Positive taxon correlations with axis 1 were the migratory redfin bully, smelt, inanga, torrentfish and koaro while the non-migratory Crans bully, trout and koura were negatively correlated. The only taxon significantly positively correlated with axis 2 was koaro while redfin bully, smelt, shortfin eel, and torrentfish were negatively correlated. Distance inland, altitude and downstream blockage were all negatively correlated with axes 1 and positively correlated with axis 2 (Table 3.2). There was a positive relationship between the species and environmental data tested with a Mantel test (P = 0.001).

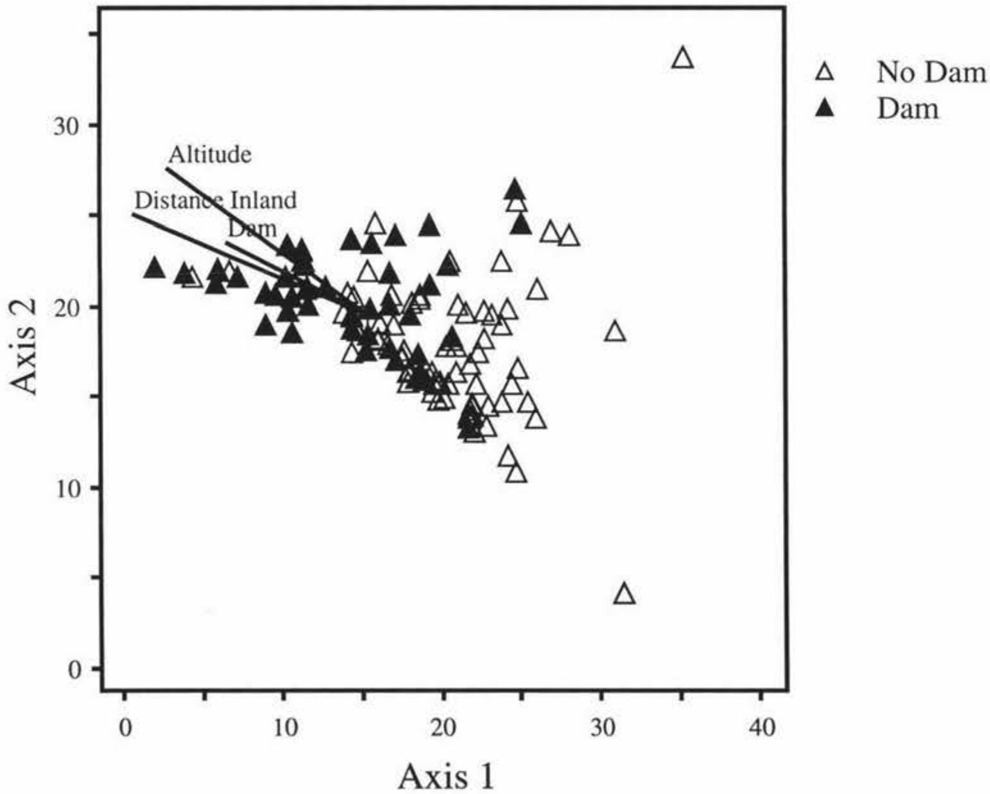

Fig. 3.1 Axis one as a function of axis two for a detrended correspondence analysis for fish communities in the Taranaki region from NZFFD using Dataset A (394 sites). Open symbols are sites with no migratory barrier, closed symbols are sites with migratory barriers. Vector arrows show direction of influence of environmental variables from centroid.

As in Dataset A ordination of Dataset B graded the sites from those without barriers to sites with barriers along axis 1 (Fig. 3.2). The first and second axes of the DECORANA account for 55% and 24% of the total variance respectively. As with Dataset A the taxa associations were split into migratory and non-migratory groups. Significant positive species associations with axis 1 were trout, koura, Crans and upland bullies with koaro the only migratory species whereas, the significant negative associations with axis 1 were redfin bullies, both eel species, torrentfish and smelt. Axis 2 correlates positively with shortfin eels, inanga, torrentfish, common and redfin bullies and negatively with trout, koura, Crans and upland bullies. Of the 19 environmental variables available with this dataset only altitude, distance inland and whether or not there is a migratory barrier were significantly correlated with the first two axes. They were positively correlated with axis 1 and negatively correlated with axis 2 (Table 3.2).

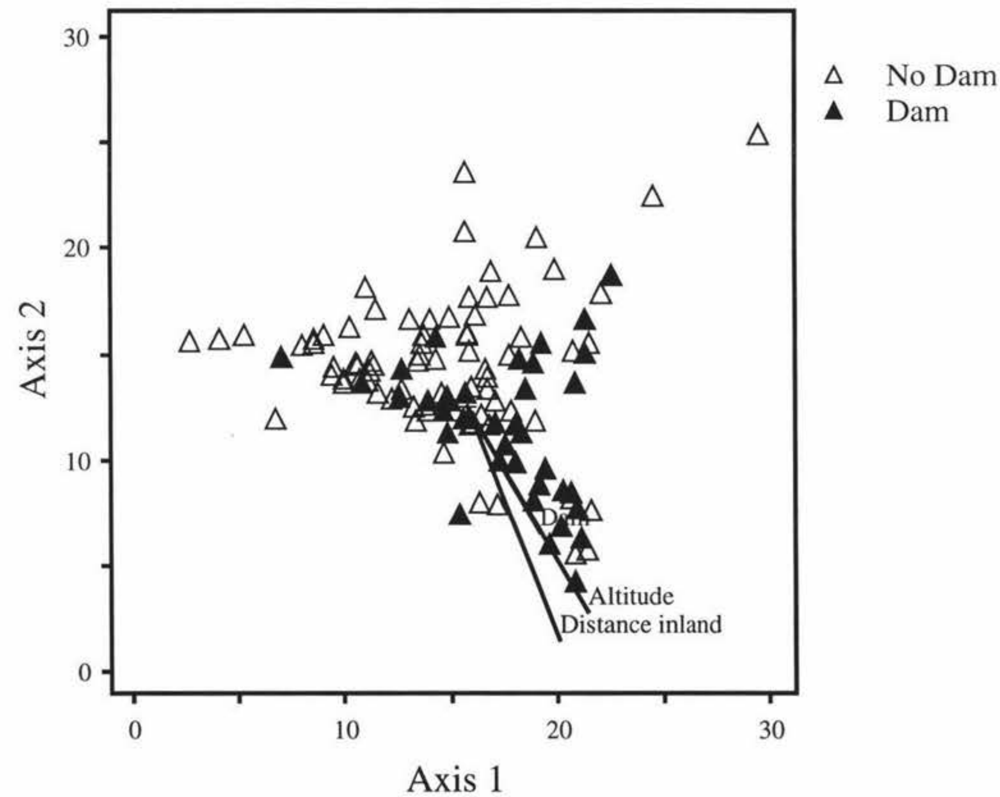

Fig. 3.2 Axis one as a function of axis two for a detrended correspondence analysis for fish communities in the Taranaki region from NZFFD using Dataset B (283 sites). Open symbols are sites with no migratory barrier, closed symbols are sites with migratory barriers. Vector arrows show direction of influence of significant environmental variables from centroid.

Development of the predictive model

The 232 sites characterised as having no migratory barrier (Dataset C) were used as reference sites for the predictive model construction. To overcome any bias associated with a reduction in the number of survey sites with increasing elevation, sites were split into 10 even groups of 23 sites. This grouping resulted in the altitudinal range covered by each group increasing with altitude (Fig.3.3).

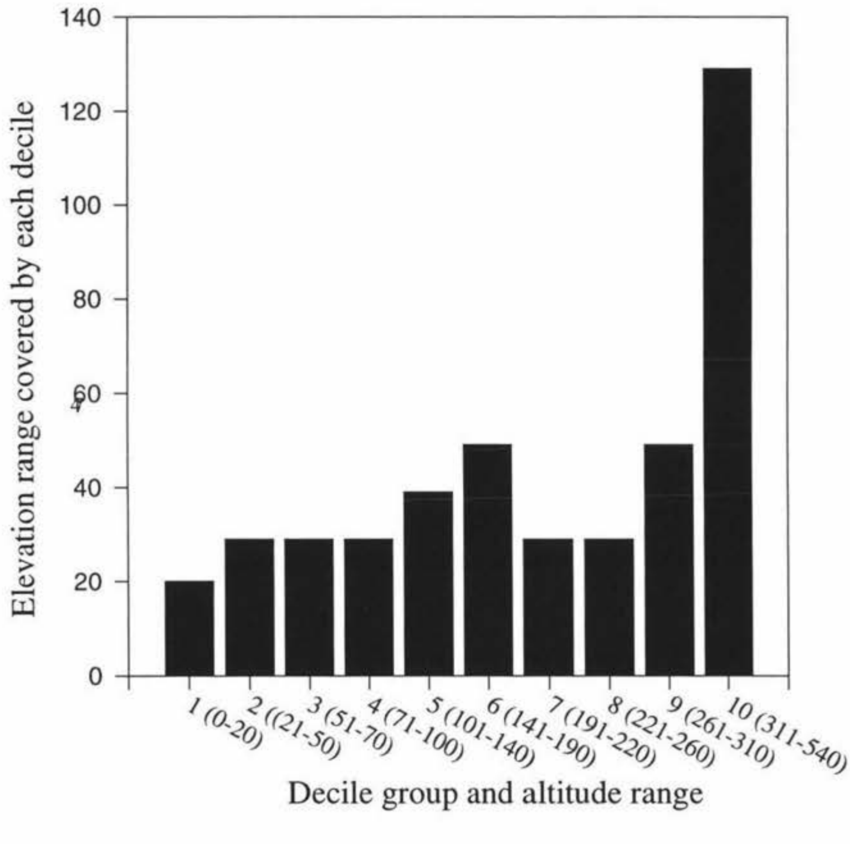

Fig. 3.3 Elevation range (m) and altitude (m) covered by each of the ten reference site groups used in the predictive model from NZFFD sites for Taranaki.

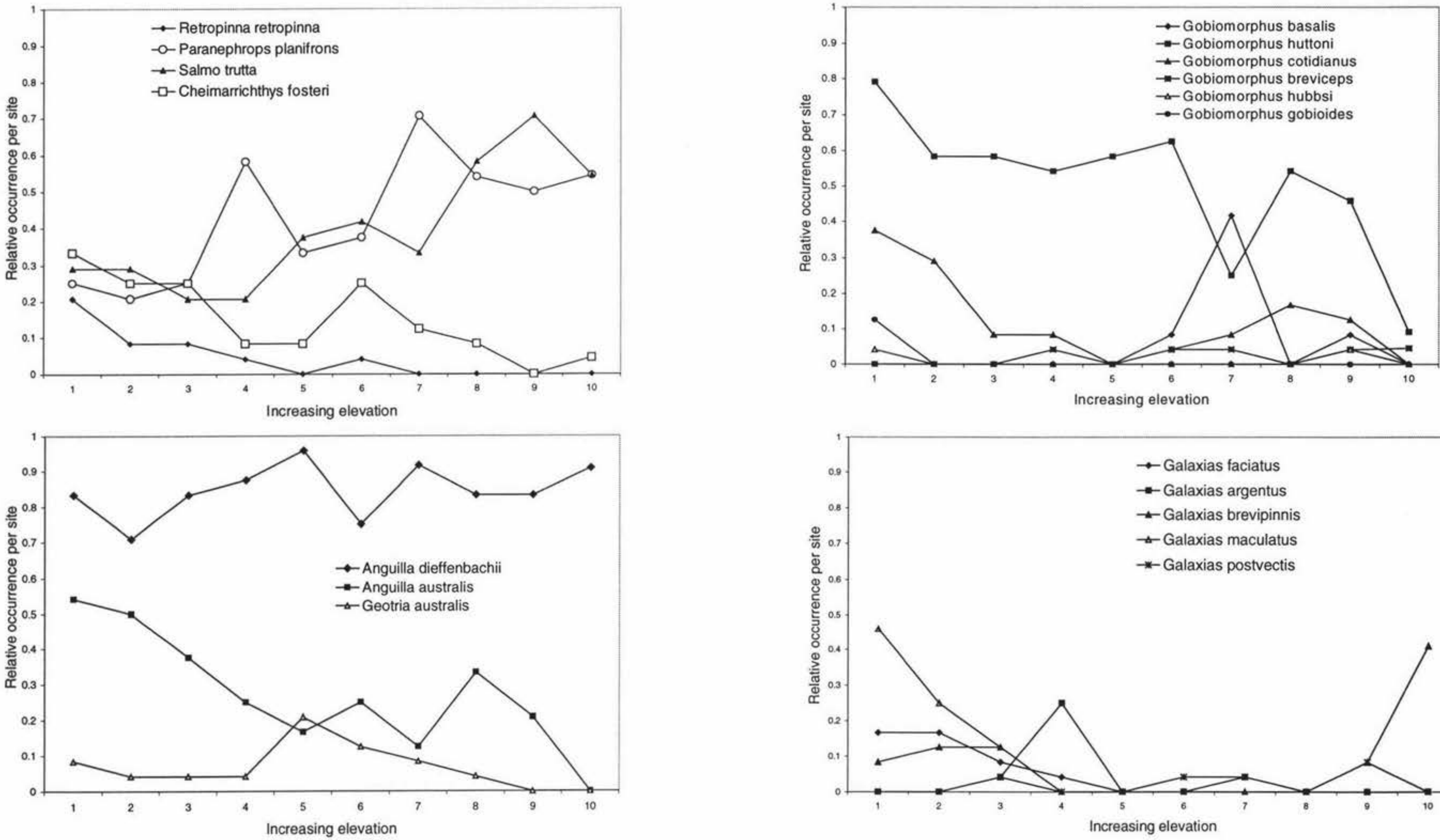

Fig. 3.4 Trajectories of percentage occurrence for each taxon in each of the ten-altitudinal ranges for the 232 reference sites Taranaki from NZFFD (see Fig. 3.3 for altitude range for each group)

Within each group of 23 sites, the number of occurrences for each species per site was summed and then divided by the number of sites to give the relative occurrence of that species in each group. This process was repeated for all species. The relative occurrence per site of each species for each group of sites is the probability of that species occurring at that elevation or distance inland. The relative occurrence for each species then becomes the predictive model for that species (Fig. 3.4). Non-migratory species were excluded from the model calculations, as their presence or absence is not related to migratory barriers. However, trout were left in, as their migratory status is equivocal.

How the model works - an example

In order to compare the predicted fauna with that actually found at test sites taxa with a predicted probability of occurrence greater than 25% were considered. These taxa were further divided into two non-exclusive categories. The taxa with probabilities of at least 50% ($P \geq 0.5$ Type A) and taxa with probabilities of at least 25% ($P \geq 0.25$ Type B). Within each of these two probability categories the number of taxa expected at a test site was calculated as the sum of individual probabilities of each of the taxa listed. The taxa expected in each probability cut-off range, expressed as a percentage of the total number of taxa listed are then compared with the taxa captured at the test sites. The percentage of taxa observed is divided by the percentage of taxa expected to give an observed over predicted ratio (O/P) for each probability category.

The procedures involved are illustrated with an example test site (Table 3.3). This test site was on the Mangatengehu Stream at 230m elevation; four species were captured at this site; both eel species and redfin and upland bullies. The probabilities greater than 25% for each of the taxa in the altitudinal range 221 – 260m are shown under the two probability cut-off levels. The number of taxa predicted was calculated by summing the number of taxa with probabilities exceeding the two probability cutoffs 0.5 and 0.25. Thus, 3 taxa were predicted in the type A range and 4 in the type B range. The number of migratory species captured in those categories was 3 because upland bully is non-migratory and thus not included. The number of taxa captured is the number of migratory taxa found in the survey at each site. Finally the fauna observed (O) was divided by the fauna predicted (P) resulting in the observed over predicted ratio (O/P) of 1.53 and 1.31 for types A and B, respectively.

TABLE 3.3. Method for the calculation of number and percentage of taxa expected at a site in two-probability ranges ($P \geq 0.5$) and ($P \geq 0.25$), their relationship with observed values, and the resultant observed over predicted ratio (Adapted from Moss et al. 1987).

NZFFD # Site No. 17601 Mangatengehu Stream	**Captured at test site**	**Probability of occurrence cutoff levels**	
Taxon		**Type A $P \geq 0.50$**	**Type B $P \geq 0.25$**
Gobiomorphus huttoni	✓	0.54	0.54
Retropinna retropinna		0	0
Anguilla dieffenbachii	✓	0.83	0.83
Salmo trutta		0.58	0.58
Gobiomorphus basalis		0	0
Galaxias postvectis		0	0
Anguilla australis	✓	0	0.33
Cheimarrichthys fosteri		0	0
Galaxias maculatus		0	0
Galaxias fasciatus		0	0
Gobiomorphus cotidianus		0	0
Galaxias argentus		0	0
Geotria australis		0	0
Gobiomorphus breviceps	✓	0	0
Galaxias brevipinnis		0	0
Gobiomorphus hubbsi		0	0
Gobiomorphus gobioides		0	0
Number of taxa predicted (sum of taxa with probability greater than cutoff levels)		3	4
Number of taxa expected (sum of individual probabilities of occurrence)		1.96	2.30
Number of taxa captured (only if migratory)		3	3
Percentage of predicted taxa expected (number expected/number predicted %)		0.65	0.57
Percentage of taxa observed (number captured/number predicted %)		1	.75
Observed/predicted ratio (percentage of taxa observed/percentage of taxa expected)		**1.53**	**1.31**

Model testing and application

To test the ability of the model to discriminate between sites with and without migratory barriers, data independent of those used in the construction of the model was used. During the summer of 1997/98 eighty-five sites on Taranaki ring plain streams were sampled at various altitudes by electro fishing and spotlighting similar to the methods used in the NZFFD. The data was run through the model and the observed/predicted (O/P) ratio calculated for the two-probability cutoff levels. The test-data consisted of 32 sites classified as having a migratory barrier and 53 sites thought to have free access. The O/P ratios for the type A and B cut off levels were combined and the resultant ratio for sites with free migratory access was found to be significantly greater than the ratio for sites with barriers ($T_{83} = 5.53$; $P < 0.0001$) (Fig 3.5).

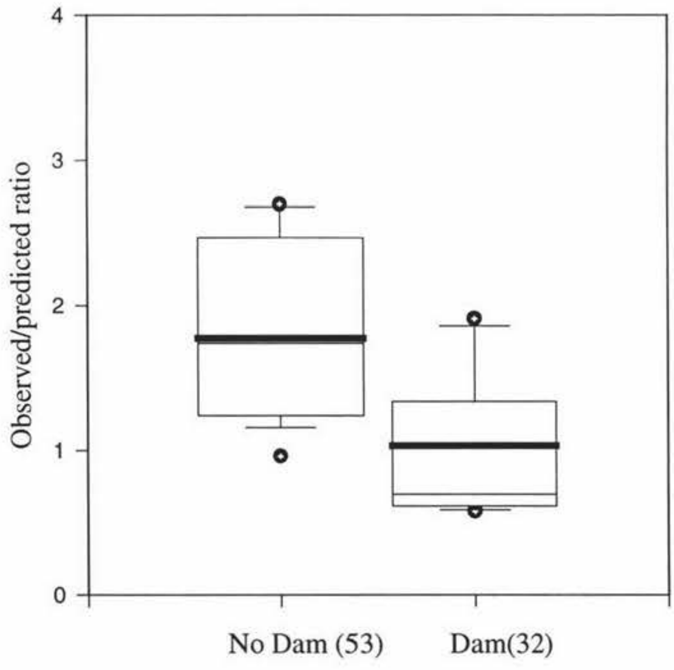

Fig. 3.5 Boxplot showing observed/predicted ratios for sites with (Mean 1.0321; SE 0.093) and without (Mean 1.7726; SE 0.088) known migratory barriers for 85 test sites in the Taranaki region

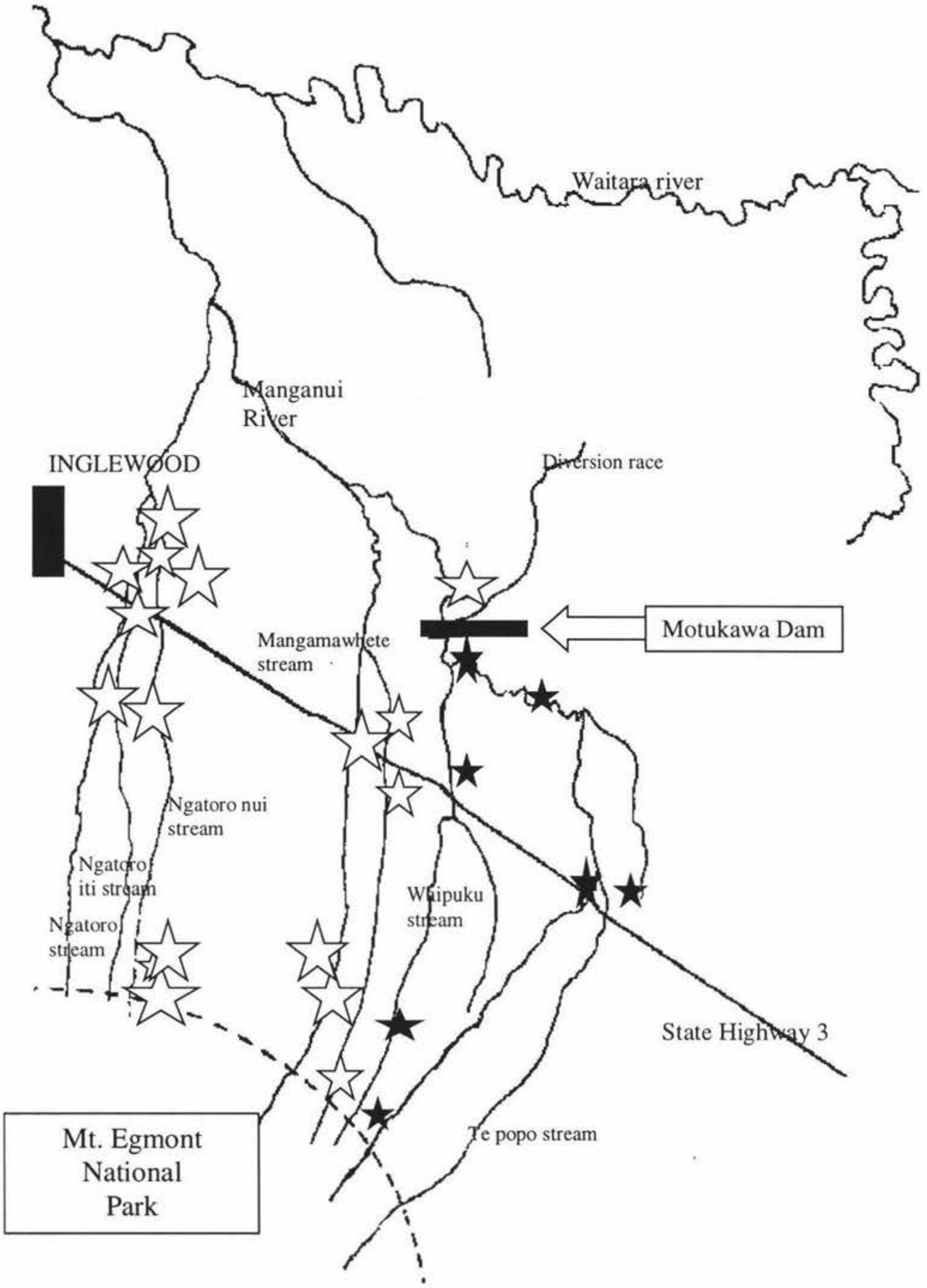

Fig. 3.6 Site map showing the positions of survey sites (stars) in relation to the Motukawa dam on the Manganui River. Open symbols are sites with free access, closed symbols are sites above dam. Relative size of star indicates large or small O/P ratio.

Application example using a single dam

Fish occurrence details for 8 sites above the Motukawa Dam on the Manganui River and 23 sites at varying elevations on tributaries entering below the dam were used to test the model. The Motukawa Dam on the Manganui River diverts most of the flow from the river via a channel to a hydroelectric scheme although a small residual flow is left in the old riverbed (Fig.3.6). These survey results were run through the model and mean O/P ratios for above and below the dam calculated. The resulting ratios for type A and B cut off levels were combined and the resulting ratio for sites without barriers was again found to be significantly greater than for sites with barriers (T_{29} = 3.58; P = 0.001) (Fig. 3.7).

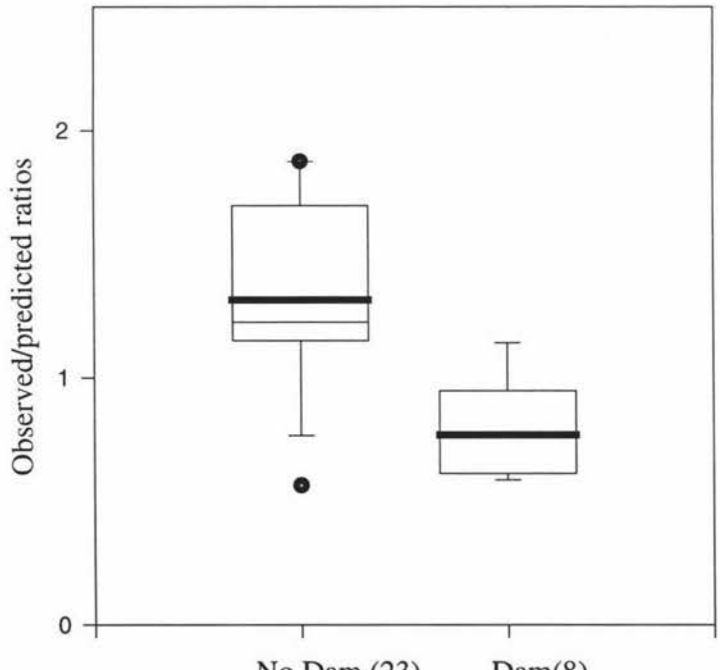

Fig. 3.7 Boxplot showing observed/predicted ratios for sites on tributaries entering the Manganui River above (Mean 0.7676; SE 0.085) and below (Mean 1.3143; SE 0.084) the Motukawa Dam on the Manganui River.

An alternative test

Another approach for use of the model is to establish a range of acceptable O/P ratios such that if a site's O/P ratio falls outside the range, the site fails. Bailey et al. (1998) suggested using the interquartile range of the reference distribution as acceptable, thus, an O/P ratio falling below the first quartile would fail. Another approach is to use one standard deviation above or below the mean of the reference distribution as an acceptable range. To observe the reference distribution the 232 reference sites were run through the model (Fig. 3.8). The mean O/P ratio was 1.45 (SD = 0.67) and 65% of the sites fell within one standard deviation of the mean. If interquartile criterion range were used the cut off O/P value would be < 1.025. In the Motukawa dam example all but one of the 8 sites above the dam would fail (87.5% fail) and of the 23 sites not affected by the dam, six (26%) would fail. If the standard deviation criterion is used as the range, an O/P ratio less than 0.78 would fail. For the Motukawa dam 5 of the 8 sites above the dam (62%) would fail, while 2 (8%) of the 23 sites below the dam would fail.

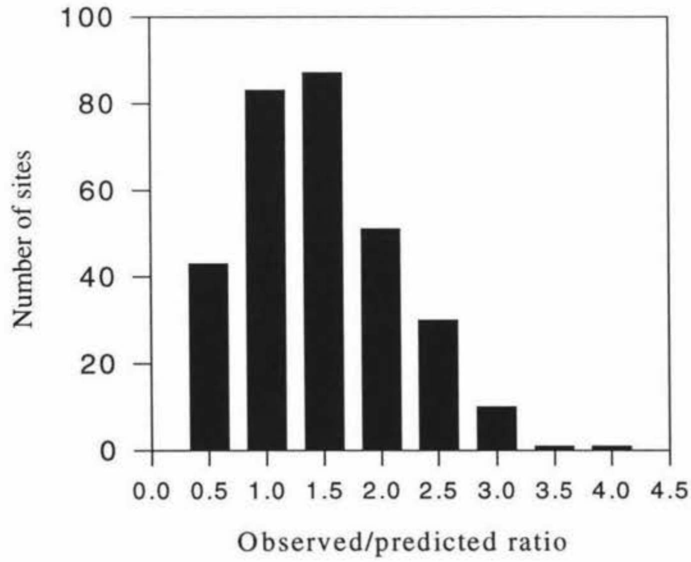

Fig. 3.8 Distribution of observed/predicted ratios for the 232 Taranaki ring plain reference sites

DISCUSSION

The multivariate analysis of environmental and habitat variables in this study highlighted elevation and distance from the sea as the most important factors affecting fish community structure in the Taranaki region. This result has been found in a number of other New Zealand studies which have concluded diadromy is the most important factor influencing the distribution of native fish in New Zealand (Hayes et al. 1989; McDowall 1993, 1996; Jowett and Richardson 1996; Jowett et al. 1996; Richardson & Jowett 1996). While diadromy also appears to be the overriding factor controlling the fish populations in this study, fish community assemblages are undoubtedly influenced by small-scale habitat variables even if not at the scale measured in these surveys. The habitat variables recorded on the database cards generalise the measures over the reach surveyed and thus any important small-scale habitat variables may be obscured. Another potential problem related to use of the NZFFD data is the visual estimation of most measures included in the database and the subjectivity resulting from the many contributors. The grouping of sites into 10 categories was also somewhat arbitrary, as there is a compromise between number of groups and the number of sites per group. The two probability cut off levels ($P \geq 0.5$ and $P \geq 0.25$) used in the model gave similar results. However, the lower probability cut off level will be necessary at higher elevations where the number of species predicted is low.

The use of the presence or absence of specified fish taxa at any point along the length of a water-body to measure environmental impact is dependant on the use of reference sites based in that region. McDowall (1996) discussed the value of using the altitudinal trajectories of occurrence for individual species from the NZFFD and pointed out that these trajectories could be interpreted as the probability that the species will be found in each elevational range. He concluded that although adapting these trajectories using locally relevant species would have the disadvantage of reducing the number of sites available this would be offset by the fact that regional curves would be explicit to local conditions. McDowall (1998) found these trajectories of fish occurrence differed between regions in New Zealand. Reynoldson and Rosenberg (1996) using a similar predictive reference site model with macroinvertebrates investigated the effect of reducing the number of sites and found that reducing the sites by up to 75% did not significantly reduce the predictive ability of the model.

The 102 waterways in this study all originate on the slopes of Mount Taranaki and all emerge at a similar altitude from native forest into predominantly dairy farmland. Thus, the waterways all have similar underlying geology, gradient, rainfall and land-use attributes at similar elevations. This environmental homogeneity over an altitudinal gradient makes this region ideal for the implementation of a relatively simple predictive model using fish communities. The application of the model to different regions in New Zealand would therefore require regionally based reference sites, which, because other regions are not so homogeneous may require a more complicated model than that developed for Taranaki.

This study was undertaken to provide a method for quantifying the effects of barriers to migration on native fish communities in the Taranaki region. To achieve this goal the fauna expected at any altitude in the absence of migratory barriers must be known. A predictive model based on unimpacted (reference) sites was chosen as having the potential to achieve this objective. The determination of the reference condition from reference sites is based on the premise that sites least affected by human activity will exhibit biological conditions most similar to those at natural pristine locations. The predictions in this model are intended to represent the natural long-term characteristics of the communities and are not intended to predict within year variations in the fauna. The average ratio for a series of sites with similar migratory access should be around unity but individual sites can be expected to take values above or below unity (e.g. Fig 3.8). Unusually low O/P ratios are used as an indication of a migratory barrier and high O/P ratios indicate open access and high water and habitat quality. However, a number of samples are required (at least 3) and the ratios averaged to lessen the effect of chance differences in sampling. Where a fish pass has been installed on a dam the model can be used to monitor the effectiveness of the pass by comparing O/P ratios.

The use of an arbitrary cut off point based on the reference distribution has been suggested by Bailey et al. (1998). If the interquartile or one standard deviation range were used, the Motukawa dam would fail. However, the interquartile cutoff would mean that 25% of the reference sites or 18% for the standard deviation cut off of the sites would fail. This highlights the difficulty in using an arbitrary cut off; if there is an impact other than the dam a group of sites may fail even if the dam is not having an impact.

The symmetrical topography and homogeneity of land-use and habitat variables in relation to elevation on the Taranaki ring plain permitted the use of a single variable, altitude, as a predictor of fish community structure. Reference sites were used to characterise least impacted conditions and provided the basis for community composition predictions. A procedure initially developed by Wright et al. (1984) using macroinvertebrates was adapted to enable the translation of probabilities of fish occurrence into observed over predicted ratios. The ratio was then used as a measure of the condition of a test site in relation to the reference condition. Comparison of observed/predicted ratios above and below potential barriers permitted the assessment of the impact of migratory barriers or the effectiveness of fish passes on fish community structure. Alternatively, the impact of a dam or the efficiency of a fish pass can be assessed using the O/P ratios from the model by using a predetermined pass/fail cut off value. However, the comparison of above/below values is recommended to counteract the possibility of effects other than the dam under investigation impacting fish communities in the study waterway.

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Chapter 4: Diadromy and longitudinal patterns of upstream penetration of freshwater fish in Taranaki

ABSTRACT

Diadromous fish species dominate the New Zealand freshwater fish fauna and make up 15 of the 16 native fish species found on the Taranaki Ring Plain. Trajectories of occurrence in relation to elevation and distance from the sea are described for 11 diadromous and 2 non-diadromous species using data from the New Zealand freshwater fish database and data collected over the summer of 1997/98. Distinctive distributions were found for most of the species related to their differing migratory strategies and abilities. The species were ranked based on components of these trajectories in order to compare their penetrative ability. Comparison of the ranking methods used revealed relatively consistent results. The ranking of the 11 diadromous species relative to each other revealed similar rankings for the same species from the West Coast of the South Island. The non-migratory native fish, Crans bully was not found on the western side of the mountain. This distribution is thought to be the result of the local extinction of non-migratory species in high gradient streams.

Keywords: Diadromy, freshwater fishes, Taranaki, distribution trajectories of occurrence

INTRODUCTION

The distribution patterns of riverine fish in New Zealand are influenced by the obligate requirement of a large proportion of the fauna to migrate to or from the sea at some stage in their lifecycle. This migratory requirement, diadromy, is considered the most important factor influencing freshwater fish distribution in New Zealand (Hayes et al. 1989; McDowall 1993, 1998). The New Zealand fauna is unique worldwide in that more than half the species are diadromous, which impacts on many aspects of the ecology and biogeography of the fauna (Hayes et al. 1989; McDowall 1990, 1996 a, 1998). The upstream penetration of fish is influenced by the interaction of both the species-specific migratory ability of the fish and the physical attributes of the waterway. The attributes of the fish include factors such as the instinctive migratory drive (McDowall 1993), sustained swimming speed (Mitchell 1989), type of diadromy i.e., whether anadromy, catadromy or amphidromy (McDowall 1998), and ability to pass barriers (McDowall 1990). The attributes of the river are the physical and chemical factors that impede upstream movement whether they are natural i.e., waterfalls and stream mouth closure (McDowall 1993) or man made such as dams (Jowett 1987).

The attributes of the waterway impacting on fish migrations are many and varied. The effect of migratory barriers in the form of dams, waterfalls and stream mouth closure is dependant on a number of factors including the altitude, height and shape of the barrier or the timing of stream mouth closure (McDowall 1995). The contamination of the waterway by acidic flows from volcanic sources (McDowall 1996 b), or from anthropogenic sources in the form of sedimentation (Bruton 1985; Berkman & Rabeni 1987; Rabeni & Smale 1995; Boubee et al. 1997), or nutrient/chemical inputs (McDowall & Eldon 1980; Richardson 1997) can also impede access. Areas at low altitude close to the sea are likely to be more accessible as the distance is less, the gradient is likely to be low and barriers are less likely to be present. Inland habitats at higher elevations are conversely more likely to be difficult to access because of impediments to migration discussed above. Therefore, the local suitability of habitats may be secondary to factors related to access, in determining species richness and abundance. Proximate habitat quality can not be determined by simply comparing relative occurrence of diadromous species because while habitats where species occur are obviously acceptable, untenanted areas are not necessarily unsuitable but could be simply inaccessible to those species (McDowall 1993). The diadromous fish species found at a given point have arrived there from outside, thus, the community assemblage is dependent on the species pool available to occupy any space present after the effects of all the variables mentioned above. This led McDowall (1995) to

conclude that stream fish communities must be understood in terms of their assembly at least partly under the influence of invasive processes that take place outside the habitat of the community.
There are three subcategories of diadromy and they must be understood to appreciate their impact on fish community ecology. The subcategories are anadromy, catadromy and amphidromy (McDowall 1988, 1998). They affect fish distribution, as there are differences in the life-stages that undertake them and differences in the direction of migration (McDowall 1998). Anadromous fish are usually mature adults when they leave the sea and enter rivers to spawn. They do not usually feed in freshwater and spawning is at the upstream limit of migration. Catadromous and amphidromous fish enter rivers as juveniles, and gradually move upstream to find suitable adult habitat. Amphidromous species spawn in freshwater, where their larvae hatch and immediately move to sea. Catadromous fish however, return to sea to spawn when at or approaching maturity (McDowall 1988).

Distinctive patterns of distribution, habitats and trajectories of occurrence have been described for New Zealand freshwater fish both for certain regions (McDowall 1998a, In prep.) and nationally (McDowall 1990, 1996, 1998 b; Minns 1990). If the ranking of trajectories of occurrence for individual species relative to each other is found to be similar in regions of differing topography and land use, this would imply that migratory trajectories are species specific traits at least partially independent of proximate habitat suitability. This paper examines the distribution of 11 diadromous fish species in relation to two parameters, altitude and distance from the sea. The aim is to quantify patterns of fish species distribution in Taranaki in relation to penetrative ability and to compare them to rankings for the same species established for the West Coast of the South Island by McDowall (In prep.). Two non-migratory species were included in the analysis to contrast their distributions with those of the migratory species.

METHODS

Data used in this study were obtained from two sources. The first is historical data on fish distributions for the Mount Taranaki ring plain derived from the National Institute of Water and Atmosphere's New Zealand Freshwater Fish Database (NZFFD; McDowall & Richardson, 1983). The NZFFD includes information on fish assemblages, site elevations, and distances from the sea for ca. 420 sites on rivers draining Mount Taranaki. The second data source was from 85 sites in the region surveyed over the summer of 1997/98 and included details on environmental habitat variables, elevation and distance inland. For both datasets the majority of the fish occurrence data was collected using portable backpack, pulsed DC electric fishing machines; although night spotlighting was also used on occasions. Combining the NZFFD data for the Taranaki ring plain with data from the 1997/98 survey resulted in data for a total of 525 sites being available. However, of these, 230 sites were listed on the database card as having a specific downstream blockage (dam, weir or waterfall) and these sites were discarded. Species recorded at less than ten sites were considered too rare to accurately determine their trajectories of occurrence. Their removal from the dataset left 13 species available for further analysis (Fig 4.1). The environmental measures accompanying the species data were incomplete, only site elevation, distance from the sea, map co-ordinates, and whether or not there is a downstream barrier was available for all sites. Fish abundance measures used in the NZFFD were not consistent so all fish occurrence data was converted to presence/absence.

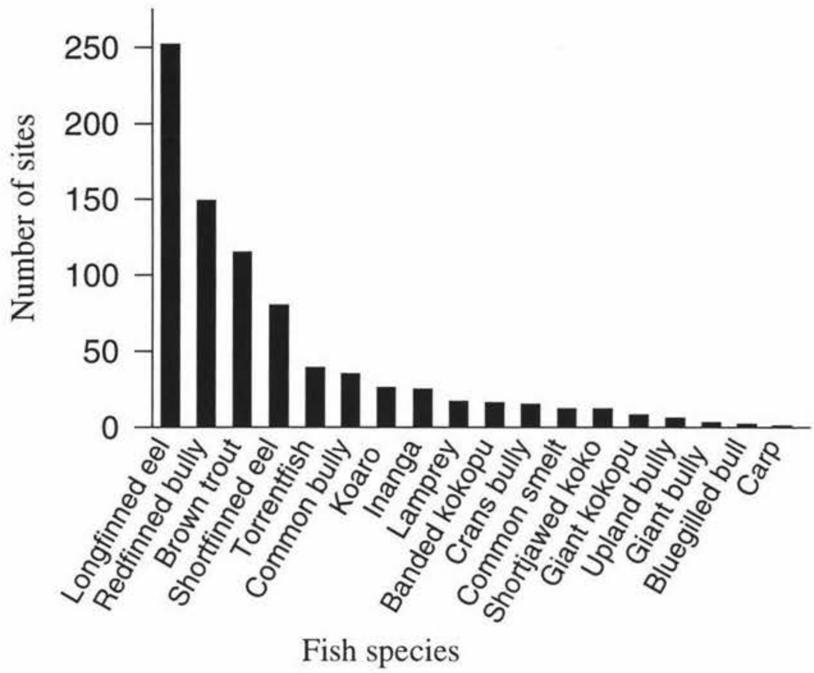

Fig. 4.1 Number of sites from the 295 Taranaki Ring plain sites where each of the eighteen freshwater fish species occur.

Data analysis

Site elevation and river channel distance to the sea for sampling sites were estimated from NZMS 260 1:50 000 topographic maps. Site frequency declined with increasing elevation (Fig. 4.2a) and distance from the sea (Fig. 4.2b). To counteract this bias in number of sites, the data was arranged in order of increasing altitude and then split into ten groups of twenty-nine sites (deciles). This process was repeated for site distance from the sea. The range of elevation and distance from the sea covered by each group is given in Table 4.1. The proportion of occupied sites within each decile group was then calculated for each of the species. To enable comparison of rankings for migratory drive and ability between the Taranaki and Westland South Island migratory fish faunas the following methods used by McDowall (In Prep) were repeated as follows. Site records were grouped in bands containing 25 meters of elevation and 5 km of inland penetration. The number of sites within each of the bands at which a taxon occurred was divided by the number of sites in that band to give the relative occurrence of taxa in each band. Linear regression lines were fitted to cumulative relative occurrence plots using the REG procedure of SAS (1995). Maximum, median and the value for 80% of the sites were calculated from the data for altitude and distance from the sea attained for each of the species. The species were then ranked from 1 (= low) for lowest values of each of the three measures and steepest regression line coefficient, to 11 (= high) for the highest values and flattest slope of regression line. A final combined ranking was obtained by summing the rankings. To evaluate the difference between the ranking methods and the rankings between the two regions Spearman rank correlations were performed using the CORR procedure of SAS (1995). To compare rankings for individual species, residuals were obtained by calculating the difference between ranks for each species.

Table 4.1. Elevation and distance from sea covered by each decile group from 295 Taranaki ring plain fish survey sites.

Decile number	1	2	3	4	5	6	7	8	9	10
Distance inland (km)	0-2	2-4	4-7	7-12	12-15	15-17	17-24	24-41	41-45	45-50
Altitude (m)	0-20	21-50	51-80	81-110	111-170	171-210	211-240	241-280	281-370	371-550

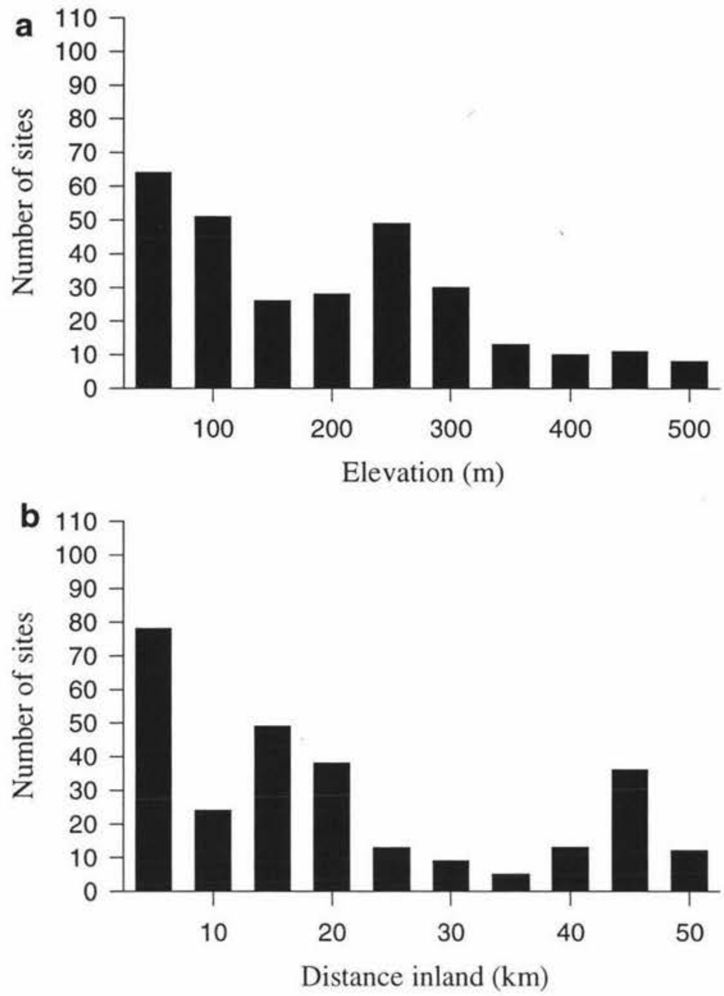

Fig. 4.2. Frequency distribution for 295 Taranaki ring plain study sites based on (**a**) elevation and (**b**) distance from the sea.

RESULTS

Common names for fish species are used throughout; the scientific names and higher classification are listed in Table 4.2. Eighteen fish species were captured in total, of these; thirteen were retained for analysis after the removal of rare species. Of these, three species are catadromous, two anadromous and seven amphidromous, twelve are native and one, brown trout, was introduced. At the 295 sites used in the analyses the most prevalent species were the longfin eel (252 sites), redfinned bully (149 sites), brown trout (115 sites) and shortfin eel (80 sites) while the remaining species were relatively rare (Fig. 4.1). There is a general reduction in the number of species with increasing altitude (Spearman rank correlation $r_s = -0.74$, $P = 0.01$) (Fig. 4.3) however, this may relate at least partly to a reduction in sites with altitude (Fig. 4.2).

Table 4.2. List of species family, scientific and common names, and types of diadromy in Taranaki ring plain waterways.

Family	Scientific name	Common name	Migratory category
Anguillidae	*Anguilla australis* Richardson	shortfin eel	catadromous
	Anguilla dieffenbachii Gray	longfin eel	catadromous
Retropinnidae	*Retropinna retropinna* (Richardson)	common smelt	anadromous
Galaxiidae	*Galaxias maculatus* (Jenyns)	inanga	catadromous
	G. argenteus (Gmelin)	giant kokopu	amphidromous
	G. fasciatus Gray	banded kokopu	amphidromous
	G. postvectis Clarke	shortjaw kokopu	amphidromous
	G. brevippinis Günther	koaro	amphidromous
Geotriidae	*Geotria australis* Gray	lamprey	anadromous
Pinguipedidae	*Cheimarrichthys fosteri* Haast	torrentfish	amphidromous
Eleotridae	*Gobiomorphus huttoni* (Ogilby)	redfin bully	amphidromous
	G. cotidianus McDowall	common bully	amphidromous
	G. basalis Gray	Crans bully	non diadromous
Salmonidae	*Salmo trutta* Linnaeus	brown trout	non diadromous

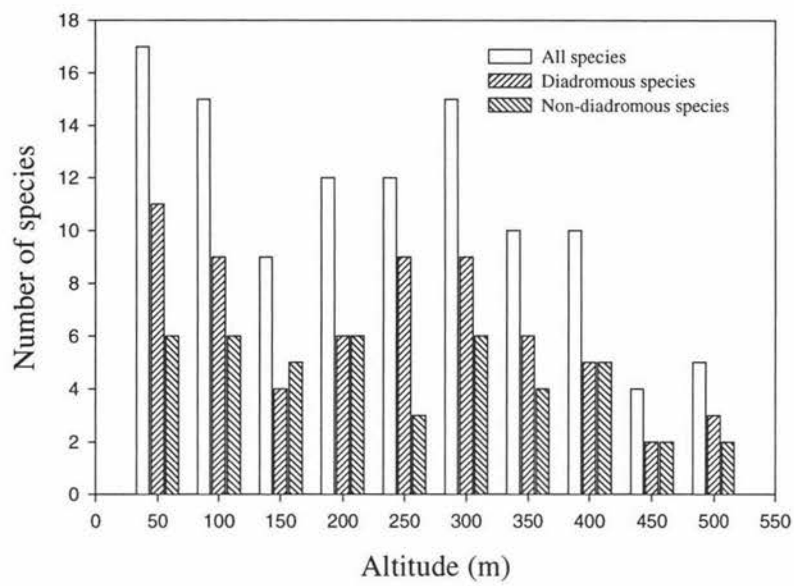

Fig. 4.3 Number of species at sites over altitudinal range from 0 to 500 m a.s.l for the Taranaki ring plain.

Relative frequency of occurrence

The plots of relative frequency of occurrence show that the elevation (Fig. 4.4) and distance from the sea (Fig. 4.5) attained by each of the 13 species varied considerably. The majority of the species have their highest relative frequency of occurrence at or near the sea, and reduces with elevation and distance inland. The exceptions are the non-migratory brown trout and Crans bully, and the amphidromous galaxiids (banded kokopu, shortjaw kokopu and koaro). The catadromous longfin eel was widely distributed throughout the range of elevation/distance from the sea, whereas the shortfin eel reduced in relative abundance with elevation/distance. The anadromous common smelt and catadromous inanga show similar patterns of penetration with relative abundance peaking close to the sea with an abrupt reduction in occurrence and are absent above the sixth decile-group of sites. The amphidromous redfin bully, common bully and torrentfish all have similar patterns of occurrence, peaking near the sea and gradually reducing over the full range of elevation and distance from the sea. The only migratory fish rare or absent near the sea is the shortjaw kokopu. The non-migratory Crans bully shows a peak in occurrence over a relatively narrow range of decile groups. The altitude decile grouping for Crans bully is lower than the distance inland grouping, as this species is absent form the short-run waterways on the Western side of Mount Taranaki.

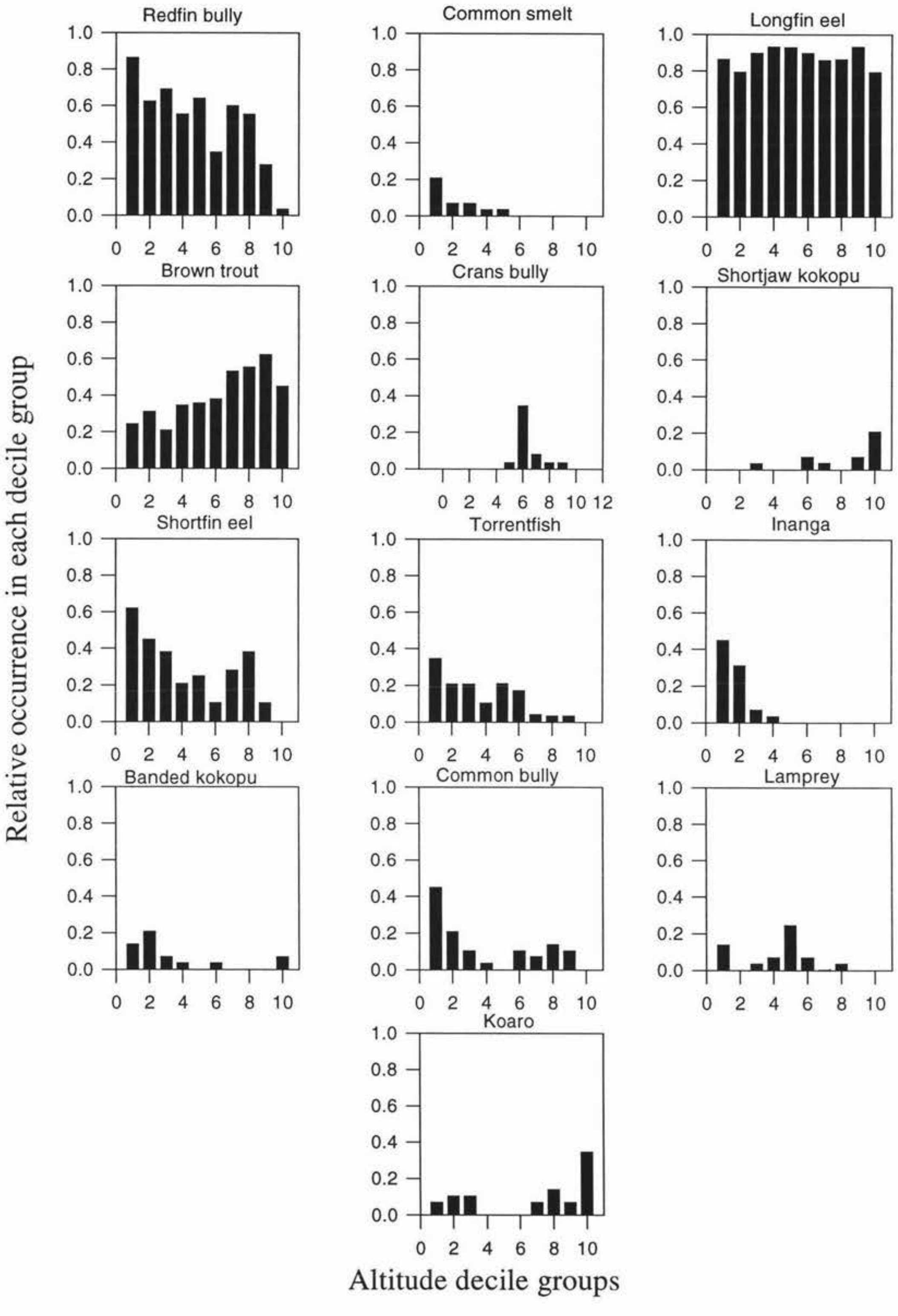

Fig. 4.4. Occurrence of fish species in 295 Taranaki ring plain streams across altitudinal decile groups (see Table 4.1 for altitude ranges).

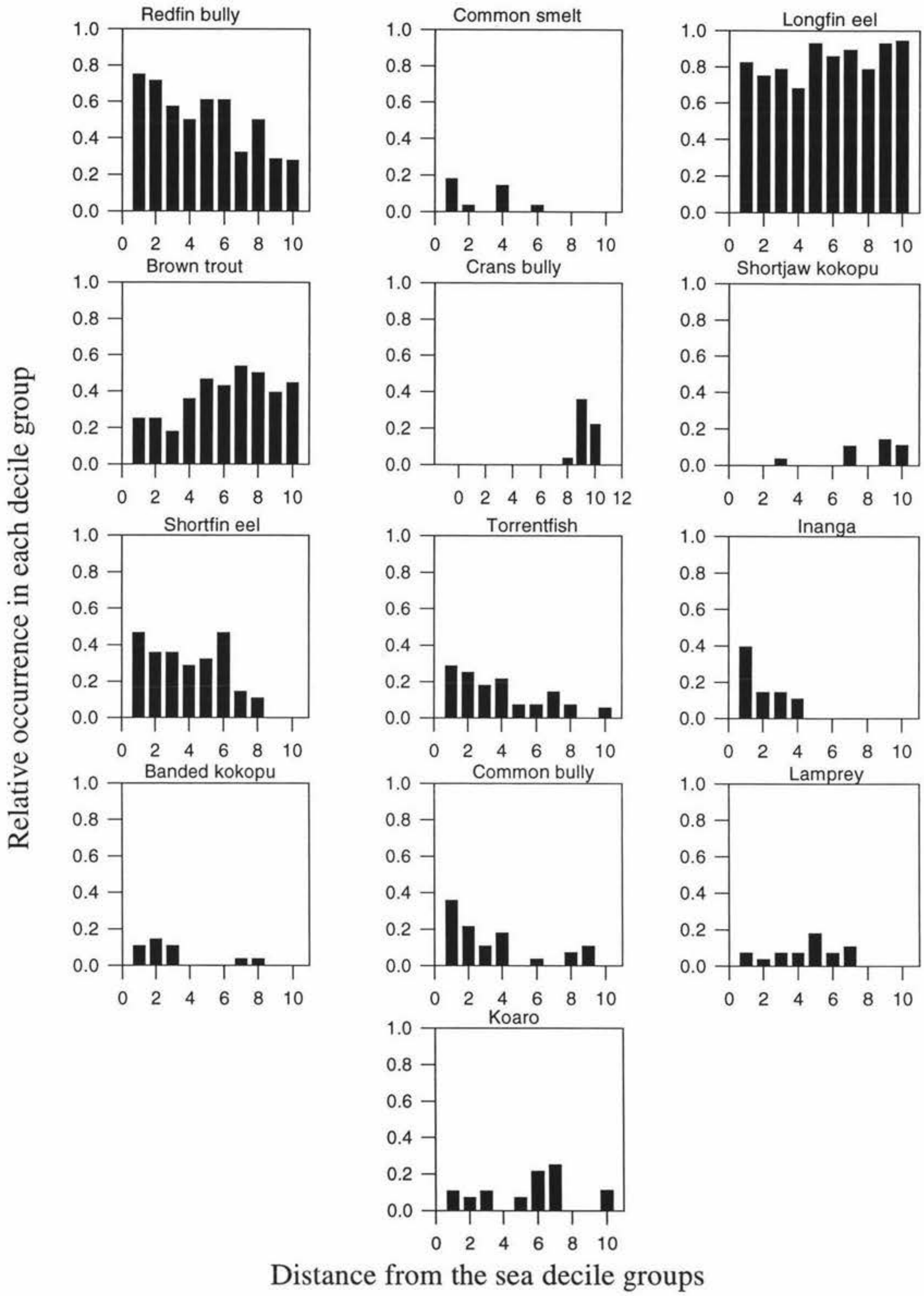

Fig. 4.5. Occurrence of fish species in 295 Taranaki ring plain streams across distance from the sea decile groups (see Table 4.1 for distance ranges).

Ranking of species

The eleven migratory species were ranked for migratory penetration in relation to elevation (Table 4.3) and distance from the sea (Table 4.4). Correlation among the species rankings for inland and altitudinal penetration revealed that the four parameters used were relatively consistent for the eleven species (Table 4.5). Altitude however, was not as consistent as distance inland. The slope coefficient for the cumulative plots was the least consistent parameter used, whereas comparison of the combined distance inland and altitude rankings revealed they were consistent (r_s = 0.76, P = 0.006). The residuals from the difference between rankings illustrate the unanimity of the ranking positions for each of the species (Table 4.6). Rankings were most consistent for distance from the sea. The altitude rankings were influenced by a large difference in slope coefficient for banded kokopu. The combined residuals give a measure of the consistency of the ranking methods on the individual species (Table 4.6). These residuals revealed that shortjaw, banded kokopu and lamprey had the most inconsistent rankings while for most other species the parameters used were relatively consistent especially common smelt and inanga, which were consistent throughout all parameters.

Table 4.3. Ranking of diadromous species from Taranaki ring plain by elevation with rankings for the same species from the West Coast South Island from McDowall (In prep.).

	Maximum altitude (m)			Median Altitude (m)			Altitude at 80% of sites			Regression coefficient cumulative plots			All altitude measures combined	
Species	Altitude	Taranaki rank	West Coast rank	Altitude	Taranaki rank	West Coast rank	Altitude	Taranaki rank	West Coast rank	Co-efficient	Taranaki rank	West Coast rank	Taranaki rank	West Coast rank
Inanga	50	1	3	15	1	4	40	1	2	0.41	1	6	1	3
Smelt	140	2	1	30	2	1	50	2	1	0.32	3	1	2	1
Lamprey	250	3	5	130	8	7	130	4	8	0.41	2	3	3	6
Torrentfish	360	6	7	60	5	6	160	5	9	0.21	6	4	4	6
Common bully	290	5	2	30	3	5	240	6	3	0.19	8	2	5	2
Shortfin eel	269	4	9	75	6	8	240	7	5	0.2	7	7	6	8
Redfin bully	400	7	4	100	7	9	240	8	6	0.23	4	8	7	9
Banded kokopu	400	8	8	30	4	3	80	3	4	0.09	11	5	8	4
Shortjaw kokopu	460	9	6	310	11	2	440	11	7	0.23	5	10	9	5
Longfin eel	550	11	10	170	9	11	290	9	10	0.18	9	9	10	10
Koaro	540	10	11	270	10	10	410	10	11	0.18	10	11	11	11

Table 4.4. Ranking of diadromous species from Taranaki ring plain by distance from the sea with rankings for the same species from the West Coast South Island from McDowall (In prep.).

	Maximum distance from sea (km)			Median distance from sea (km)			Distance from sea at 80% of sites (km)			Regression coefficient cumulative plots			All distance inland measures combined	
Species	Distance	Taranaki rank	West Coast rank	Distance	Taranaki rank	West Coast rank	Distance	Taranaki rank	West Coast rank	Co-efficient	Taranaki rank	West Coast rank	Taranaki rank	West Coast rank
Inanga	10	1	2	2	1	2	5	1	2	0.02	1	4	1	2
Smelt	15	2	1	3	2	1	10	2	1	0.59	2	1	2	1
Banded kokopu	32	4	3	4	3	3	12	3	3	0.67	3	2	3	3
Torrentfish	36	5	8	5	4	11	12	4	10	0.86	5	7	4	10
Shortfin eel	39	6	10	7	5	7	16	5	8	1.06	6	10	5	9
Common bully	44	7	4	10	6	5	17	6	5	0.84	4	5	6	5
Lamprey	21	3	7	15	8	4	17	7	9	1.49	8	6	7	6
Redfin bully	50	10	6	12	7	8	22	9	7	1.27	7	8	8	8
Koaro	49	9	9	15	9	9	20	8	6	1.51	10	9	9	9
Longfin eel	50	11	11	15	10	10	39	10	11	1.5	9	11	10	11
Shortjaw kokopu	47	8	5	25	11	6	44	11	4	2.03	11	3	11	4

Table 4.5. Spearman rank correlation coefficients of comparisons between methods for ranking of 11 diadromous fish species for Taranaki ring plain using four parameters. The upper half of the matrix is for altitude and the lower half for distance from the sea (* = $P <$ 0.05; ** = $P < 0.01$; *** = $P < 0.001$).

	Ranking method used			
	Maximum distance/altitude	Median distance/altitude	Distance/altitude at 80% of sites	Regression coefficient
Maximum distance/altitude	-	0.73*	0.79**	0.73*
Median distance/altitude	0.78*	-	0.87**	0.28
Distance/altitude at 80% of sites	0.85**	0.97***	-	0.43
Regression coefficient	0.74*	0.85***	0.93***	-

Table 4.6. Residuals for the difference between the four ranking parameters using altitude and distance from the sea for Taranaki freshwater fish fauna.

Species	Residuals for difference between ranking methods using distance inland	Residuals for difference between ranking methods using altitude	Mean residuals for the difference between distance and altitude ranking methods
Inanga	0	0	0
Smelt	0	1	0.5
Koaro	2	0	1
Shortfin eel	2	2	2
Longfin eel	2	2	2
Torrentfish	3	2	2.5
Common bully	4	4	4
Redfin bully	5	4	4.5
Shortjaw kokopu	3	8	5.5
Banded kokopu	1	12	6.5
Lamprey	6	7	6.5
Total	28	42	35

Comparison of rankings between Taranaki and Westland

The residuals for the difference between Taranaki and Westland altitude rankings revealed similar rankings (Table 4.7). Altitude rankings for koaro and longfin eel were identical and four other species were only two places different. The greatest difference occurred with banded and shortjaw kokopu; both ranked higher in Taranaki than Westland. Residuals for the difference between regions using distance from the sea also yielded similar rankings for most species. Koaro, redfin bully and banded kokopu are identical and five other species only one place different; however, shortfin eel, torrentfish and shortjaw kokopu were 4, 6 and 7 places different respectively. The mean residuals for both altitude and distance from the sea revealed that the rankings for Taranaki and West Coast were relatively concordant ($r_s = 0.69$, $P = 0.02$). Eight of the species were less than two mean rank places different while shortfin eel, torrentfish and shortjaw kokopu were 3,4 and 5.5 places different respectively (Table 4.7).

Table 4.7. Residuals for the difference between the rankings of 11 diadromous fish from the Taranaki ring plain and rankings for the same species from the West Coast South Island from McDowall (In prep.). Residuals calculated using altitude, distance from the sea and mean residuals for altitude and distance inland combined.

Species	Residuals for difference between Taranaki and Westland altitude rankings	Residuals for difference between Taranaki and Westland distance inland rankings	Mean residuals for difference between Taranaki and Westland rankings
Koaro	0	0	0
Longfin eel	0	1	0.5
Smelt	1	1	1
Redfin bully	2	0	1
Inanga	2	1	1.5
Common bully	3	1	2
Banded kokopu	4	0	2
Lamprey	3	1	2
Shortfin eel	2	4	3
Torrentfish	2	6	4
Shortjaw kokopu	4	7	5.5
Total	23	22	22.5

DISCUSSION

There is a large variation revealed in the penetration of the thirteen fish species over gradients of altitude and distance from the sea. However, quantifying these differences is difficult because of the interaction between biotic and abiotic factors that impact on migration. For example, the limited upstream penetration shown by some of the species may suggest a lack of ability/drive to migrate, however, it may also reflect a lack of suitable habitat. The shortfin eel is described by McDowall (1990) as inhabiting swampy/lagoon or lake habitats and most prevalent at low elevations. The shortfin eel distribution on Mount Taranaki reduces with elevation and does not exceed 269-m a.s.l. However, there are few swamps or lakes higher than 100-m a.s.l in the region so the reduction with elevation may relate to reducing habitat rather than elevation per se. Of the diadromous species, only shortjaw kokopu was absent from low elevations and probably relates to the lack of suitable habitats at lower elevations (McDowall et al. 1996). The plots for common smelt and inanga show limited upstream penetration, and is consistent with other studies where both inanga and smelt species have shown a preference for, or restriction to low elevation, low gradient streams (Davis et al. 1983; McDowall 1990).

The influence of elevation or distance from the sea appears to act differentially on some species. For example, the upstream penetration for common smelt peaked at 15 km from the sea and 140 m a.s.l, and torrentfish peaked at approximately 300 m a.s.l and 40 km from the sea. This suggests a low migratory drive and/or ability for these species. However, common smelt and torrentfish penetrate 180 km from the sea and 300 m a.s.l in the Mangatainoka River and common smelt penetrate 130 km and 440 m a.s.l in the Oroua River (Joy unpublished data). Gradient may therefore be more important than distance traveled as an upper limit to penetration for these species.

The fish distributions did not appear to correlate with the different forms of diadromy found in the Taranaki fauna. This may relate to the wide range of strategies within diadromy. An example is the catadromous classification for longfin eel and inanga. Longfin eel has a minimum freshwater residence time of more than twenty years whereas for inanga it is only usually one year (McDowall 1990). Thus, disregarding the physiological differences between species the different time available to penetrate upstream will undoubtedly influence distributions.

The ranking of species provides an indication of the relative penetrative ability/drive over elevational and distance gradients for each of the species. Over ranges of elevation and distance from the sea, species drop out in a seemingly orderly fashion reflecting their migratory characteristics. The upstream limits to penetration for each of the species will be either barriers in the form of waterfalls or dams or the limit of their climbing/swimming ability and/or drive. Only longfin eel attained the highest elevation sampled (550 m), and longfin eel and redfin bully attained the greatest distance inland sampled (50-km). An upper limit of 400m elevation applied to four species; torrentfish, redfin bully, banded kokopu and shortjaw kokopu. Three species; lamprey, common bully and shortfin eel all have upper limits of approximately 300 m. Whilst two species; inanga and common smelt have upper limits of 150 m. The limits mark points where significant changes in community composition occur and mark declines in species richness moving upstream.

The proportion of a fauna that is diadromous will affect the way a fish community recovers from perturbation. Diadromous fish communities are resilient as the migratory species can re-invade an area after a disturbance whereas non-migratory species will become locally extinct. The relative abundance plots show different plots for both non-migratory species, Crans bully and brown trout. Crans bullies are found only in the longer run rivers on the eastern side of Mount Taranaki. Perhaps this distribution reflects the greater stability of the lower gradient eastern waterways. The rivers on the western side of the mountain are high gradient and close to the sea and thus, would be more likely to flush out fish during high rainfall events than the lower gradient eastern waterways.

The plots illustrate the frequency of occurrence rather than abundance, however, although there was no quantitative abundance data available for all the sites, it would be expected that there would be a parallel decline in abundance with frequency of occurrence (McDowall 1988). Furthermore, changes in age and size composition over altitudinal gradients would be expected as shown in other studies. Generally, juveniles are more abundant at sites closer to the sea as shown in bluegill bully (*Galaxias hubbsi* Davis et al.

1983), torrentfish (McDowall 1973; Davis et al. 1983; Bonnett 1986), and redfin bully (McDowall 1965).

The rankings for the eleven diadromous species revealed relatively consistent ranks for most of the species between two regions of differing topography and land-use. This consistency suggests that the patterns found are more the products of the species-specific migratory ability/drive than proximal habitat requirements. The species with significantly different rankings between Taranaki and Westland were the shortjaw kokopu, torrentfish and shortfin eel. This may indicate that these species have specific habitat requirements independent of distance from the sea or altitude.

Significance for conservation and management

1. Habitat quality or degradation cannot be assessed by looking at species presence/absence without taking into account the migratory characteristics of the species.
2. Artificial barriers will exclude some species from their favored habitat and could have serious long term effects on populations.
3. Some species such as redfin bullies and torrentfish may be better indicators of barrier impacts than others such as eels or koaro.

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SYNTHESIS

A number of consistent patterns were revealed by the analysis of the data from the 85 Taranaki ring plain sites surveyed over the summer of 1997/98 and from the New Zealand freshwater fish database. The number of fish species increased following downstream increases in depth, width and reducing elevation and distance from the sea. Parallel to this increase in species richness was a decline in native riparian vegetation, overhead cover and water quality measured by invertebrate indices and chemical measures. The increase in species richness downstream generally occurred in an additive pattern although there was some species replacement especially by the non-migratory species. Ranking the migratory species for inland and elevational penetration revealed consistency between ranking methods and the regional comparison with the West Coast of the South Island.

Consistent relationships between fish communities and environmental variables were revealed by the different methods of analysis used. These relationships were the influence of elevation, distance from the sea, stream size and the percentage overhead cover on the structuring of communities. The environmental variables related to community structure were however, themselves related to altitude and distance from the sea. This interrelation of habitat variables and community assemblage meant that isolating the importance of individual variables was made difficult, if not impossible by the overwhelming influence of migration on the community structure.

Diadromy appeared to influence the species distributions in two ways, by allowing the recolonisation after perturbation and by restricting colonisation of suitable habitats beyond the reach or ability of certain species. The high incidence of diadromy in the Taranaki fauna means that access is of primary importance in structuring the fish communities and the large number of dams in the region has had a discernable negative effect on freshwater fish communities.

Appendix 1: Habitat template models and Campbell Island stream invertebrates: are subantarctic island streams different?

ABSTRACT

An invertebrate faunal survey of 20 sites on 19 Campbell Island streams was carried out over the summer of 1996/97. Twelve of the 16 benthic invertebrate taxa known from the island were collected. The most abundant group was the Crustacea, which contained an isopod (*Notidotea lacustris*) and two amphipods belonging to the families Eusiridae and Gammaridae. Dipteran larvae collected were species of Chironomidae, one species of Empididae and a simuliid, *Austrosimulium campbellense*. Other taxa found were a trichopteran, the pursed caddis *Oxyethira albiceps* (Hydroptilidae), two plecopterans (*Rungaperla campbelli* and *R. longicauda*) and unidentified Oligochaeta. Campbell Island streams are stable, deeply incised and have a unique benthic invertebrate fauna. Dominant environmental factors affecting communities include altitude, substrate size and stability, exposure to nutrient rich rain, and possibly the presence of fish. The number of taxa in each stream was considerably less than would be expected in similar mainland New Zealand streams and none of the taxa collected are included in the nucleus of genera commonly found in mainland New Zealand streams. However, despite the species poor lotic invertebrate communities found on the island and the remarkably distinctive makeup of these communities, the application of habitat models to describe them proved unsuccessful.

Keywords: Campbell Island, benthic invertebrates, habitat templets, streams.

INTRODUCTION

The application of descriptive and/or predictive models to stream invertebrate communities is increasing both in New Zealand (e.g. Biggs et al. 1990; Scarsbrook & Townsend 1993; Death 1995) and worldwide (Hughes 1995; Reynoldson &

Rosenberg, 1990; Wright 1995). Several studies have attempted to describe New Zealand invertebrate communities within an ecoregion framework (Biggs et al. 1990; Harding & Winterbourn 1997) despite the fact that earlier work by Winterbourn and his students suggested that the majority of New Zealand streams are dominated by a ubiquitous nucleus of common genera (Winterbourn et al. 1981; Rounick & Winterbourn 1982). Other studies have taken a less geographically based approach to describing New Zealand stream invertebrate faunas by applying general ecological models to describe communities within a framework of habitat characteristics primarily focused on disturbance, productivity and habitat heterogeneity (Biggs 1995; Scarsbrook & Townsend 1993; Death 1995).

Campbell Island (11 331 ha) is located 700 km south of the New Zealand mainland at 52° 53′ south and 159° 10′ east and is the southernmost of New Zealand's subantarctic islands. It is an isolated superoceanic, peat-covered island with numerous offshore islets and stacks and a maximum altitude of 558 m. The mean annual temperature is 6°C and rainfall is moderate at 1,360 mm and is spread evenly throughout the year (Clark & Dingwall 1985). Over 380 terrestrial arthropods are known from Campbell Island, but only 16 species of stream invertebrate (Gressitt 1964, 1971; McLellan 1977; Crosby 1980; Sublette & Wirth 1980; Young 1995). In this paper we describe the results of the most intensive survey (19 streams) of the stream invertebrate fauna made on Campbell Island to date and consider them within the framework of a descriptive model of habitat characteristics (Scarsbrook & Townsend 1993).

STUDY SITES

The study sites were chosen in an attempt to survey as wide a cross section of the streams on the island as possible (Fig. 1). Many streams could be sampled only near their mouths since they run through very steep gullies for much of their courses and are often inaccessible. The study sites were all on 1st- or 2nd- order streams, between 0.2m -3 m wide ranging in altitude from 1 to 400 m a.s.l. All sites were on separate streams except for sites 2 and 3, which were both on Tucker Cove Stream. One site (Kirk stream) was near where the stream entered the only lake on the island

(Sixfoot Lake) and another site (Sixfoot Lake) was on the outflow from this lake. Because access was difficult, streams in the southeastern corner of the island were not included in this study.

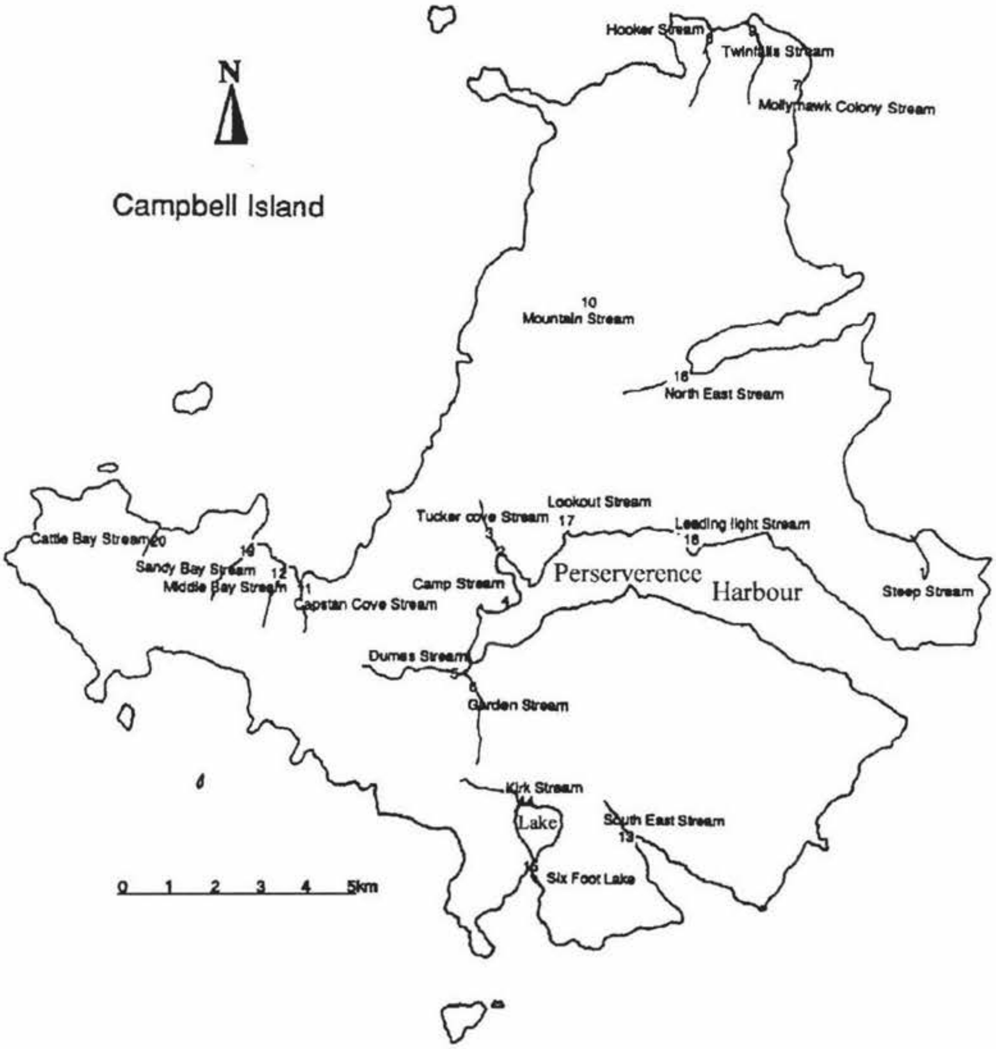

Fig. 1. Location of stream sites sampled on Campbell Island between December 1996 and February 1997 (Unnamed streams were given the name of a nearby geographical point).

METHODS

Environmental measures

Channel width and midstream depths were measured at five equidistant points along each study reach and averaged. Current velocity was assessed by recording the time taken for a cork to travel 2 m. Temperature was measured with a glass mercury thermometer and pH with an Orion model SA 250 portable pH meter. Substrate composition was assessed visually as the percentage of substrate in each of six categories, bedrock, boulders (>27 cm), large cobbles (13-26 cm), small cobbles (6-12 cm), gravel (2-5 mm) and sand (<2 mm). Percent moss cover, periphyton cover and riparian vegetation were visually assessed over 20m of stream. Altitude and stream order were derived from a 1: 25 000 scale topographical map. Channel stability at each site was assessed using the method of Pfankuch (1975), which involves scoring 15 variables (weighted in relation to their perceived importance) in three sections of the stream channel - substrate, lower and upper banks according to the observer's evaluation of predetermined criteria. The ratings are combined to give an overall stream stability score that can range from 40 (most stable) to 160 (least stable).

Substrate heterogeneity was inferred from a measure of substrate diversity (Minshall 1984; Scarsbrook & Townsend 1993), based on the size distribution of the stream bed particles estimated above. Substrate diversity was measured using Simpson's index (1949), which has the form:

$$D = \sum \left(\frac{n_i(n_i - 1)}{N(N-1)} \right)$$

Where n_i = the number of stones in the *i*th class and N = the total number of stones measured

Invertebrate sampling

Collections of invertebrates were made from riffles at each of the 20 sites between December 1996 and February 1997. A three-minute kick net sample was taken at each site using a 250 µm mesh net, stones that could be dislodged were brushed into the net and immovable substrates were surface brushed. Samples were preserved in 10% formalin. Invertebrates were identified to the lowest level possible and differentiated into apparent morphospecies in all cases.

Statistical Analysis

Community structure was analysed using multivariate ordination and classification techniques. Ordination was carried out using detrended correspondence analysis (DECORANA) using the PC-ORD multivariate statistical package (McCune & Mefford 1995). Environmental variables to which gradients corresponded were evaluated by correlating environmental measures made at the study sites. Classification of site communities into distinct groups was carried out again using PC-ORD (McCune & Mefford 1995). Euclidean and relative Euclidean distance measures were used to create clusters by group averaging. Quantitative distance measures were calculated on logarithmically transformed data [ln (x+1)].

RESULTS

Habitat characteristics of Campbell Island streams

All Campbell Island streams examined were deeply incised with apparently very stable substrates. Blanket peats up to 10 m thick cover the island and some of the streams are so deeply incised that the peat soil banks close in over the top forming caves. Nine of the 20 sites had more than 50% overhead cover provided principally by the shrubs *Dracophylum scoparium* or *D. longifolium*, ferns and grasses below 150m a.s.l, and the tussocks *Chionochloa antarctica* and *Poa litorosa* at higher altitudes. A summary of environmental data recorded at the study sites are shown in Table 1. Pfankuch stability scores ranged from 41 to 65 and indicated high stability. pH at 18 sites ranged between 5.7 and 7.7, however, Steep stream was strongly acidic (4.4) while the lower site on Tucker Stream was 8.2. In many places the acidity of the peat soil is possibly neutralised by the limestone bed rock found over western and central areas of the island. The galaxiid fish *Galaxias brevipinnis* was seen in large numbers in Sixfoot Lake and some of the lower altitude streams.

Table 1. Summary of environmental characteristics measured at each of the 20 sites on Campbell Island between December 1996 and January 1997. Sites are listed in order of ascending altitude.

Sites	Width (m)	Depth (cm)	Alt. (m)	Temp (°C)	Pfankuch	pH	Dist. inland (m)	% Cover
Lower Tucker st.	1.2	10	1	9	61	8.2	20	10
Dumas st.	2.7	8	1	8.5	67	7.2	30	60
Garden st.	1.2	12	1	9	57	6.9	30	60
Capstan Cove st	2	6	1	8	57	7.4	10	20
Middle Bay st.	1.1	4	1	8	53	7.6	10	10
Sixfoot lake st.	2.9	8	1	9	50	7.7	10	0
Northeast st.	2.7	10	1	9	68	6.4	50	60
Lookout st.	0.9	6	1	8	52	6.6	5	80
Leadinglight st.	0.6	4	1	8	43	6.5	2	0
Sandy Bay st.	1.2	6	1	8	65	7.5	10	60
Kirk st.	1.1	20	3	9	53	6.3	1000	20
Southeast st.	1.4	10	5	8	58	7.6	20	30
Camp st.	2.1	13	10	8.5	49	6.9	150	50
Upper Tucker st.	1.2	12	20	8	64	7.5	500	50
Hooker st.	3	20	40	8.5	38	6.7	90	10
Twinfalls st.	0.2	10	40	7	41	5.7	60	10
Cattle Bay	0.9	5	50	8	60	7.6	230	60
Mollymawk st.	0.4	3	80	8	42	6.9	80	80
Steep st.	0.7	6	140	7	58	4.4	300	70
Mountain st.	0.2	20	400	8	55	7.1	5000	0
Mean	1.4	9.8	39.3	8.2	54.2	6.9	388.2	67
Range Max	3	20	400	9	68	8.24	5000	80
Min	0.2	3	1	7	38	4.4	2	0

Cluster analysis of all the environmental data split the sites into three groups (Fig. 2). They were the higher altitude sites (group A), lower altitude sites (group B), and Mountain stream (C). The latter was the smallest, highest and most open site. High altitude streams were narrow with smaller substrates, while the lower altitude streams were wider, warmer and had larger substrates.

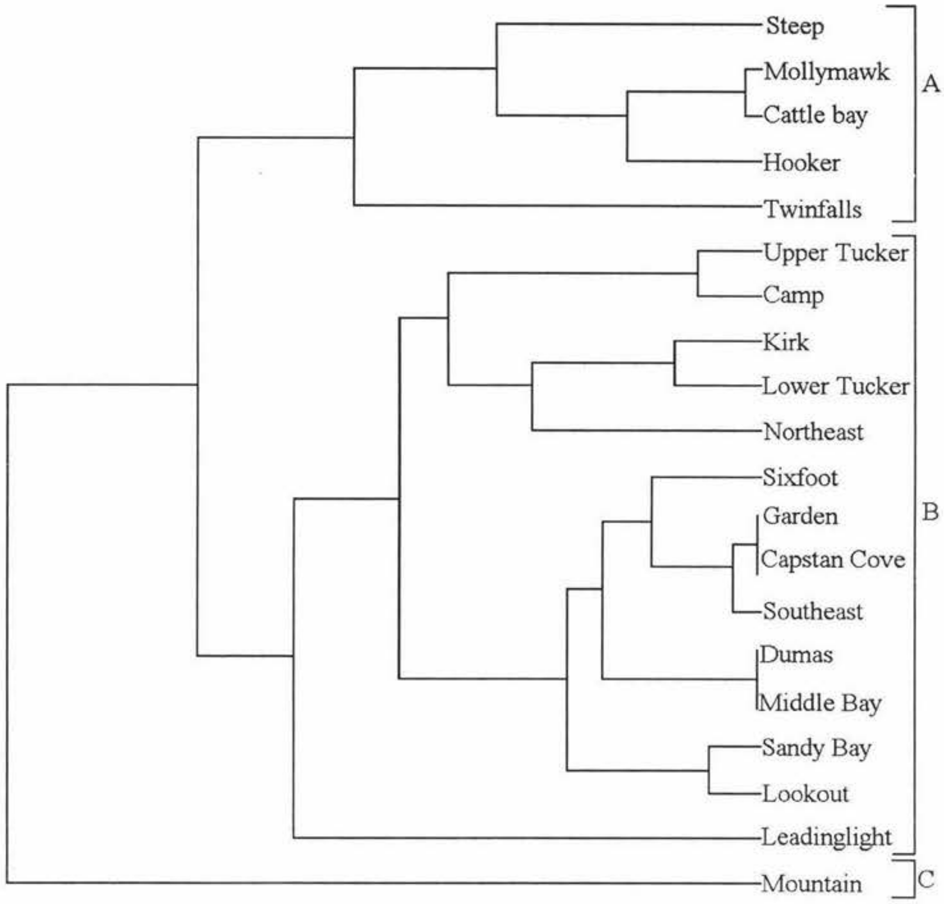

Fig 2. Cluster analysis of log transformed environmental data collected at each of 20 study sites on Campbell Island between December 1996 and February 1997.

Benthic invertebrate fauna

A total of 12 taxa (morphospecies) were collected, the most abundant group overall being the isopod *Notidotea lacustris* and two unidentified amphipods belonging to the families Eusiridae and Gammaridae. Five species of Diptera were found (three chironomids; *Eukiefferiella* sp., *Chironomus* sp. and *Maoridiamesa*; an empidid and a simuliid *Austrosimulium campbellense*). One trichopteran, the hydroptilid caddis *Oxyethira albiceps* and two plecopterans *Rungaperla campbelli* and *R. longicauda* and unidentified Oligochaeta were also collected. The higher altitude sites all had similar taxonomic compositions and were dominated by Crustacea, whereas the lower altitude sites were more variable in species composition (Fig 3).

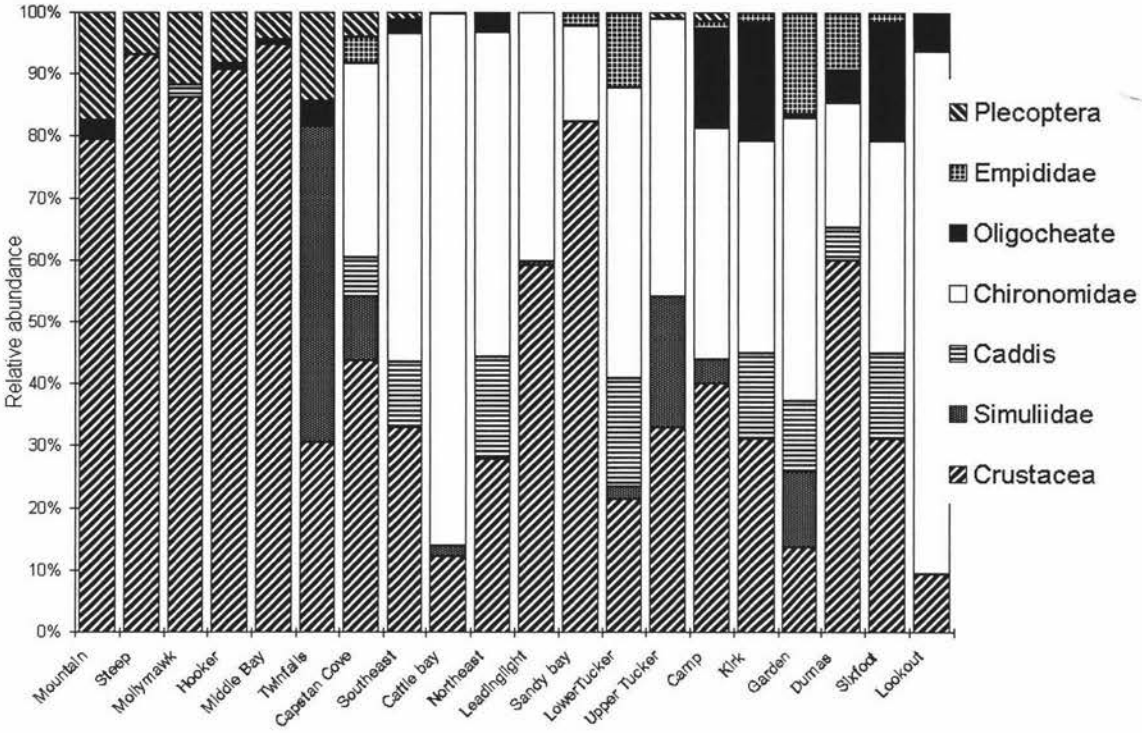

Fig. 3 Relative abundance of higher taxa of invertebrates collected at each of the 20 study sites on Campbell Island between December 1996 and February1997. Groupings as for cluster (Fig. 5). Sites are listed in order of decreasing altitude.

The number of taxa per site ranged from 3 to 8 and the number of individuals at each site ranged from 32 to 409 (Fig. 4). The number of individuals at each site increased with altitude ($F_{1,18} = 13.5$, $P = 0.002$, $r^2 = 0.43$) and log (distance inland) ($F_{1,18} = 21.8$, $P = 0.000$, $r^2 = 0.55$) (Fig. 4). However, there was no relationship between species richness and altitude ($r^2 < 0.1$, $P > 0.05$).

Invertebrate community structure

Clustering with Euclidean (Fig. 5) and relative Euclidean (not shown) distance measures revealed similar trends and resulted in three broad groups and one out-group. Group A contained higher altitude sites and Middle Bay stream with a sub-group of Capstan Cove, Southeast and Cattle Bay streams. Group B consisted of intermediate altitude sites Northeast, Leadinglight and Sandy Bay streams. Group C contained five of the seven streams draining into Perseverance Harbour and the sites above and below Sixfoot Lake. Lookout stream was the outgroup with the lowest species richness and abundance.

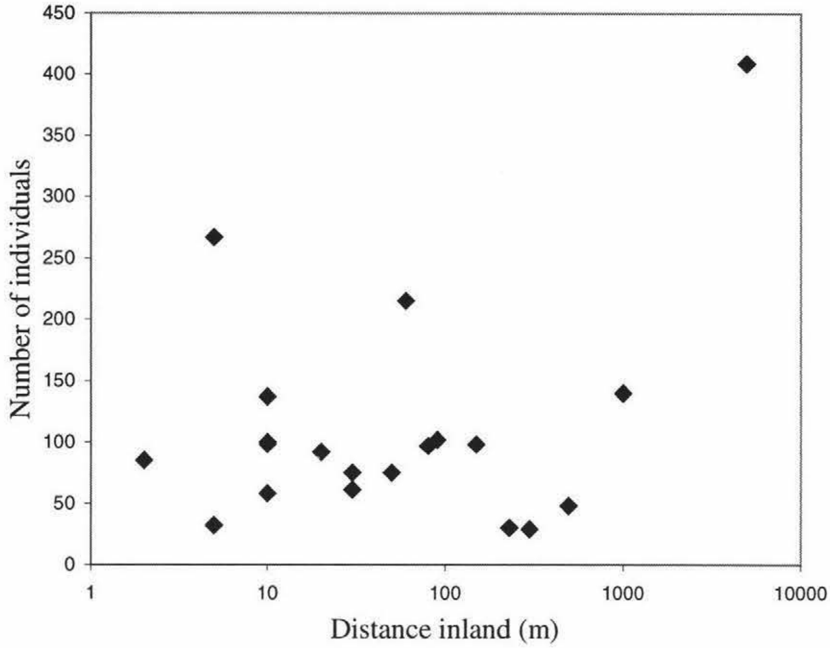

Fig 4. Number of individual invertebrates collected from each of the 20 sites on Campbell Island between December 1996 and February 1997 as a function of distance inland. Regression equation: number of individuals = 89.3 + 0.06 distance inland, $r^2 = 0.55$.

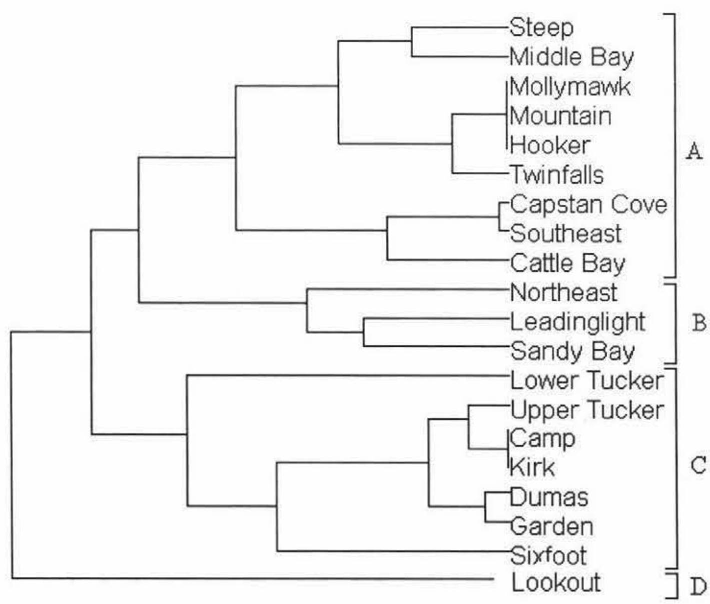

Fig. 5 Cluster analysis of the log transformed data using group average from invertebrate communities collected by kick net at each of the 20 study sites on Campbell Island between December 1996 and February 1997.

Fig. 6 Axis one of a detrended correspondence analysis as a function of axis two for invertebrate communities collected at the 20 sites on Campbell Island between December 1996 and February1997.

Ordination (Fig. 6) also split the high altitude sites at the center left of axis 1 from the Perseverance Harbour and Lake sites on the center right. These two groups are essentially groups A and C in the species cluster (Fig. 5). The group on the center left (group A in the cluster) consists of Mountain, Mollymawk, Hooker, Steep, Twinfalls, Cattle Bay, Middle Bay and Southeast streams. On the center right (group C in the cluster) is Garden, Camp, Upper Tucker, Kirk, Dumas and Sixfoot Lake streams. Sandy Bay, Leading light and Northeast streams are grouped together at the top center (group B in the cluster). Lookout stream is on its own as in the cluster (lower right). Capstan Cove and Lower Tucker are together lower center. Axes 1 and 2 of the DECORANA together accounted for 68% of the variation in the data. Correlation of the 19 measured environmental variables with the first two axes showed that axis 1 was positively correlated with temperature (r = 0.68), percentage small cobbles (r = 0.55), and decreasing stability (r = 0.50) and negatively correlated with percentage boulders (r = -0.62) and altitude (r = -0.52). Axes 2 and 3 were not correlated with any measured environmental variable.

Distinct groups of taxa were associated with the two main DECORANA axes and their associated environmental variables. Axis 1 was positively associated with *Maoridiamesa* sp., *Oxyethira* and Empididae and negatively associated with Eusiridae and *Rungaperla.* Taxa associated positively with axis two were *Eukiefferiella* sp. while *Maoridiamesa* and Gammaridae were negatively associated. The higher altitude sites had a similar community composition, dominated by Crustacea and Plecoptera. The make up of the Perseverance Harbour and Lake Sites was more variable with higher species diversity (Fig 3) whereas Chironomidae were the dominant taxon in most sites other than the high altitude sites.

DISCUSSION

Of the 12 invertebrate taxa collected in this study, all had previously been recorded from Campbell Island (Crosby 1980). The majority of the taxa collected have restricted or poorly known distributions within New Zealand and none are included in the common core of taxa generally found in New Zealand streams (Rounick & Winterbourn 1982; Winterbourn et al. 1981). Unlike the New Zealand mainland fauna, there are no mayflies, no coleoptera, no large diptera and no mollusca. The invertebrate communities found on Campbell Island are thus taxonomically very different from those found in similar streams on the New Zealand mainland and Stewart Island and the number of species is an order of magnitude less (Chadderton 1988, 1990; Rounick & Winterbourn 1982; Winterbourn et al. 1981). The relationship between the number of taxa and island area illustrates that Campbell Island is particularly depauperate compared to Kapiti and Stewart Islands (Table 3). This comparison suggests that the effect of isolation is greater than that of area.

Table 3. Number of benthic invertebrate taxa from selected islands

Island	Area	Number of benthic invertebrate fauna
Stewart Island*	114,000km^2	66
Campbell Island	11,000km^2	16
Kapiti Island ϕ	2,000km^2	56

* Chadderton (1988)

ϕ I. M. Henderson (unpublished data)

The habitat templet model as applied to lotic systems (Scarsbrook & Townsend 1993; Townsend & Hildrew 1994) predicts that in habitat types differing in disturbance frequency and the availability of spatial refugia the benthic invertebrates will show distinct life history traits and community patterns. The predictions are that in habitats experiencing a high disturbance frequency and low refuge availability (spatially homogeneous) the invertebrate community will be characterised by low species diversity and the occurrence of mobile weedy species. Conversely in habitats having low disturbance frequency and high refuge availability (spatially heterogeneous) the prediction is that the invertebrate community will be characterised by sedentary and specialist species and diversity will be high. To evaluate the habitat templet model (Scarsbrook & Townsend 1993; Townsend & Hildrew 1994) substrate heterogeneity was plotted against stability for each of the Campbell Island invertebrate communities (Fig. 7). The life history traits and community structure found on Campbell Island do not appear to conform to the model predictions. For example the sites in the upper left of the figure which are predicted to have high diversity and consist of sedentary specialist species are in general the sites with lowest diversity. The lower right of the figure where diversity is predicted to be low, is where the sites from this study with the highest species richness generally occurred. However as Campbell Island streams appear very stable the ability of the model to differentiate between sites on this basis will be limited.

The taxonomic make up of the stream communities in this study was distinctive. Classification (Fig 5) and ordination (Fig 6) of the sites revealed a group of higher altitude sites of similar community make up. These streams: Mountain, Steep, Mollymawk, Hooker, Twinfalls, and Middle Bay (Group A in the classification) had similar taxonomic compositions consisting chiefly of Crustacea and Plecoptera, and they had low numbers of taxa. The rest of the sites apart from Lookout stream had a distinctive makeup but few similarities. Lookout stream was an outgroup having a low number of species and individuals.

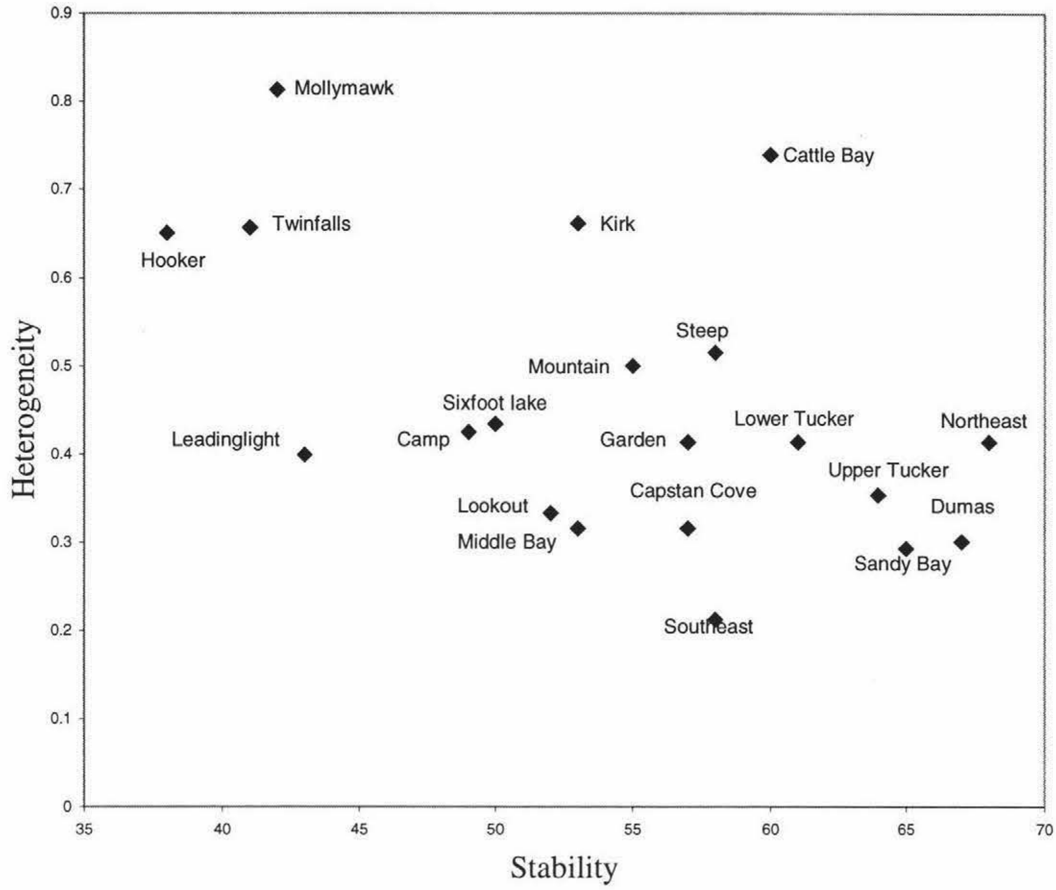

Fig. 7. Position of the study sites within the framework of the habitat templet model (Scarsbrook & Townsend 1993; Townsend & Hildrew 1994).

A major factor structuring terrestrial vegetation community patterns on Campbell Island is the input of ion rich nutrients from the sea via mist and rain. This maritime complex is most broadly developed along the exposed northwest to southwest facing coasts (Meurk et al. 1994). Similarly, maritime influences can be expected to influence stream communities as found on Stewart Island by Chadderton (1998,1990). Isopod numbers are lower at the Perseverance Harbour sites, which are sheltered from the prevailing winds and this may influence habitat requirements of this taxon. Interestingly *Notidotea* was most abundant at high altitude sites where the direct influence of the sea (e.g. by sea-spray, tidal movement) would be expected to be least, and contrasts with the almost exclusively coastal distribution of the *Austridites* spp on Stewart Island (Chadderton 1988,1990). The presence of the fish *Galaxias brevipinnis* may also influence the invertebrate community structure of these streams by predation as Koaro are known to eat chironomid and simuliid larvae (McDowall and Eldon 1980). It was not possible to test for any influence, as establishing Koaro presence at all sites was not possible. Four of the streams; Steep, Mollymawk, Hooker and Twinfalls have large waterfalls below the sample sites which possibly exclude koaro, and Isopoda and Plecoptera dominated the fauna at these sites.

Campbell Island streams are stable, deeply incised and have a unique small unbalanced benthic invertebrate fauna associated with the small size of the island and its geographical isolation. The environmental factors associated with the flowing water invertebrate communities appear to include altitude, substrate size and stability, exposure to nutrient rich rain and possibly the presence of fish.

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