# Habitat use by New Zealand fish and habitat suitability models

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*Cover photograph: Shortfin eel, Karekare Beach stream, by Stephen Moore.*

The habitat suitability curves and general additive models (GAMs) described in this report are available from Ian Jowett or NIWA.

Also available: **A guide to instream habitat survey methods and analysis.** *NIWA Science & Technology Series No. 54* (2008) by Ian G. Jowett, John W.Hayes, & Maurice J.Duncan.

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# Abstract

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The concept of habitat suitability is familiar to most people who collect fish, plants, or aquatic insects from rivers and target those habitats in their search for those biota. Authoritative publications on aquatic biota often include qualitative descriptions of the habitats and physical conditions in which the biota are likely to be found. Usually this is a qualitative description of the physical habitat (water velocity, depth, substrate, and perhaps cover), but can be at a larger scale, such as pools, runs, or riffles. The quality of the different habitats in a stream, for a given animal, is defined by the relative abundance of animals in them. Usually, animals will be most abundant where the habitat quality is best, in lesser numbers where the habitat is poor, and absent from unsuitable habitat. In fact, we use the relative abundance of animals to define habitat suitability.

Habitat suitability criteria have more influence on flow assessments than any other aspect of the analysis. Failure to use appropriate criteria can result in inappropriate flow assessments and this is one reason why the use of habitat suitability criteria has been criticised.

In this study, we use measurements of habitat use for over 21 000 fish of different species to develop habitat suitability curves and generalised additive models (GAMs) for the common fish species in New Zealand rivers. The data were obtained mainly from daytime single-pass electric fishing surveys performed by NIWA and Department of Conservation staff in wadeable rivers and streams. Data for banded kokopu were obtained by night observations, inanga by day bank-observation, and giant kokopu data were obtained by electric fishing and nets set overnight. In total, there were measurements of habitat use at 5184 locations in 124 rivers.

We developed habitat suitability curves for each fish species using a consistent set of procedures available in the HABPRF program. The procedures examined habitat use and preference in a number of different ways in order to make the best possible subjective assessment of habitat suitability. The procedures were:

- tabulating the range of depths, velocities, and substrates that were sampled and the average depth, velocity, and substrate in which each species was found
- calculating forage ratios for depth, velocity, and substrate index using all data
- calculating forage ratios for depth, velocity, and substrate index for each river in which the species was found, and then averaging these relationships
- plotting contours of fish density with depth and velocity using LOESS
- developing a logistic GAM using depth, velocity, and substrate index as predictors and plotting contours of probability of use with depth and velocity
- comparing the GAM and LOESS contours to determine whether it was necessary to introduce a depth/velocity interaction term
- normalising the forage ratio relationships to a maximum value of 1 and using these to develop preliminary suitability curves
- developing final habitat suitability curves, taking into account the shape of the GAM functions, habitat use curves, the inability of the smoothed curves to adequately describe suitability at the extremes (e.g., the suitability of zero depth), and substrate stability with high water velocity.

While many fish undoubtedly make use of habitat on a micro scale, most habitat suitability observations describe mesohabitats – the characteristics of the area in which the organism lives, rather

than the microhydraulics of its precise location. In assessing suitability for one species, we are often assessing conditions for a number of species that live in that area. Riffle-dwelling fish are an example, where the habitat suitability curves describe riffle conditions, rather than microhabitat of the location of an individual fish.

When we considered fish locations in terms of pool, run, and riffle habitat (assessed by Froude number), we found that adult eels, lamprey, a variety of juvenile galaxiids, and adult kokopu use pool habitat; torrentfish, bluegill bullies, koaro, alpine galaxias, and upland longjaw galaxias use riffle habitat, and juvenile eels, trout, and some galaxiid and bully species are mainly in run habitat.

The classifications of pool, run, and riffle habitat do not necessarily mean that those fish are likely to be found entirely in pools, runs or riffles. The margins of riffles often contain slow flowing water and many of fish species that use run habitat actually live along the margins of riffles.

Although habitat suitability criteria for many New Zealand fish species are described here, they can be improved by collecting more data, particularly for the rarer species. The method of data collection is important for the derivation of habitat suitability models. The conditions in which fish are sampled should not be extreme (i.e., normal flow and water temperature, usually in summer) and the full range of habitats should be sampled with equal effort, whether they are likely to hold fish or not. This can be difficult because it requires sampling shallow water over a full velocity range and deep water over a full velocity range.

This review of habitat suitability curves has involved developing curves for 10 new species or life stages and revising existing curves for 19 species or life stages. The revised curves are similar to those derived more than 10 years ago with much fewer data. This is reassuring because it suggests that habitat use does not vary significantly between rivers, something that was evident in this study when analysing habitat suitability for individual rivers. Generally, the habitat suitability curves show a slightly wider range of preferences than the earlier curves. However, for some species, high velocity preferences have been reduced by considering the substrate stability under high velocities. Generalised additive models (GAMs) were generally better predictors of presence/absence than the conventional habitat suitability curves. Overall, the hydraulic habitat preferences of the species are consistent with their known use of pool, run, and riffle habitats.

# 1. Introduction

The concept of good habitat is familiar to most people. For example, angling texts describe likely trout streams and more recent books (e.g., Hill & Marshall 1985) accurately describe locations where trout are likely to be found. It is possible to determine the relative quality, for a given animal, of the different habitats from the abundance of animals in them. Usually animals are most abundant where the habitat quality is best, in lesser numbers where the habitat is poor, and absent from totally unsuitable habitat. Instream habitat usually refers to the physical habitat – water velocity, depth, substrate, and perhaps cover. However, other relevant factors, such as aquatic vegetation and presence of other species, can be incorporated into the evaluation of habitat suitability.

Habitat suitability or preferential habitat use has been known and applied in biological studies of animals for many years (Manly et al. 1993). In one of the first New Zealand studies of habitat suitability, Campbell & Scott (1984) found that 0+ brown trout moved from runs to pools and adopted shoaling behaviour when water velocity in runs fell below 0.3 m/s. They suggested that run habitat was optimum for juvenile brown trout and that 0.3 m/s could be used as a minimum velocity criterion. Since then, studies have been carried out to determine habitat preferences of native fish (e.g., Glova & Duncan 1985; Jowett & Richardson 1995; McCullough 1998; Jowett 2002; Baker et al. 2003).

The aim of using habitat suitability criteria in instream habitat analysis and flow assessments is to maintain, or even improve, the physical habitat for instream values, or to avoid situations where poor habitat becomes a limiting factor. This requires detailed hydraulic data, as well as knowledge of the ecosystem and the physical requirements of stream biota. The basic premise of habitat methods is that if there is no suitable physical habitat for the given species, then they cannot exist. However, if there is physical habitat available for a given species, then that species may or may not be present in a survey reach, depending on other factors not directly related to flow, or to flow related factors that have operated in the past (e.g., floods). In other words, habitat methods can be used to set the “outer envelope” of suitable living conditions for the target biota.

Habitat suitability criteria have more influence on flow assessments than any other aspect of the analysis. Failure to use appropriate criteria can result in inappropriate flow assessments and this is one reason why the use of habitat suitability criteria has been criticised. Therefore, habitat criteria need to be considered for all life stages and, where appropriate, suitability criteria for the production of food for those life stages should also be included. Selection of appropriate criteria and determination of habitat requirements for an appropriate flow regime requires a good understanding of the species’ life cycles and food requirements (Heggenes 1988, 1996).

This report covers the following aspects of habitat suitability:

- the concept of habitat suitability
- habitat suitability models
- methods and data used to develop habitat suitability criteria and models for common New Zealand fish species.

# 2. Stream ecology

Biologists and anglers who study rivers are well aware that aquatic species are likely to be found in association with specific habitats, and many aquatic species are found in similar hydraulic conditions in a wide range of rivers. These have been termed habitat niches, and include both physical and biotic characteristics of the environment (Odum 1971). The habitat niche concept is essentially the same as habitat suitability. These concepts have been widely applied in both terrestrial and aquatic biological studies, with the understanding that the presence of suitable habitat for any species is a necessary condition for survival.

Water velocity is probably the most important characteristic of a stream. Without it, the stream becomes a lake or pond. In gravel bed rivers, an average velocity of 0.2-0.3 m/s or higher tends to provide for most stream life, because velocities lower than this provide unsuitable habitat for a number of fish species (Jowett & Richardson 1995) and their primary food source (benthic invertebrates) (Jowett et al. 1991), and allow deposition of sand and finer materials, as well as the development of nuisance growths of long filamentous algae (Biggs & Stokseth 1996). In large rivers, water depth of more than 0.4 m provides habitat for brown trout (Hayes & Jowett 1994), but in small streams depths in excess of 0.05 m are adequate for most native fish (at least for benthic native fish) (Jowett & Richardson 1995).

## 2.1 Habitat suitability and mesohabitat

Most habitat suitability criteria describe the meso-scale habitats in which the organisms are found. This contradicts the widely held belief that habitat suitability criteria usually define microhabitat. While many fish undoubtedly make use of habitat on a micro scale, most habitat suitability observations describe mesohabitats – the characteristics of the area in which the organism lives, rather than the microhydraulics of its precise location. Riffle-dwelling fish are an example, where the habitat suitability curves describe riffle conditions, rather than microhabitat of the location of an individual organism.

Measurements of habitat use are taken at a fish's location and usually the depth and mean column velocity will be similar to those in the general vicinity. Nose velocities (velocity taken at a fish's nose) fall more strictly into the category of microhabitat measurements, but these are not used in traditional habitat modelling because the hydraulic models (other than 3D models) predict mean column velocity. Habitat suitability criteria for New Zealand native fishes typically have been based on measurements in lanes or areas of 2–3 $m^2$ of 'homogeneous' depths and velocities from which the species have been collected by electro-fishing (Jowett & Richardson 1990, 1995). Clearly these area averaged measurements relate to meso-habitat rather than microhabitat, especially given that the nose or microhabitat velocity for benthic species is zero or very near zero.

Flow assessments based on habitat have been criticised for considering only a target species or a limited number of species and ignoring biotic interactions (Hudson et al. 2003). However, mesohabitats are also generally occupied by other organisms and habitat suitability criteria developed from observations in these mesohabitats may therefore include biotic interactions. For example, the habitat use and behaviour of many invertebrate species are considered to be influenced by the presence of predatory fish, therefore habitat suitability criteria developed in the presence of predatory fish should implicitly account for this and would be applicable to other situations where predatory fish occur. Riffles provide habitat for benthic invertebrates and a number of native fish species and juvenile trout (that feed on benthic invertebrates). Habitat suitability criteria that describe the locations in which these organisms are found also describe what could be termed 'riffle habitat'. Thus, habitat requirements of a given species can be used as indicators or surrogates for broader meso-habitat values. For example, habitat suitability criteria for common and redfin bullies specify optimum depths of 0.11–0.19 m and velocities of 0.28–0.38 m/s. As a rule of thumb, good run habitat occurs where the numerical value of the velocity exceeds 1.24 times the numerical value of the depth, so the common and redfin bully criteria describe habitat that is intermediate between run and riffle.

# 3. Habitat suitability models

The terms in habitat suitability modelling can be confusing because suitability, use, and preference have specific meanings, but are commonly used interchangeably. Even the term habitat can be used to mean a general area of a river, such as a riffle where a species might reside ('riffle habitat'), or might refer to species locations on a smaller scale (e.g., depths of 0.11–0.19 m and velocities of 0.28–0.38 m/s are suitable bully habitat). When we refer to habitat use, we refer to the physical characteristics of locations at which fish were found, whereas habitat availability describes range of physical habitat that occurs in the river. In this report, we use the term preference for the calculated forage ratio or forage ratio normalised to 1, as described in Section 3.3. We use the term suitability for the suitability curves that are derived subjectively, as described in Section 3.5.1.

Bovee (1986) described three categories of habitat suitability criteria. Category I curves were based on expert opinion. Category II curves were based on the frequency of habitat use, and Category III curves were based on preference by adjusting habitat use for habitat availability as described in Section 3.3. In this report, the habitat use curves are equivalent to Bovee's Category II curves and the forage ratio/preference curves are equivalent to his Category III curves.

Habitat suitability criteria are used with hydraulic models in the assessment of flow requirements. Conventionally, habitat suitability is based on water depth, velocity, and substrate, but other variables could be used if required. The values of suitability vary between 0 (unsuitable) and 1 (ideal). The overall suitability of a point in the stream is the product of the respective suitability scores for depth, velocity, and substrate (Fig. 3.1). This means that if any of the individual suitability scores is zero then the point is unsuitable for that habitat use.

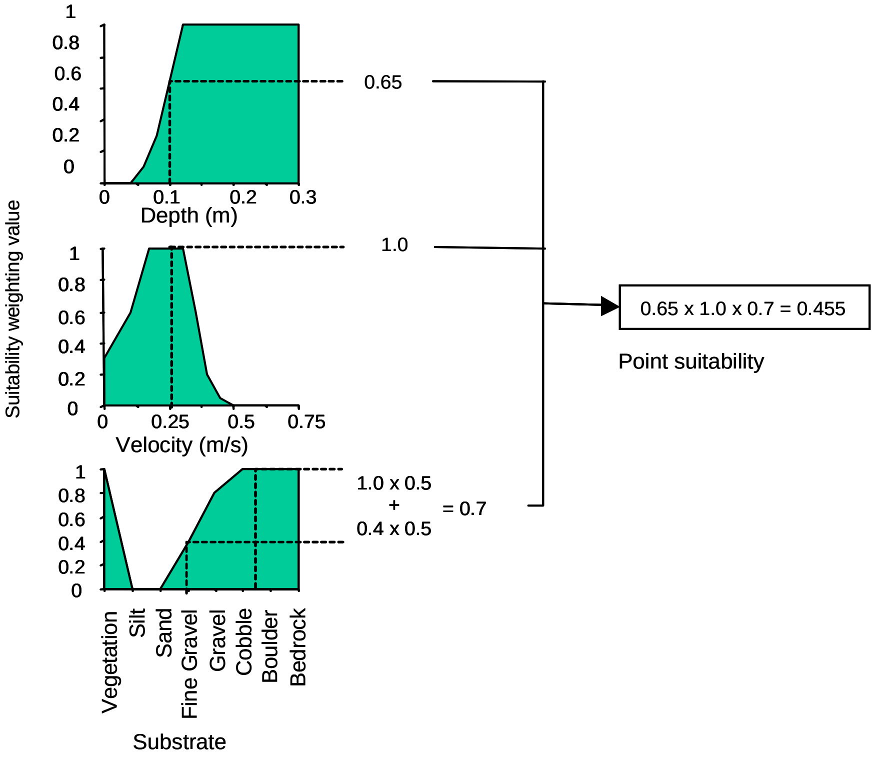

**Figure 3.1: Conventional calculation of habitat suitability at a point in a river with a depth of 0.1m, a velocity of 0.25 m/s and 50% cobble and 50% fine gravel substrate.**

The total amount of habitat in the reach is summed for all points at each flow after multiplying the habitat suitability of each point by the area it represents, to give the weighted usable area (WUA).

Habitat suitability criteria and interpretation of weighted usable area (WUA) have been criticised (Mathur et al. 1985; Scott & Shirvell 1987; Castleberry et al. 1996; Kondolf et al. 2000; Hudson et al. 2003). Morhardt & Mesick (1988) summarised the criticisms as follows:

1) when calculating the combined suitability index, variables are treated independently and potentially significant interactions between variables are ignored
2) weighted usable area, which results from the use of suitability criteria, is an index and cannot be measured directly
3) different estimates of weighted usable area can be obtained by using different methods of combining the suitability indices
4) weighted usable area combines elements of habitat quantity and habitat quality. A large area of low-quality habitat can produce the same weighted usable area as a small amount of high-quality habitat.

Multivariate statistical models, such as exponential polynomials (Gore & Judy 1981; Orth & Maughan 1983; Jowett & Richardson 1990; Hayes & Jowett 1994), quadratic logistic regression (Thielke 1985; Hayes & Jowett 1994), and generalised additive models (Hastie & Tibshirani 1990) are alternatives for fitting habitat suitability data; they overcome the problem of independence and can incorporate interaction terms.

If habitat suitability curves or multivariate models are fitted to abundance or occurrence data, the index that is generated from these curves is an index of abundance or probability of use. Jowett et al. (1991) showed that the combined suitability index formed by multiplying the suitability indices together was correlated with species abundance for benthic invertebrates. Thus, a large area of low-quality habitat can support the same number of fish as as a small area of high-quality habitat with the same weighted usable area, assuming that the fish populations are at stocking capacity and not restricted by territorial considerations.

Jowett & Davey (2007) compared habitat suitability curves and GAMs and found that, despite the theoretical advantages of GAMs, both methods gave similar results in most situations.

In this report, we develop habitat suitability curves and GAMs for most common native fish species in New Zealand rivers.

## 3.1 Collection of habitat suitability data

The locations of aquatic species can be found by electric fishing for small benthic fish, bank and snorkel observation, and high resolution sonar (DIDSON) for large fish day or night, or spotlighting for nocturnal habitat use. For example, habitat preference data for native fish (Jowett & Richardson 1995) were based on electro-fishing measurements of fish densities within small habitat units, unlike adult trout habitat (Hayes & Jowett 1994) and inanga (Jowett 2002) measurements, where the characteristics of individual fish feeding locations identified by bank observation were measured. McCullough (1998) used spotlighting to locate night feeding positions of banded kokopu.

The sampling methods and strategy used to obtain data for habitat suitability studies need careful consideration. The method of sampling should not disturb the fish to the extend that they move out of the sampling area, the selection of sampling sites should be unbiased, and a large range of habitats should be sampled. For example, if the habitat preferences of a fish species are known or suspected, there may be a tendency to sample only those habitats likely to contain those fish. If sampling is biased towards fish locations, there will be relatively little variation in number of fish found over the range of habitats sampled.

Ideally, a sampling programme is designed to sample a wide range of habitats with near equal effort. The preference calculation is an attempt to counter habitat availability bias caused by the full range of habitats not being equally prevalent, or not being sampled with equal effort – but it can itself introduce bias/distortion, especially in regions of low frequencies in either the habitat use or availability distributions (e.g., commonly at the tails of the distributions).

No adjustment for availability is necessary for measurements of density (abundance per unit area), because it is assumed that fish/insects etc. will be most common where the habitat is best. If a range of habitats is sampled, the average density per sample in each interval range is a measure of habitat suitability. Standardisation of density data may be necessary if they are collected at different times or in different rivers. Standardisation converts actual abundance to relative density in each river, or group. One alternative, and possibly better, approach is to develop preference curves for each river and then average those curves so that equal weight is given to each river, irrespective of density.

As with habitat use data, availability data should be collected in all habitats available in the river and must be collected without bias. Available habitat data can be analysed as counts to determine the frequency with which a habitat variable occurred within the river. Instream habitat survey data can be used to estimate the habitat available in the river. Measurements of habitat are weighted by the area represented by each data measurement to determine the frequency distribution of available habitat.

It is very difficult to determine habitat suitability without bias, because study rivers invariably provide a limited range of depth/velocity/substrate combinations and there may be a tendency for the sampler to introduce bias by concentrating on locations where the likelihood of catching fish is greatest. Data on where the fish are not present is just as important as data on fish presence. In addition, factors other than physical habitat alone may influence fish behaviour and abundance, for example:

- food
- predation risk
- competition
- physiological and hunger state
- temperature
- light / time of day
- turbidity.

Of these factors, predation risk, time of day, and turbidity are probably related for many New Zealand fish species, with fish in cover when subject to predation risk during the day in clear water and feeding when that risk lessens.

Biotic interactions that affect habitat use, such as competition for space or reaction to predation, can be modelled and applied by the use of appropriate suitability criteria, but first the existence of an interaction needs to be established. Most habitat suitability data are collected from rivers that contain a number of fish species with varying relative abundances, so that the influence of any common intra-specific interactions on habitat use is included implicitly. Bonnett & McIntosh (2004) found that juvenile trout had no effect on habitat selection by inanga, whereas Baker et al. (2003) found that flathead galaxias were found mainly in riffles when trout were present, but used a wider range of habitats where trout were absent. Although some studies have shown small changes in galaxiid habitat use in the presence of trout (see review in McDowall 2006), the preferred habitats of most native fish species in areas, such as Northland, where there are no, or very few trout, are similar to those in streams further south where there are trout present (Richardson & Jowett 1998).

## 3.2 Day and night habitat use

A common criticism of habitat suitability criteria is that diel variation in habitat selection is frequently ignored, despite repeated recommendations that nocturnal habitat use also be considered (Orth 1987; Jakober et al. 2000; Johnson & Covich 2000). Most studies use only daytime observations because they are easier and more convenient to collect, or because often resources are insufficient to collect both daytime and night-time data. This approach assumes that habitat selection is constant over the diel cycle, but many freshwater fishes have distinct diurnal, crepuscular, or nocturnal patterns of activity (Glova et al. 1987; Helfman 1993; Reebs 2002) and may switch between distinct sheltering or resting and foraging behaviours on a daily basis (Fraser et al. 1993; Thurow 1997; Bradford & Higgins 2001). If fish select different daytime and night time microhabitats, then the total amount of useable habitat and the relationship between habitat area and discharge may also differ between day and night. Therefore, using habitat suitability criteria based solely on daytime observations of microhabitat selection may fail to identify which type of habitat is potentially limiting and either over- or under-estimate optimum and minimum flow requirements.

Day and night habitat use data were collected in the Waipara River in January and March 2005. In total, 394 x 3 $m^2$ sites were electric fished during the day, and 612 similar-sized sites were electric fished at night. Within each site, all the fish caught were identified, counted, measured and returned. Mean depth and velocity were calculated from three measures within each site.

Native fish habitat-use at night was compared with habitat use during the day. Sufficient data were available for eight species (Table 3.2.1). With the exception of large shortfin eels (> 300 mm in length), all the species used lower or similar velocity and similar depth water at night compared to daytime use. There were not enough longfin eels caught to separate large and small fish, but we expect large longfin eels would exhibit a similar change in use as large shortfin eels. Because most fish tended to use higher velocity water during the day, habitat suitability curves produced from daytime measurements will lead to a higher assessment of flow requirements for these species. However for large eels, night time habitat suitability criteria would be more conservative.

David (2003) studied habitat use by 16 giant kokopu in two streams in the Taieri catchment, and found that the fish were concealed in cover during the day, moving out to open water at night. During winter, giant kokopu used low velocities (maximum velocity 0.08 m/s), silt substrates and moderate depths (0.2–0.6 m) both day and night. On summer nights, fish moved from cover to velocities of up to 0.17 m/s. McDowall et al. (1996) collected daytime habitat information for shortjaw kokopu, but noted that they utilised small pools for foraging at night. Banded kokopu exhibit similar diurnal habits (McCullough 1998), and the data used for developing the banded kokopu habitat suitability curves presented in this report were derived from night observations.

**Table 3.2.1: Comparison of average day (394 sites) and night (612 sites) velocity and depth values for fish species collected in the Waipara River, January and March 2005; standard deviation shown in brackets. Average values were weighted by the number of fish (N) caught at each site**

| Species | Time | Velocity (m/s) | Depth (m) | N |
|---|---|---|---|---|
| Bluegill bully | Day | 0.53 (0.21) | 0.17 (0.03) | 1295 |
| | Night | 0.52 (0.29) | 0.18 (0.04) | 3119 |
| Torrentfish | Day | 0.76 (0.25) | 0.17 (0.03) | 219 |
| | Night | 0.61 (0.24) | 0.17 (0.06 | 635 |
| Upland bully | Day | 0.36 (0.14) | 0.13 (0.04) | 859 |
| | Night | 0.29 (0.28) | 0.14 (0.04) | 2864 |
| Common bully | Day | 0.41 (0.24) | 0.16 (0.06) | 62 |
| | Night | 0.16 (0.20) | 0.16 (0.05) | 152 |
| Canterbury galaxias | Day | 0.22 (0.16) | 0.11 (0.03) | 87 |
| | Night | 0.17 (0.23) | 0.14 (0.02) | 166 |
| Longfin eel | Day | 0.25 (0.17) | 0.41 (0.22) | 14 |
| | Night | 0.15 (0.15) | 0.25 (0.25) | 76 |
| Shortfin eel (<300 mm length) | Day | 0.26 (0.20) | 0.25 (0.27) | 45 |
| | Night | 0.18 (0.16) | 0.16 (0.05) | 224 |
| Shortfin eel (>300 mm length) | Day | 0.17 (0.19) | 0.60 (0.20) | 69 |
| | Night | 0.33 (0.27) | 0.22 (0.20) | 223 |

## 3.3 Calculation of habitat suitability

In conventional habitat analyses, suitability criteria are derived independently for water depth, velocity, and substrate composition. The data can take two forms (i) the number or density of fish in small areas sampled over a wide range of habitats or (ii) observations of fish locations accompanied by measurements of available habitat. Both of these methods require that habitat use and availability be sampled throughout each of the study areas (sampling protocol C; Bovee et al. 1998). A common mistake is to sample habitat availability independently of use. Any measurement of habitat availability must include all available habitats that were sampled for use (since these were also part of the total set of available habitat locations, from which the fish selected its location). If random sampling were used, the sampling effort required for an adequate sample would be prohibitive. For example, if large fish are only found in the deepest part of a reach, random sampling of depths may not include the deepest part of the river, and this would make any calculation of preference impossible.

The most familiar index of selection (or preference), at least with respect to habitat suitability criteria, is the forage ratio. The forage ratio is the proportion of used habitat units of a category (for example, velocities between 0.20 and 0.25 m/s) divided by the proportion of habitat units of that category available in the whole sample:

$$w_i = \frac{u_i / \sum_{i=1}^{n} u_i}{a_i / \sum_{i=1}^{n} a_i}$$

where $w_i$ is the forage ratio for the $i^{th}$ of $n$ habitat categories, $u_i$ is the number of fish in each habitat category $i$, $\Sigma u_i$ is the total number of fish over all habitat categories, $a_i$ is the number of samples from category $i$ and $\Sigma a_i$ is the total number of samples (Manly et al. 1993).

This formulation simply says the forage ratio is proportional to the number of fish in a habitat category (bin) divided by the number of samples in that habitat category, or the average density of fish found in the habitat category. The forage ratio measures the strength of selection for a particular habitat category. A value of $w = 1$ indicates neutral selection; habitats with $w < 1$ are used less commonly than expected by chance and habitats with $w > 1$ are used more commonly than expected by chance. As this discrete formulation of the forage ratio depends on the 'width' of the habitat categories and rarely forms a smooth function, continuous forage ratio functions are often derived for velocity, depth and the substrate index[1] using kernel smoothed frequency distributions of abundance and habitat availability in each river (Hayes and Jowett 1994; Jowett 2002).

Suitability indices ($si$) are derived from the forage ratios by dividing the forage ratio by its maximum value, so that the suitability index has values of between 0 and 1. An average suitability function for all rivers can be derived by arithmetically averaging the suitability functions of all rivers.

Once habitat suitability curves have been derived for the independent variables, independent suitability index scores for depth ($si_d$), velocity ($si_v$) and substrate ($si_s$) can be calculated for a given point in the habitat survey reach and then multiplied together to form the commonly used composite habitat suitability index ($HSI$) (Jowett et al. 1991; Bovee et al. 1998):

$$HSI = si_d \times si_v \times si_s$$

Other formulations, such as a geometric mean, are possible but multiplying the indices together is the most commonly used method, and has a certain logic because habitat suitability is zero if any one of its components is zero.

In terms of Bovee's (1986) categories of habitat suitability criteria, frequency of habitat use curves $u_i / \sum_{i=1}^{n} u_i$ are category II curves and preference curves $w_i = \frac{u_i / \sum_{i=1}^{n} u_i}{a_i / \sum_{i=1}^{n} a_i}$ are category III curves.

The adjustment of habitat use for habitat availability (i.e., calculation of forage ratio) is usually the preferred method of calculating habitat preference, when the data consist of observations of habitat use in a single river and where the range of available habitats may be restricted or at least biased. However, the calculation of preference is subject to uncertainty when sample sizes are small. The division of a small number by an even smaller number can give a spuriously high preference. In Figure 3.3.1, the secondary peak in preferred velocity (0.5 m/s) is spurious and is a result of low availability at velocities greater than 0.5 m/s.

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[1] The substrate index is based on the percentage of 8 substrate categories (R bedrock; B boulder; C cobble; G gravel; F fine gravel; S sand; M mud/silt; V vegetation/woody debris). The substrate index = 0.08R + 0.07B + 0.06C + 0.05G + 0.04F + 0.03S + 0.02M + 0.01V. This gives an index that is similar to the logarithmic phi scale of substrate size. See Section 4.1 for more detail on substrate size and substrate index.

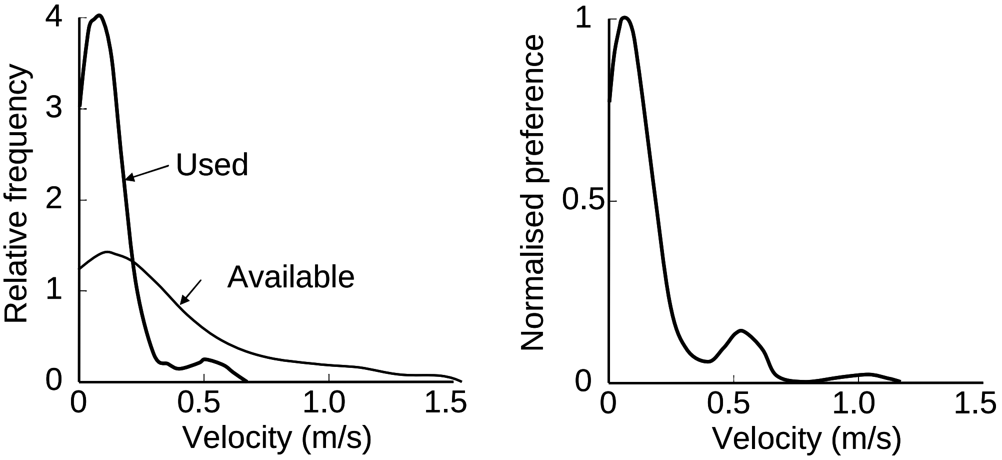

**Figure 3.3.1: Derivation of velocity preference curves for juvenile rainbow trout from comparison of the locations used by fish (left) and available habitat (left) to derive preference (right). Note how the occurrence of a few fish at higher velocities is exaggerated by the preference calculation.**

The calculation of preference can sometimes indicate that the ‘preferred’ habitat of a fish species is very different from the habitat that most were using. For example, if the sampling effort is focused on catching fish, there will be very little difference between the habitat that was sampled (available) and the habitat where fish were found (use). This will show that the fish have no particular habitat preference. However, if most fish were found at a depth of 0.2 m and a velocity of 0.3 m/s, the conclusion that they don’t have any “preference” seems inconsistent with the locations where most fish were found. If the use criteria were applied to an instream habitat analysis, the analysis would indicate that a flow that maximised the area of river with depths and velocities of 0.2 m and 0.3 m/s was optimal. In other words, the flow assessment would aim to maintain habitat similar to that in which the fish were found. If the preference criteria were used, the analysis would indicate that the area of suitable habitat increased as the water surface area increased, and it would be difficult to define a flow that was appropriate for that fish species.

Thus, in the development of habitat suitability curves, it is important to consider the habitat that the fish were actually using as well as the apparent preference. If a large number of fish have been collected in a variety of habitats, the habitats in which they have been found will be a strong indicator of the conditions in a river that will support that fish species.

## 3.4 Generalised additive models

Generalised additive models or GAMs offer a flexible approach to the development of multivariate models that can be used with hydraulic models to predict relative abundance or probability of use. GAMs (Hastie & Tibshirani 1990) have been used in studies of terrestrial ecology to predict the distribution of vegetation types (Leathwick & Rogers 1996; Leathwick & Austin 2001). GAMs combine nonparametric regression and smoothing techniques. Nonparametric regression relaxes the usual assumption of linearity and reveals the shape of the relationship between the independent variables and the dependent variable. Thus, GAMs are well suited to situations where there are multiple independent variables whose effects need to be modelled non-linearly, and where the dependent variable is not normally distributed. These models can be applied within an instream habitat hydraulic model to predict how probability of occurrence changes with flow, in the same way that habitat suitability criteria are used with a hydraulic model to predict how WUA changes with flow. The models permit the response probability distribution to be any member of the exponential family of distributions, but those that are most likely to be applied to instream flow assessments are non-parametric logistic models, using presence/absence data, and non-parametric log-linear Poisson models, using abundance data.

A GAM based on depth ($d$), velocity ($v$), and substrate ($s$) can take the form:

$prediction = constant + f(d) + f(v) + f(s) + f(sv) + f(sd) + f(dv)$

where each function (e.g., $f(d)$) has a linear and non-linear component fitted by cubic splines, and the prediction is transformed into abundance using a reverse logarithmic transform, or to probability of occurrence using a reverse logistic transform. The degrees of freedom are constrained to give a smooth, but flexible, curve. Bovee et al. (1998) noted that habitat selection by fish often appears to have thresholds, such as cases where a fish species uses a wide range of depths once the depth has exceeded a threshold. Increasing the degrees of freedom allows the function to adopt a shape that reflects these thresholds. Parameters can be excluded where coefficients are not statistically significant.

Conventional habitat suitability models assign a suitability of 1 to a point where the habitat values are considered optimum. Thus, when habitat suitability values are multiplied by the area they represent, and are summed, the resulting number is termed the weighted usable area or area of suitable habitat. However with logistic GAMs, the probability of occurrence is calculated at each point and is then multiplied by the area it represents, before it is summed over the reach. In most cases, the probability of occurrence predicted by a logistic model will be considerably less than 1 and thus the equivalent of “weighted usable area” is a weighted probability of occurrence.

In this study, the probability of occurrence ($p$) of each native fish species was modelled using a GAM with a binomial error distribution and a logistic link function. Water velocity ($v$), depth ($d$) and the substrate index ($s$) were included as continuous predictors, plus a constant ($c$):

$$\ln [p/(1 - p)] = c + f(v) + f(d) + f(s)$$

As discussed above, habitat selection by fish often appears to have thresholds; for example, many fish species will use a wide range of depths once the depth has exceeded some critical minimum value (Bovee et al. 1998). Consequently, we used between 2 and 4 degrees of freedom to allow the function to adopt a shape that reflected these potential thresholds, while limiting the tendency for curves to become too complex and unrealistic.

Percent classification success was used as a measure of the ability of the habitat variables to account for fish presence/absence. We also plotted contours of GAM predictions on velocity-depth axes, holding substrate constant. These contour plots allowed us to evaluate the biological realism of the model predictions beyond the boundaries of the observed data and to examine whether the model predictions conformed to expectations based on hydraulic principles. For example, we expected unimodal rather than bimodal surfaces, and expected probability of use to be low at high velocities and depths. We also compared the GAM contour plots with contours fitted by LOESS (defined below) and if necessary introduced an interaction term to improve the fit.

LOESS is a nonparametric method for estimating regression surfaces pioneered by Cleveland et al. (1988), Cleveland & Grosse (1991), and Cleveland et al. (1992). The LOESS procedure allows great flexibility because no assumptions about the parametric form of the regression surface are needed. The LOESS procedure can be used in situations where the parametric form of the regression surface is unknown, and is suitable when there are outliers in the data and a robust fitting method is necessary.

## 3.5 Method used to derive habitat suitability curves

Habitat suitability curves, as used in flow assessments, are often made subjectively after considering both habitat use and average fish abundance, giving less weight to parts of the curve where the preference is based on a small number of samples (e.g., the low sampling frequency at velocities above 0.5 m/s in Fig. 3.2.1). For example, a range of optimum velocities might be specified rather than the single optimum velocity that results from the numerical calculation. The suitability curves developed in this report define a range of optimum habitat values (i.e. suitability = 1), as well as unsuitable habitat (suitability = 0). A typical modification might assign a habitat suitability value of 1 to preference values of greater than 0.8. There is no analytical reason for this simplification, but it does seem reasonable that a range of values (e.g., velocities) can provide optimum conditions.

In this study, we developed habitat suitability curves for each species using a consistent set of procedures available in the HABPRF program developed by Ian Jowett. The procedures examined habitat use and preference in a number of different ways in order to make the best possible subjective assessment of habitat suitability. The procedures were:

- tabulating the range of depths, velocities, and substrates that were sampled and the average depth, velocity and substrate in which each species was found
- calculating forage ratios for depth, velocity, and substrate index using all data
- calculating forage ratios for depth, velocity, and substrate index for each river in which the species was found, and then averaging these relationships
- plotting contours of fish density with depth and velocity using LOESS
- developing a logistic GAM using depth, velocity, and substrate index as predictors and plotting contours of probability of use with depth and velocity
- comparing the GAM and LOESS contours to determine whether it was necessary to introduce a depth/velocity interaction term
- normalising the forage ratio relationships to a maximum value of 1 and using these to develop preliminary suitability curves, assuming that values greater than 0.8 represented ideal habitat
- developing final habitat suitability curves, taking into account the shape of the GAM functions, habitat use curves, the inability for the smoothed curves to adequately describe suitability at the extremes (e.g., the suitability of zero depth), and substrate stability with high water velocity.

The following example of calculating depth suitability for shortfin eels < 300 mm is used to explain the analysis in more detail.

A total of 2192 locations were sampled in 58 rivers that contained shortfin eels. The data used in the analysis were the depth, number of eels, and the name of the river where the sample was collected, at each location. The average depth at which eels were found was 0.22 m, and they were found at depths ranging from 0.04 m to 1.2 m. The depths of the sampling locations were used as the measures of habitat availability, and the depths in which each eels were found were the measures of habitat use. Figure 3.5.1 shows the histogram and kernel smoothed frequency distributions fitted to the use measurements. In this figure, the number of eels in each 0.1 m depth range is shown as the histogram along with the kernel smoothed frequency distribution. The sum of the count over all depth ranges is 4703, which is the total number of eels when each sample was adjusted to a 10 m$^2$ sampling area.

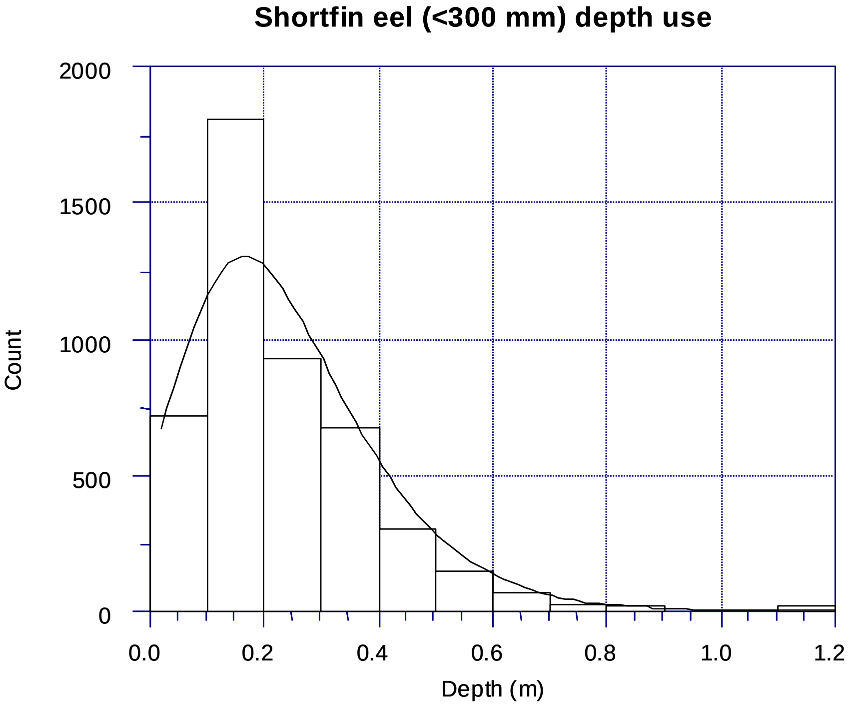

**Figure 3.5.1: Analysis of depth use by shortfin eels < 300 mm**

The graph for depth availability (Fig. 3.5.2) is similar to the graph for depth use (Fig. 3.5.1), but the sum of the counts over all depth ranges is 2192, the total number of locations sampled.

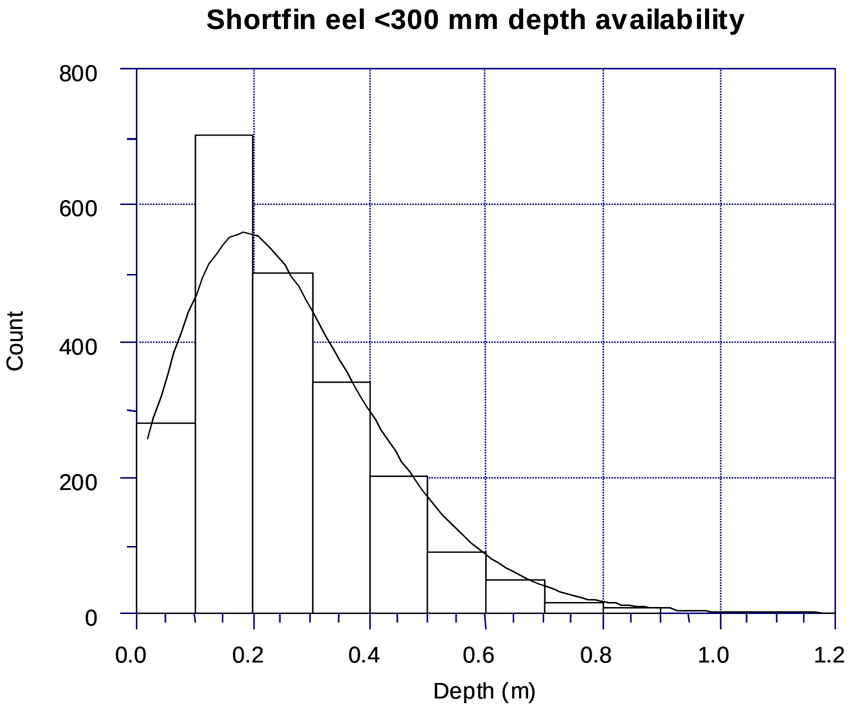

**Figure 3.5.2: Analysis of depth availability by shortfin eels < 300 mm**

The forage ratio or preference was then calculated as the proportion of use divided by the proportion of availability for each ordinate or bin. Figure 3.5.3 shows the results of dividing use by availability for both the histogram data and the kernel smoothed data. For example, in the depth range 0–0.1 m, there were 716 eels (from Fig. 3.5.1) in 280 locations (Fig. 3.5.2). The total number of locations sampled was 2192 and the total number of eels was 4703, and the forage ratio is (716/4703)/(280/2192) or 1.19, as shown in Fig. 3.5.3. Because the frequency distributions of use and availability are similar, there is relatively little variation in preference (solid black line in figure) except in the data range 1.1–1.2 m, where there were 2 locations sampled and 17 eels found, to give a forage ratio of 3.9.

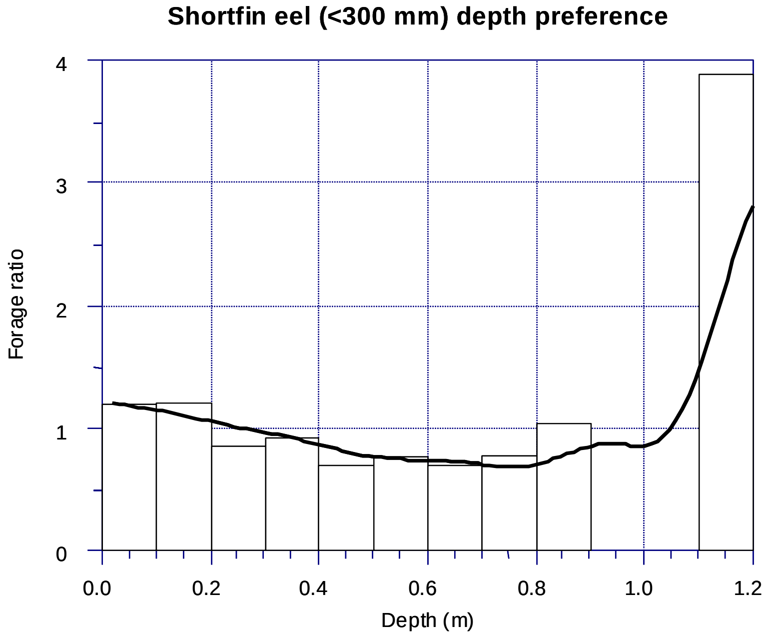

**Figure 3.5.3: Analysis of depth preference by shortfin eels < 300 mm**

It is possible to derive relationships between preference and depth for every individual river containing shortfin eels, and then to average those relationships. However, to ensure that the average relationship was not biased by rivers with insufficient data, preference/depth relationships were not developed for individual rivers where the number of eels in that river was less than 5, and the relationship was developed only for depths that occur in more than 10% of the rivers. Fig.3.5.4 shows the comparison between the preference/depth relationship derived using all data and the group average relationship derived by averaging the preference/depth relationships for each river. By averaging and including only data in depth ranges found in more than 10% of rivers (i.e., excluding depth ranges where there are few data), the apparent increase in preference at depths greater than 0.8 m was removed and the averaged relationship shows a higher preference for shallow water than the relationship derived from all data.

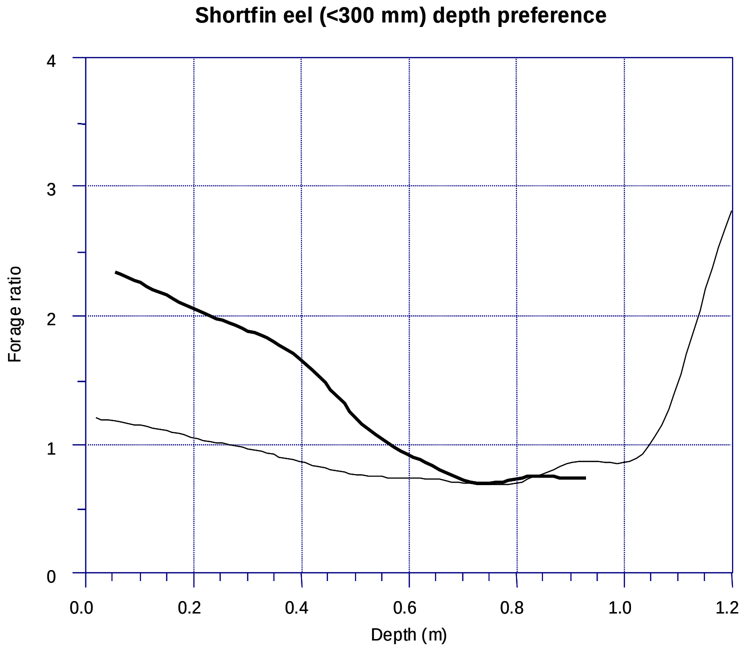

**Figure 3.5.4: Forage ratio/depth relationship derived using all data (thin line) and the group average relationship derived by averaging the forage ratio/depth relationships in each river (thick line).**

The analysis of habitat suitability can then be carried out in a similar way for velocity and substrate, with the kernel smoothed frequency of availability, use, and the preference curves derived from all data and by averaging preference relationships for each individual river shown on one graph.

Interaction between depth and velocity was examined by plotting the depth and velocity measurements on a graph and fitting contours of eel densities using LOESS (Fig. 3.5.5). Fig. 3.5.5 shows the contours fitted to eel numbers and confirms the habitat suitability analysis in that eel numbers decline with depth and velocity.

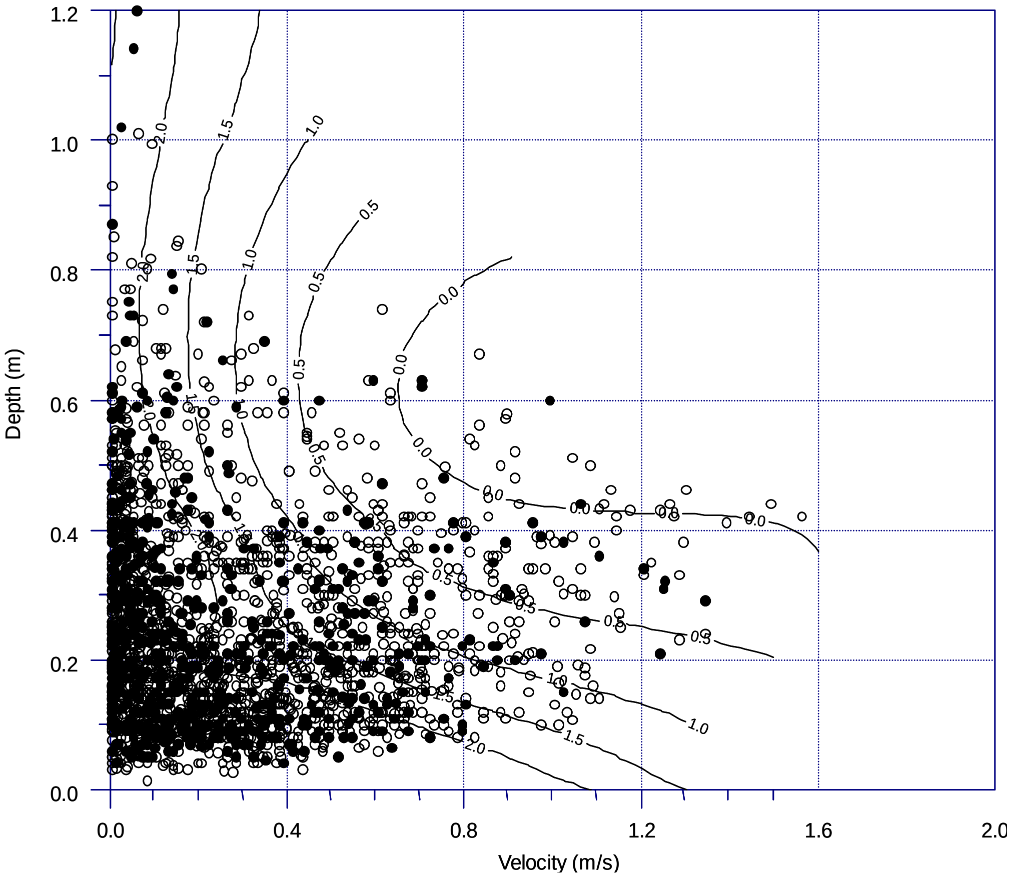

**Figure 3.5.5: Depth and velocity at all sampling locations, with LOESS contours fitted to shortfin eel densities. Locations containing eels are shown shaded.**

It is also possible to develop a generalised additive model (GAM) with a binomial error distribution and a logistic link function. GAMs produce curves for each variable, rather like the preference curves in more conventional forage ratio habitat analyses (Fig.3.5.4) and so can be compared visually.

The data used in this study is a mixture of fish abundance in sampling lanes of uniform depth and velocity (Jowett & Richardson 1995) and fish numbers in small 2–3 m$^2$ sampling patches. The latter samples usually contain low numbers of fish and are more like presence/absence data than abundance data. All data were standardised to a standard sampling area (10 m$^2$) to avoid overweighting cases where data had been collected over areas larger than 2–3 m$^2$. Either a binomial or Poisson model could be fitted to these data and both were investigated. In the binomial analysis each fish was treated as being present or absent. If the standardised fish data lay between 0 and 1, the presence of 1 fish was assumed, otherwise ceiling of the number (i.e. the number rounded up). The binomial model gave values of between 1 and 0 whereas the Poisson model predicted fish densities that were often very small, with magnitudes varying from species to species. The logistic model was used for the analysis because it predicts probability of use and this value is easier to interpret than abundance and is consistent with conventional use on instream habitat analysis.

Figure 3.5.6A (p 22) shows the logistic GAM functions for depth, velocity and substrate. The left axes give the function values that are used in the logistic GAM equation shown in Section 3.4. The logistic GAM predicts probability of use, and these functions show that the probability of use declines with depth, but then begins to increase when the depth exceeds about 0.9 m in a similar way to the forage ratio for all data in Fig.

3.5.4. This is caused by there being only a few measurements in deep water and a high probability of use as shown in Fig 3.5.3, and can be avoided by excluding data with depths greater than 0.9 m (Fig. 3.5.6B).

It is possible to include an interaction term. The GAM can be used to predict values on a depth/velocity grid to produce contours of predicted probability of use (Fig. 3.5.7). This contour diagram can be compared with the more flexible LOESS model (even though the LOESS model shows contours of fish density, while the GAM shows contours of probability of use) to see whether it is necessary to introduce an interaction term to improve the fit of the model.

In this case, when the depth-velocity interaction term was included, it was not significant, as indicated by the statistical tests (results not shown) and the similarity in the LOESS and GAM contour plots (Figs 3.5.5 & 3.5.7, respectively).

The GAM can also be used to predict the probability of use at each location and a comparison of these predictions with actual observations gives a measure of the goodness of fit. In this model, the shortfin GAM correctly predicted that eels would be present in 71% of cases, using a probability of use cut level[2] of 0.7 (i.e., if the predicted probability of use was < 0.7 eels were assumed to be absent and if >= 0.7 eels were present). This analysis used all data to develop GAMs that were the best fit to the data. This was considered adequate for comparison with conventional habitat suitability curves, which were also based on all available data. Techniques, such as split-samples or jack-knifing, could be used to evaluate the predictive power of the models, but this was not considered a necessary step in the development of habitat suitability.

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[2] This cut level is the probability of use that gives the greatest measure of agreement as calculated by Cohen’s kappa (Landis & Koch 1977).

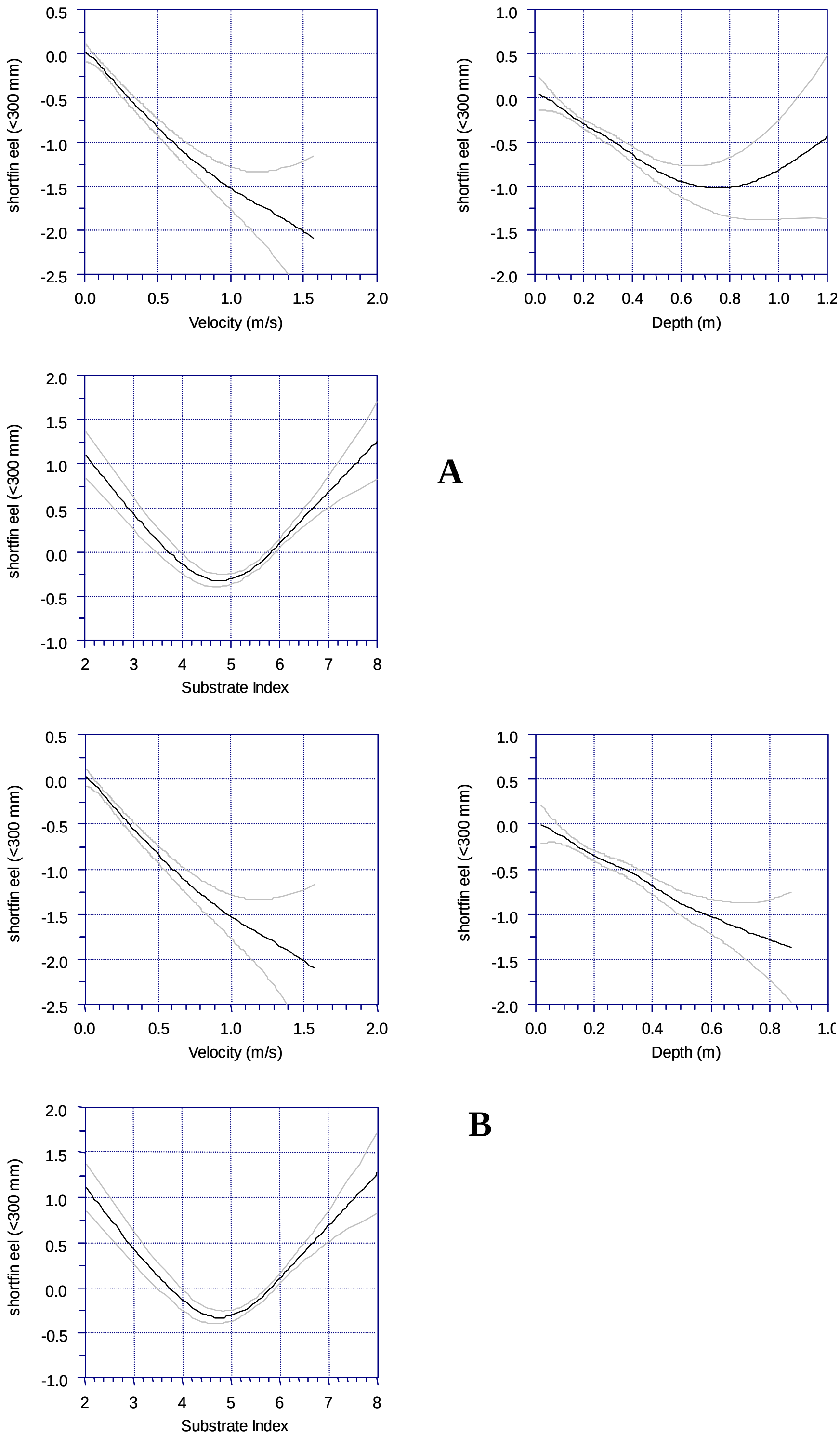


**Figure 3.5.6:** **Generalised additive logistic model of shortfin eel probability of use using depth, velocity and substrate index with all depths (A) and excluding depths > 0.9 m (B). 95% confidence intervals are shown in grey.**

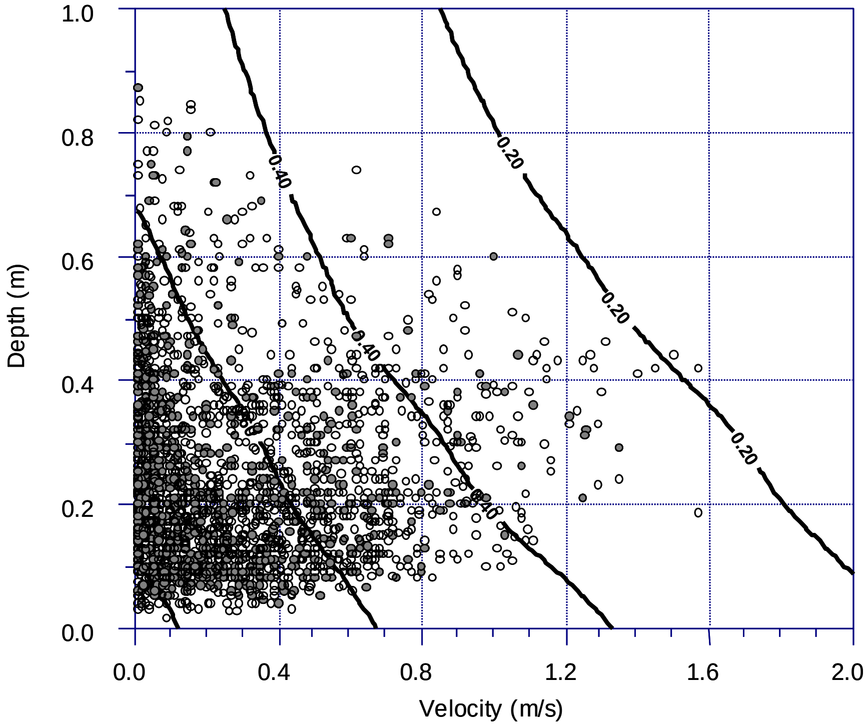


**Figure 3.5.7: Contour plot of GAM of probability of use (excluding depths > 0.9 m) using depth and velocity for a substrate index of 5 on left and plot showing locations sampled on right with points filled if shortfin eels were present.**

Finally, the forage ratio curves, such as those in Fig. 3.5.4, were subjectively converted into habitat suitability curves with ordinates varying between 0 and 1. The forage ratio curves were normalised so that the curve based on all data and the curve based on averaging individual curves from all rivers both plot with a maximum ordinate of 1, as in Fig.3.5.8. This was used to define a range of optimum habitat (e.g., any habitat with a suitability index > 0.8 and a range of unsuitable habitat (e.g., habitat with a suitability index < 0.2), as shown on the left of Fig. 3.5.8, with the final suitability curve shown on the right. The forage ratio (preferred) curve (left of Fig. 3.5.8) was also compared with the curve of habitat use (centre Fig. 3.5.8). In this case, the forage ratio depth curve is very similar to the depths used by small shortfin eels and was consistent with the GAM curve for depth (Fig. 3.5.7), which shows a near linear reduction in probability of use as depth increases.

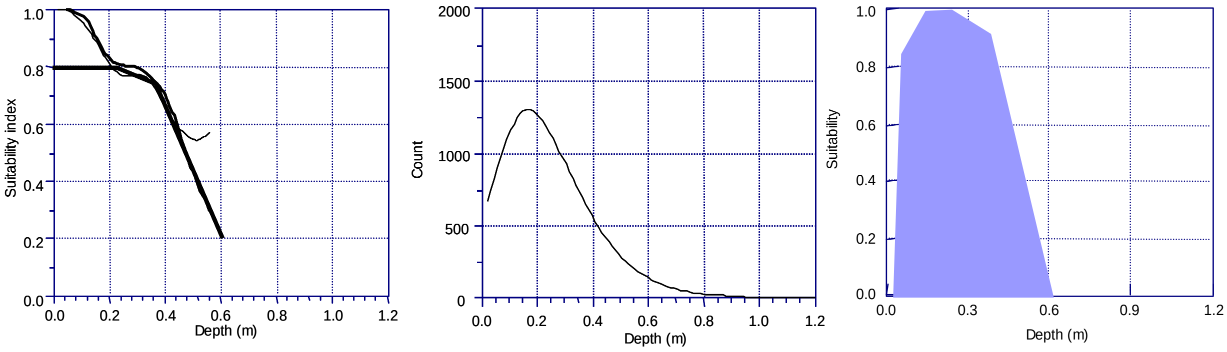


**Figure 3.5.8: Left: normalised forage ratio/depth relationship derived using all data (thin line), the group average relationship derived by averaging the forage ratio/depth relationships in each river (intermediate line) and selection of suitability curve (thick line); centre: frequency of use curve; right: habitat suitability curve after comparison of forage ratio and use curves.**

### 3.5.1 Development of final habitat suitability curves

In defining the final suitability curve, we consider (i) suitability values at the extremes, (ii) compare forage ratio curves with the LOESS contours and GAM curves and (iii) check whether the habitat preferences (forage ratio curves) are consistent with the habitat that is used by the species.

Most importantly, the habitat suitability curves must be hydraulically and physically plausible. Velocities that are classed as suitable should not be so high as to cause movement of the stream substrate. This can be checked by comparing the average substrate size used by the species with the velocity required for initiation of movement, calculated using Shields' relationship (critical dimensionless shear stress is 0.056) and Manning's equation (Henderson 1966), with the assumption that Manning's N varies according to substrate size as shown in Fig. 3.5.9.

$$Critical\ shear\ stress = 0.056\rho g(1 - sg)D = \rho g\sqrt{RS}$$

$$v = \frac{R^{\frac{2}{3}}S^{\frac{1}{2}}}{N}$$

$$Critical\ velocity = \frac{R^{\frac{1}{6}}}{N}\sqrt{0.056(1 - sg)D}$$

Where $v$ = velocity (m/s), D substrate size (m), ρ = density of water, g = acceleration due to gravity m/s$^2$, S = slope, R = hydraulic radius (m), N = Manning's N, *sg* = specific gravity of substrate (assumed to be 2.65).

Critical velocities were predicted for the average depth and average substrate size in which a given fish species was found usually represented the upper limit of the velocities in which they had been found, although preference calculation could indicate that they "preferred" velocities that were high enough to move the substrate. The critical velocity for the largest substrate size (boulder) in a depth of 0.25 m is about 1.65 m/s. It would therefore be unreasonable for a habitat suitability curve to indicate that velocities in excess of 1.6 m/s are suitable habitat in shallow water. Even in deep water, the preferred velocity for large rainbow trout was < 1 m/s (Jowett & Davey 2007). Fish can be present at locations where the critical velocity for average substrate size is exceeded, simply because the substrate size at that location is larger than average and this often happens because the substrate is armoured. However, river flows, depths, and velocities are often higher than the average measured during fish surveys. The assumptions of average hydraulic condition and average substrate size tend to counter each other. If larger substrate were assumed, the critical velocity would be higher and if higher flows were assumed the critical velocity would be lower.  The upper limit for velocity was selected after considering the critical velocity for average conditions and the highest velocities in which fish were found.

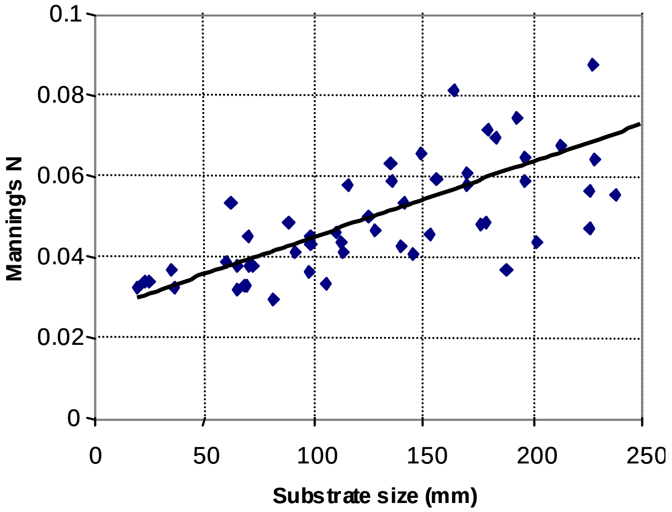


**Figure 3.5.9: Relationship between average substrate size and Manning's N calculated from "100 rivers" data (Jowett 1990).**

Values at the lower extreme of the suitability curve are also considered because the data smoothing techniques do not allow very sharp changes such as might occur when water depth reduces to zero. For example, the smoothed curves might indicate that a depth of zero provided ideal habitat, whereas there are no measurements in zero depth and the species cannot survive without water. Field observations have indicated that there are usually few fish in depths less than 0.05 m and few measurements of habitat suitability have been taken at this depth. Similarly, there may be sharp reductions in suitability at low velocities, which are not apparent in the smoothed curves but are evident when the low velocity data are examined in more detail. Occasional fish will always be found outside of the ‘normal’ conditions of habitat use and this does not invalidate habitat suitability curves, which are intended to describe preferred conditions. This becomes especially problematical when there are few locations surveyed at the data extremes, and these locations were occupied by fish. The question is then “do we take notice of these few measurements or do we take more notice of where most fish live?”. Unless there is supporting evidence for the preferences at data extremes (e.g., smelt observed in deep water and moderate velocities not sampled by electric fishing), we place most emphasis on where most of the fish are living.

If the forage ratio curves based on river averages and on all data do not agree as closely as in the shortfin eel example given above, the shape of the LOESS contours and GAM curves are used for guidance. In particular, the shapes of the GAM curves are used as a guide to the development of the final habitat suitability curve because these curves take all variables into account. For example, low numbers of fish might be observed in pools where velocities are low and depths high. Conventional univariate habitat suitability analysis would assign low suitability to both deep water and low velocity, when in fact the fish might be avoiding that habitat because of the low velocity, rather than depth. Because the GAMs consider depth, velocity, and substrate together, they can allow for associations between habitat variables (i.e., colinearity).

When habitat suitability curves are used in a flow assessment, they should not predict that optimum conditions for the species occurs at flows that are not typical of those in the streams and rivers where that species lives. For example, a species may only be found in small streams but the habitat preference analysis indicates that it has no apparent depth preferences and a preference for moderate velocity. In this situation, instream habitat analyses would indicate that large streams and rivers provide the best habitat contrary to the stream types and habitats actually used by the species. This problem occurs because the apparent habitat preference differs from the habitat that the species actually uses (i.e., the habitat use curve). Differences between ‘preferred’ habitat and actual habitat use are probably caused by sampling bias, where locations containing fish have been targeted and/or there are insufficient data points over the range of habitats used for the derivation of habitat preference. Averaging preference curves over a number of rivers often removes the influence of small samples, although it does bias the curves towards the type of river most commonly sampled. If a large variety of habitats have been sampled, the habitats in which a fish species has been found will be a strong indicator of the conditions in a river that will support that fish species.

# 4. Habitat requirements for common New Zealand fish

## 4.1 Data used for analysis of habitat suitability

Data from four sources were combined to develop the habitat suitability curves. These were mainly daytime single-pass electric fishing surveys performed by NIWA and Department of Conservation staff in wadeable rivers and streams. Data included are listed below.

1. Data from 3166 sites in 56 rivers collected specifically for developing habitat suitability curves. Areas 2–3 $m^2$ in size were fished in a variety of habitats within each river. The sampling sites were selected to cover the range of habitats available in the river (within limits of electric fishing) to allow comparison of the available habitat in each river with the habitat actually used by the various species. Although some of these surveys were designed to target specific species, all fish caught were identified and counted, and average water depth and mean water column velocity (at 0.4 of the depth above the stream bed) were calculated from 4 measurements at each sampling location. Generally average substrate size was calculated from 10 measured particles within each sample location, but for some locations, the average size was calculated from visual assessments of the substrate composition, arbitrarily assuming the following sizes for each substrate category; bedrock = 1000 mm, boulder = 256 mm, large cobble = 208 mm, cobble = 160 mm, small cobble = 112 mm, coarse gravel = 36 mm, fine gravel = 5 mm, sand = 1 mm, mud/silt = 0.01 mm and vegetation = 25 mm. Substrate index was calculated from estimates of the percent substrate composition using the relationship (Jowett & Richardson 1990): *SI = %Bedrock*0.08 + %Boulder*0.07 + %Cobble*0.06 + %Gravel*0.05 + %FineGravel*0.04 + %Sand*0.03 + %Silt*0.02 +%Vegetation*0.01*. Where % substrate composition was not recorded, the average substrate size was converted to the substrate index using the relationship in Figure 4.1.1.
2. Data from 411 sites in 33 rivers collected as part of the “100 rivers” project (Jowett & Richardson 1995). Depth-stratified lanes (<0.125 m, 0.125 – 0.25 m, 0.25 – 0.5 m and 0.5 – 0.75 m) in two runs and two riffles were sampled in each river. The average area sampled was 40 $m^2$, and all fish caught were identified and counted. Average water depth, velocity and substrate index and size were calculated from in-stream measurements within the depth-stratified lanes.
3. Data from 130 sites in 9 rivers in the Waitaki River catchment. Discrete habitat types (e.g., run, riffle, backwater) were electric fished. The average area sampled was 58 $m^2$, and all fish caught were identified and counted. Average water depth and velocity were calculated from 10 measures in each habitat type and the average substrate index and size from visual assessments using the methods described above.
4. Data from 549 sites in 4 rivers where only eels were identified and counted (Jellyman et al. 2003). The sites ranged in size from 0.25–150 $m^2$, with depth, velocity, and substrate size being measured in each site. The substrate size was used to calculate a substrate index for each site.
5. Data from 848 sites where banded kokopu (McCullough 1998; 385 in 5 streams), giant kokopu (Bonnett et al. 2002; 69 in 14 streams) or Otago non-diadromous galaxiids (Baker et al. 2003; 394 in 10 streams) were the dominant species and were caught by electric fishing, nets or observed by night spotting for banded kokopu. McCullough (1998) measured depths and velocity at the fish location, Baker et al. (2003) measured depth and velocity in the centre of a 1 $m^2$ sampling location, and Bonnett et al. (2002) measured depth and velocity at the point where the fish were first seen or captured.
6. Data from 80 locations in the Mataura catchment that were sampled for lamprey by Jellyman & Glova (2002).

This gave a total of 5184 locations in 124 rivers, with 4555 locations in 119 rivers where all fish species were counted. Information on the distribution of depth, velocity, substrate index and substrate size within the locations is shown in Table 4.1.1 and Figure 4.1.2. Because the sampling area varied between datasets, all fish data were converted to density per 10 $m^2$.

In addition to these data, we also review inanga data from Jowett (2002).

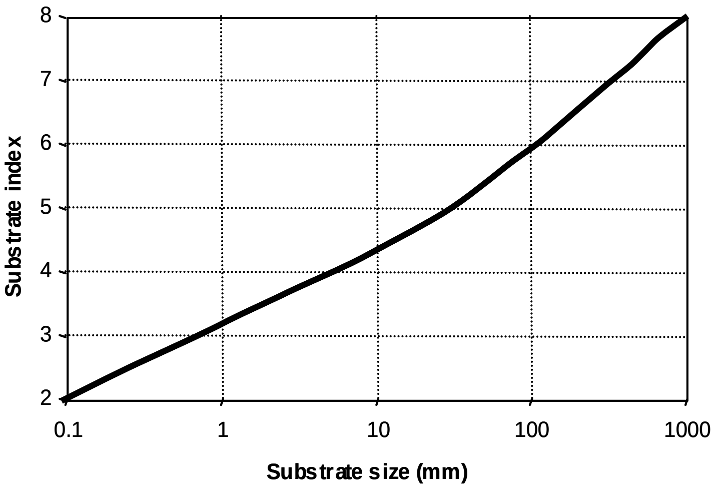


**Figure 4.1.1:** **Relationship between average substrate size and substrate index.**

**Table 4.1.1:** **Statistics for the physical variables measured at the locations used for developing habitat suitability curves. The 80 locations sampled for lamprey are not included in the table because they targeted lamprey habitat.**

| Variable | N | Mean (SD) | Median | Min | Max |
|---|---|---|---|---|---|
| Depth (m) | 5104 | 0.21 (0.15) | 0.17 | <0.01 | 1.50 |
| Velocity (m/s) | 5104 | 0.27 (0.28) | 0.18 | 0.00 | 2.0 |
| Substrate index | 5104 | 5.3 (1.1) | 5.4 | 1 | 8 |
| Substrate (mm) | 5104 | 83 (80) | 58 | 0.01 | 360 |

Data were collected for 30 native and 3 introduced fish species, with more than 21,000 fish being caught in total (Table 4.1.2). Eels were the most widespread species, found in about 50% of the rivers surveyed. Upland and bluegill bully were the most abundant species, followed by eels, brown trout and common bully, all with more than 1200 individuals being caught. Habitat suitability curves were not developed for giant bully, black flounder, and shortjaw kokopu because less than 5 individuals of these species were caught. Four other species were recorded infrequently (< 80 individuals) and habitat suitability curves for these species should be used cautiously.

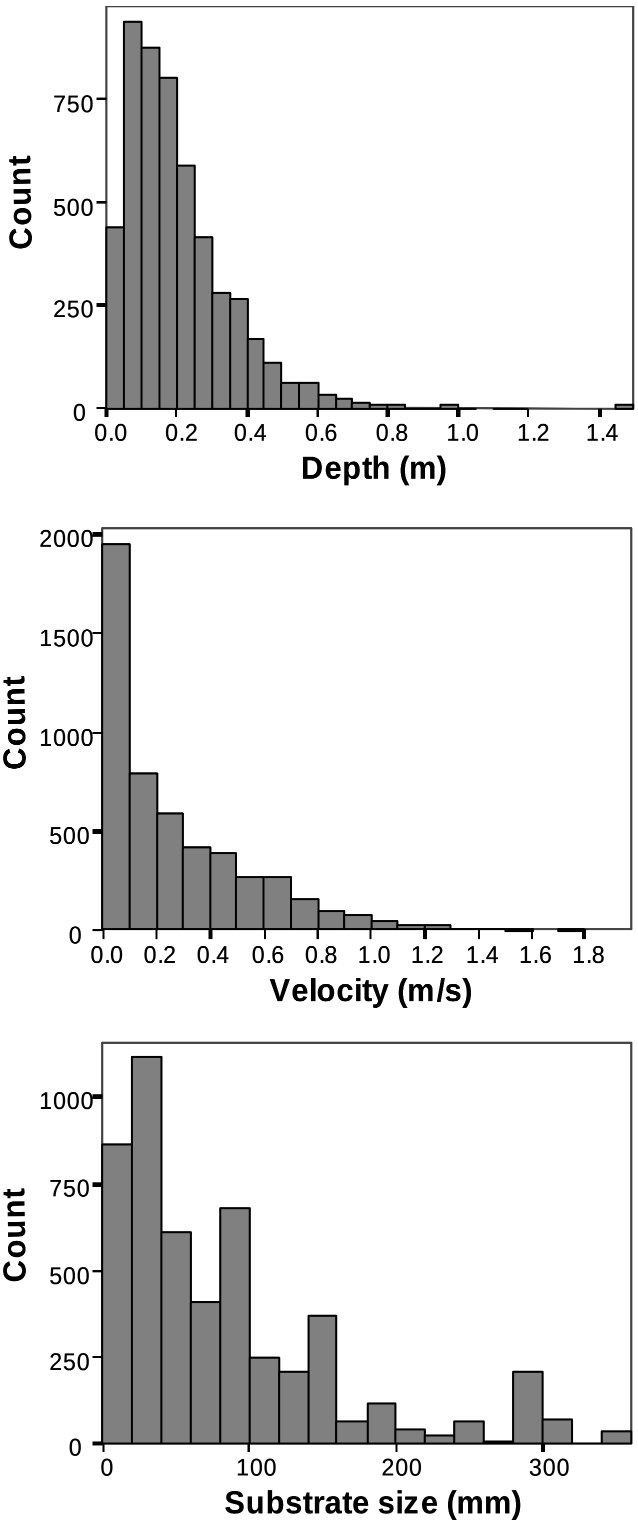


**Figure 4.1.2:** Histograms showing the distribution of depth, velocity, and substrate size at locations used for developing the habitat suitability curves.

**Table 4.1.2:** **Data summary for the numbers and average physical habitat characteristics for fish species and life stages. Mean value for the habitat variables is over all individuals of the species. Banded kokopu daytime and inanga locations sampled by electro-fishing are not included in the table.**

| Species | | No. of rivers where present (N=119 where all fish species counted) | Number of locations sampled in rivers where species was present | Number of locations where present (N=5104 eels, N = 4635 lamprey, N=4555 where all fish species counted) | Total number caught | Mean depth (m) | Mean velocity (m/s) | Mean substrate size (mm) |
|---|---|---|---|---|---|---|---|---|
| Common name | Scientific name | | | | | | | |
| Shortfin eel (<300 mm) | *Anguilla australis* | 58 | 2192 | 675 | 2137 | 0.22 | 0.28 | 69 |
| Shortfin eel (>300 mm) | | 4 | 549 | 102 | 181 | 0.38 | 0.11 | 90 |
| Longfin eel (<300 mm) | *Anguilla dieffenbachii* | 70 | 2641 | 558 | 1625 | 0.21 | 0.40 | 82 |
| Longfin eel (>300 mm) | | 4 | 549 | 155 | 389 | 0.42 | 0.14 | 127 |
| Torrentfish | *Cheimarrichthys fosteri* | 37 | 1217 | 200 | 784 | 0.24 | 0.72 | 56 |
| Koaro | *Galaxias brevipinnis* | 9 | 832 | 153 | 286 | 0.20 | 0.64 | 81 |
| Roundhead galaxias (<50 mm) | *Galaxias anomalus* | 5 | 528 | 217 | 2405 | 0.26 | 0.03 | 20 |
| Roundhead galaxias (>50 mm) | | 5 | 528 | 132 | 358 | 0.11 | 0.17 | 158 |
| Lowland longjaw galaxias (<50 mm) | *Galaxias cobitinis* | 2 | 469 | 19 | 80 | 0.21 | 0.06 | 14 |
| Lowland longjaw galaxias (>50 mm) | | 1 | 399 | 83 | 109 | 0.11 | 0.31 | 84 |
| Flathead galaxias (<50 mm) | *Galaxias depressiceps* | 4 | 233 | 11 | 41 | 0.18 | 0.06 | 175 |
| Flathead galaxias (>50 mm) | | 4 | 233 | 91 | 160 | 0.13 | 0.39 | 225 |
| Dwarf galaxias | *Galaxias divergens* | 8 | 467 | 64 | 159 | 0.12 | 0.43 | 52 |
| Banded kokopu (juvenile) | *Galaxias fasciatus* | 5 | 575 | 87 | 87 | 0.15 | 0.04 | 58 |
| Banded kokopu (adult) | | 5 | 575 | 204 | 204 | 0.18 | 0.03 | 49 |
| Alpine galaxias | *Galaxias paucispondylus* | 2 | 192 | 14 | 29 | 0.12 | 0.51 | 64 |
| Shortjaw kokopu | *Galaxias postvectis* | 2 | 34 | 4 | 4 | 0.27 | 0.18 | 152 |
| Upland longjaw galaxias | *Galaxias prognathus* | 3 | 154 | 8 | 8 | 0.14 | 0.51 | 38 |
| Canterbury galaxias | *Galaxias vulgaris* | 13 | 534 | 116 | 575 | 0.17 | 0.37 | 65 |
| Giant kokopu | *Galaxias argenteus* | 18 | 69 | 39 | 39 | 0.53 | 0.05 | 24 |
| Inanga | *Galaxias maculatus* | 3 | 129 | 129 | 595 | 0.30 | 0.05 | Not sampled |
| Lamprey | *Geotria australis* | 1 | 80 | 63 | 422 | 0.26 | 0.06 | 1 |
| Crans bully | *Gobiomorphus basalis* | 17 | 799 | 133 | 560 | 0.19 | 0.18 | 49 |
| Upland bully | *Gobiomorphus breviceps* | 36 | 1078 | 523 | 3688 | 0.19 | 0.40 | 51 |
| Common bully | *Gobiomorphus cotidianus* | 31 | 1400 | 226 | 1224 | 0.21 | 0.35 | 45 |
| Giant bully | *Gobiomorphus gobiodes* | 1 | 20 | 1 | 1 | 0.41 | 0.03 | 26 |
| Bluegill bully | *Gobiomorphus hubbsi* | 15 | 764 | 174 | 3253 | 0.24 | 0.68 | 51 |
| Redfin bully | *Gobiomorphus huttoni* | 28 | 920 | 197 | 564 | 0.21 | 0.25 | 87 |
| Smelt | *Retropinna retropinna* | 7 | 255 | 35 | 107 | 0.39 | 0.25 | 40 |
| Black flounder | *Rhombosolea retiaria* | 2 | 260 | 2 | 2 | 0.48 | 0.34 | 35 |
| Rainbow trout | *Oncorhynchus mykiss* | 9 | 679 | 82 | 252 | 0.21 | 0.53 | 53 |
| Chinook salmon | *Oncorhynchus tshawycha* | 7 | 404 | 45 | 97 | 0.21 | 0.48 | 48 |
| Brown trout | *Salmo trutta* | 45 | 1248 | 446 | 1769 | 0.20 | 0.48 | 68 |

## 4.2 Shortfin eel

Shortfin eels are native to New Zealand, Australia, and other South Pacific islands. They undertake extensive migrations between their spawning grounds in the subtropical Pacific to the adult habitat in rivers, streams, and coastal lakes. Migration to ocean spawning habitat occurs only once at the end of an eel's life, and they spend the vast majority of their lives in freshwater habitats. In comparison to most of New Zealand's native fish, eels are long-lived and large in size. They also support valuable commercial and traditional fisheries.

Although shortfin eels are good climbers, able to negotiate substantial natural and man-made structures, including facilities installed at hydroelectric dams to facilitate their passage, shortfin eels are found in greatest abundance in low gradient waterways and lakes close to the coast, and are more common in the North Island than the South Island. This might be related to their preference for relatively warm water (Richardson et al. 1994). Shortfin eels are comparatively tolerant of common pollutants such as ammonia, low dissolved oxygen, and turbidity (Richardson 1997; Dean & Richardson 1999; Boubée et al. 1997), and are often found in open, unshaded waterways in farmed catchments.

Data for shortfin eels larger than 300 mm in length were available within the 549 sites where only eel data were collected, and were analysed separately from the remainder of the shortfin data. Small shortfin eels (<300 mm) were found in a wide range of depth, velocity, and substrate conditions, although they did appear to avoid moderately swift water (>0.8 m/s). The preferences changed with size, with larger eels preferring deep, slow water, reflecting their daytime pool habitat. Large eels also exhibited a preference for large substrate, which they probably utilise as protective cover. Substantial cover is an important requirement for larger eels,: this can be provided by large substrate, overhanging and instream vegetation, undercut banks, and instream debris.

The habitat suitability data presented here are based on day observations. During the night large shortfin eels are probably found foraging for food in shallower and swifter water, whereas small shortfin eels seem to be found in shallower and slower water, as indicated in Table 3.2.1.

**Table 4.2.1: Habitat statistics for 2137 shortfin eels (<300 mm) present at 675 of 2192 locations in 58 rivers.**

| | Velocity (m/s) | Depth (m) | Substrate index | Substrate size (mm) |
|---|---|---|---|---|
| Minimum | 0.00 | 0.04 | 2.0 | 0.01 |
| Maximum | 1.34 | 1.20 | 8.0 | 256 |
| Average (SD) | 0.28 (0.26) | 0.22 (0.15) | 5.1 (1.2) | 69 (66) |

Small (< 300 mm) shortfin eels were found predominately in relatively shallow, low velocity water (Table 4.2.1). The preference curves (Fig. 4.2.1), depth/velocity contours (Fig. 4.2.2), and the GAM analysis (Figs 4.2.3 & 4.2.4) all showed a general pattern of preference for low velocity shallow water and either very fine or coarse substrate. The velocity at which 69 mm substrate just begins to move (critical velocity) at a depth of 0.22 m is 1.59 m/s.

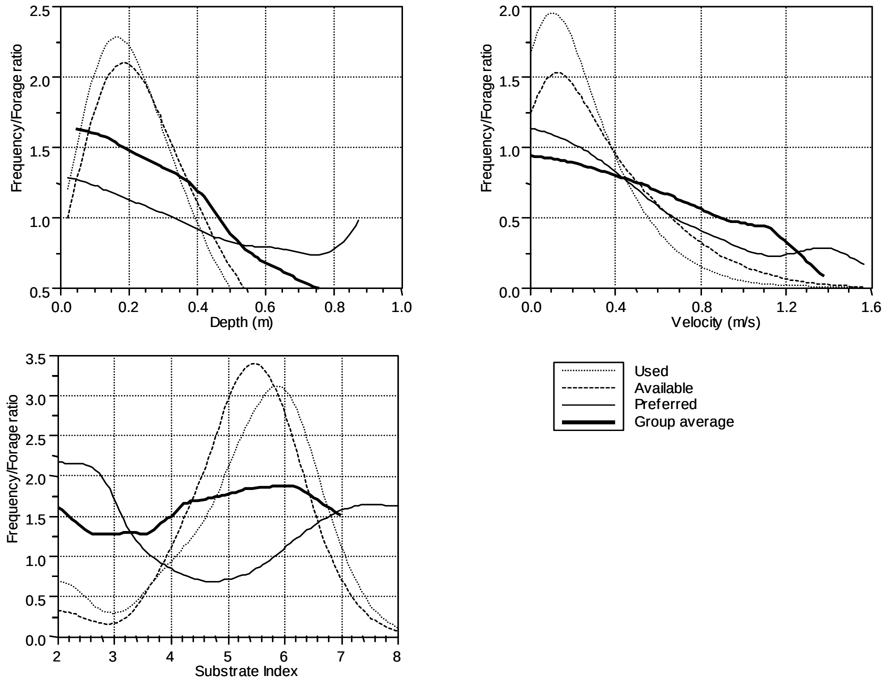


**Figure 4.2.1:** Kernel smoothed frequency of habitat availability (dashed line), use (dotted line), and the preference curves derived from all data (solid thin line) and by averaging preference relationships in each river (solid thick line) for shortfin eels < 300 mm.

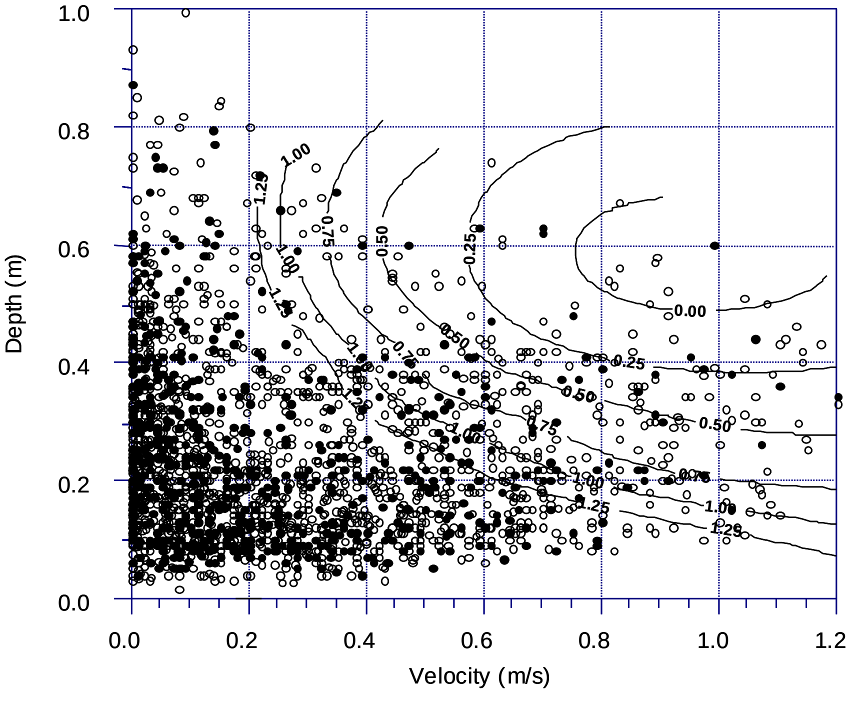


**Figure 4.2.2:** Depth and velocity at all sampling locations, with LOESS contours fitted to eel densities. Locations containing shortfin eels < 300 mm are shown shaded.

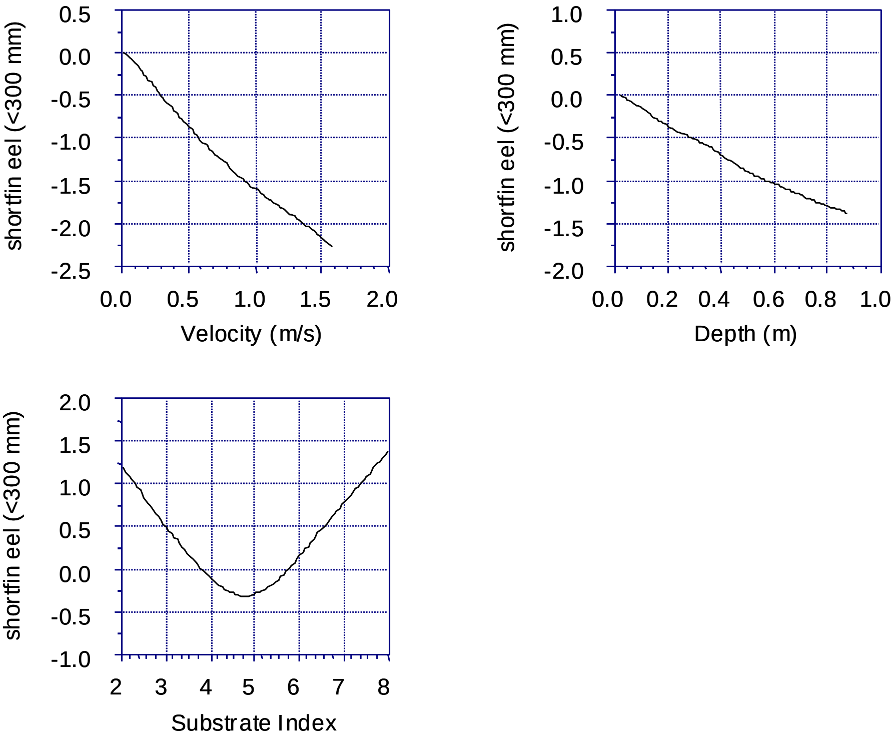


**Figure 4.2.3: Generalised additive logistic model of shortfin eel < 300 mm probability of use using depth, velocity and substrate index excluding depths > 0.9 m to give 71% correct prediction at a cut level of 0.7.**

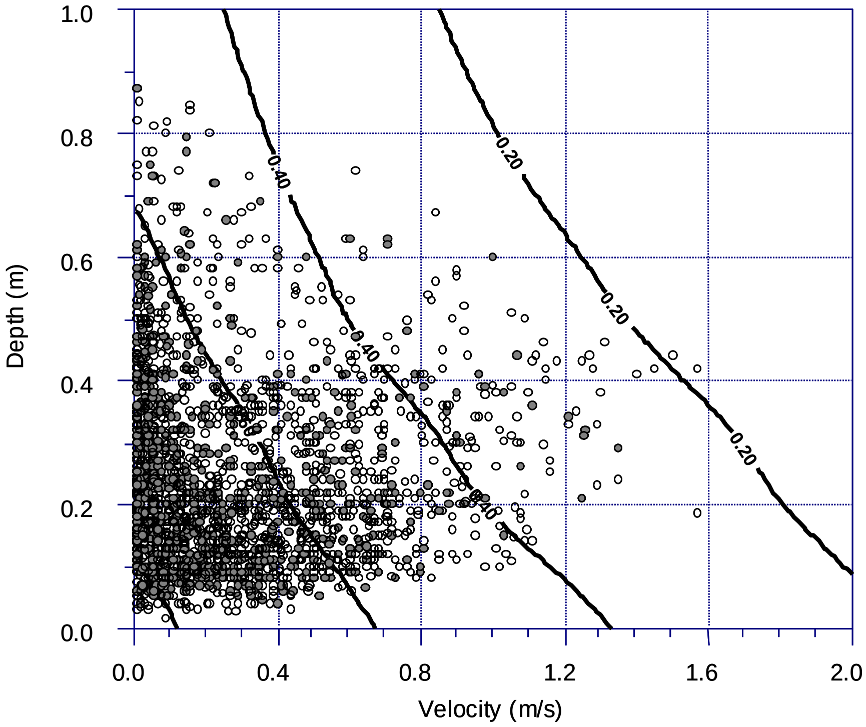
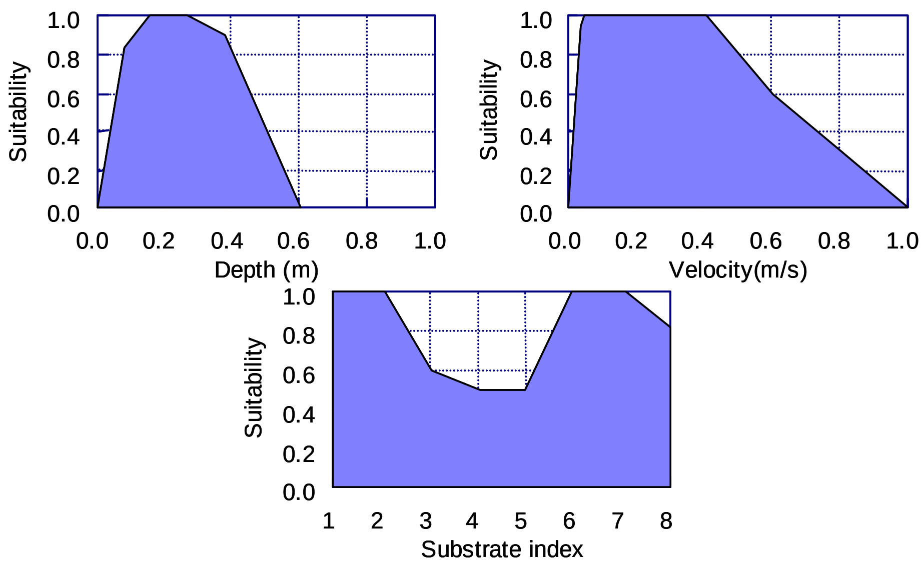
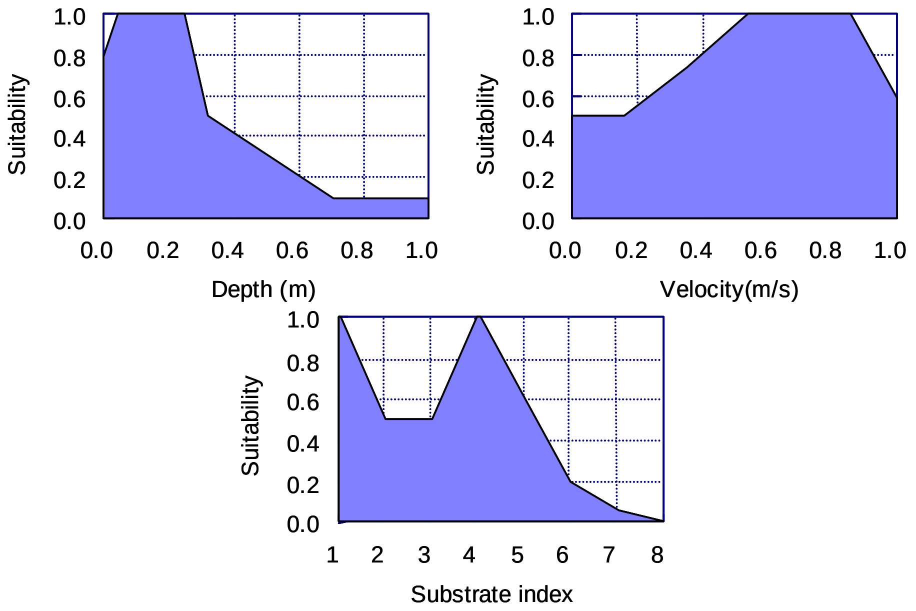


**Figure 4.2.4: Contour plot of GAM of probability of use using depth and velocity for a substrate index of 5 with locations sampled with points filled if shortfin eels were present.**

When all these 3 sets of analyses (habitat suitability, LOESS, and GAM) are compared, they show a similar trend with suitability declining relatively linearly as depth and velocity increased. The analysis of substrate preference indicated a preference for gravel/cobble sized substrate using the river average, but a preference for very fine or very coarse substrate using all data or the GAM. The group average curve is more similar to the habitat used by shortfin eels than the curve derived for all data. In the analysis with all data, the high preferences for very fine and very coarse substrates are the result of high numbers in the rivers where those substrate types area present and an absence of those substrate categories in other rivers where gravel/cobble substrates predominate. Boulder (index of 7) was the preferred substrate in 3 rivers, whereas gravel/cobble (index 5–6) was the preferred substrate in 38 of the 74 individual rivers used for averaging. Fine substrate (index 2–4) had the highest preference using all data and was the preferred substrate in 29 individual rivers. The suitability curve (Fig. 4.2.5) put more reliance on the analysis with all data and the GAM than on the river averaged curve.



**Shortfin eel < 300mm (Jowett & Richardson 2008)**



**Shortfin eel (<300mm) (Jowett and Richardson 1995)**

**Figure 4.2.5: Habitat suitability curves derived from above analyses (top) compared with the curves based on data from Jowett & Richardson (1995) (bottom).**

**Table 4.2.2: Habitat statistics for 181 shortfin eels (>300 mm) present at 102 of 549 locations in 4 rivers during the day.**

| | Velocity (m/s) | Depth (m) | Substrate index | Substrate size (mm) |
|---|---|---|---|---|
| Minimum | 0.00 | 0.06 | 2 | 0.1 |
| Maximum | 0.75 | 1.02 | 8 | 256 |
| Average (SD) | 0.11 (0.12) | 0.38 (0.17) | 5.2 (1.7) | 90 (83) |

Large (> 300 mm) shortfin eels were found predominately in relatively deep, low velocity water during the day (Table 4.2.2). The preference curves (Fig. 4.2.6), depth/velocity contours (Fig. 4.2.7), and the GAM analysis (Figs 4.2.8 & 4.2.9) all showed a general pattern of preference for low velocity (0-0.3 m/s) water with depths of 0.4 to 0.8 m and a slight preference for boulder substrate. The velocity at which 90 mm substrate (critical velocity) just begins to move at a depth of 0.38 m is 1.81 m/s.

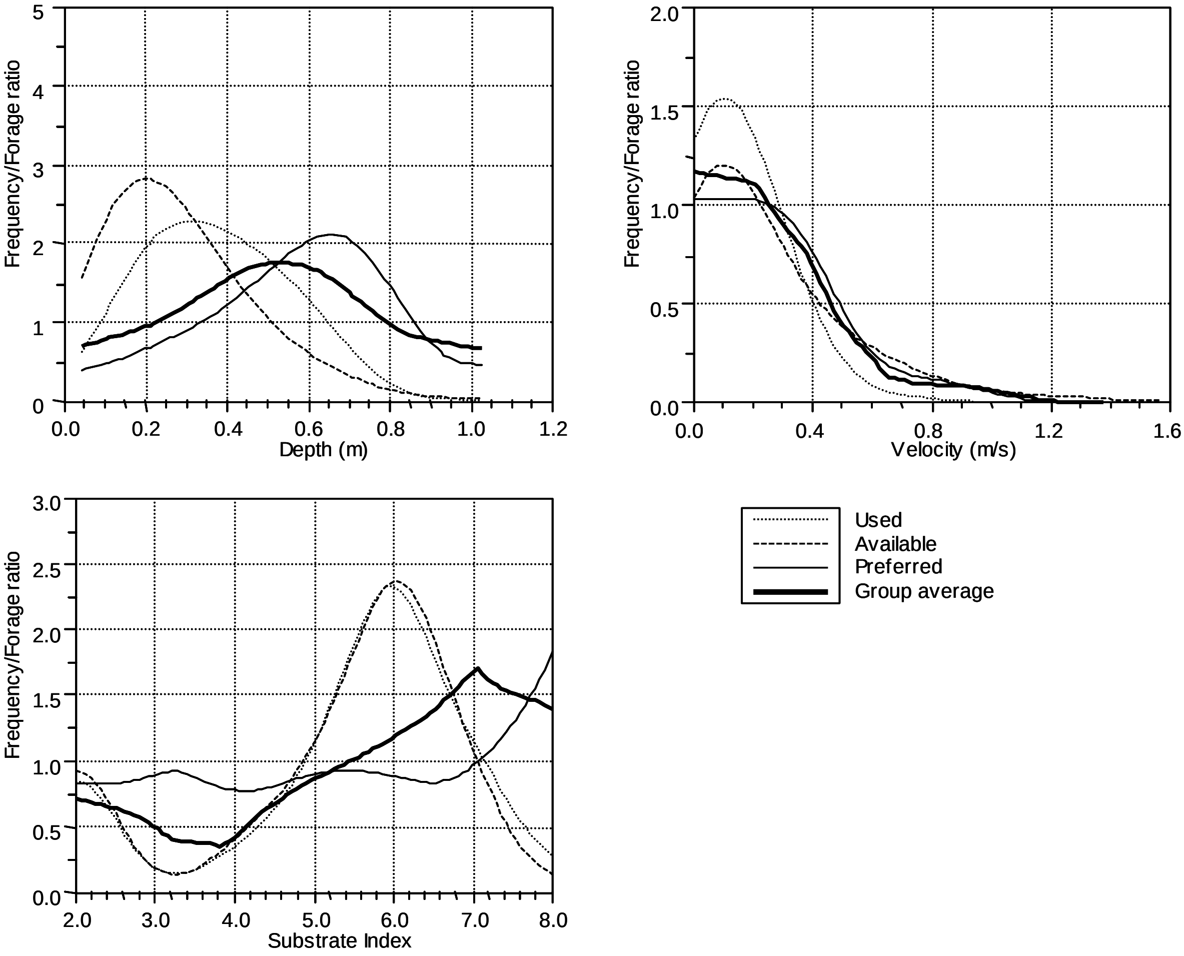


**Figure 4.2.6: Kernel smoothed frequency of habitat availability (dashed line), use (dotted line), and the preference curves derived from all data (solid thin line) and by averaging preference relationships in each river (solid thick line) for shortfin eels > 300 mm.**

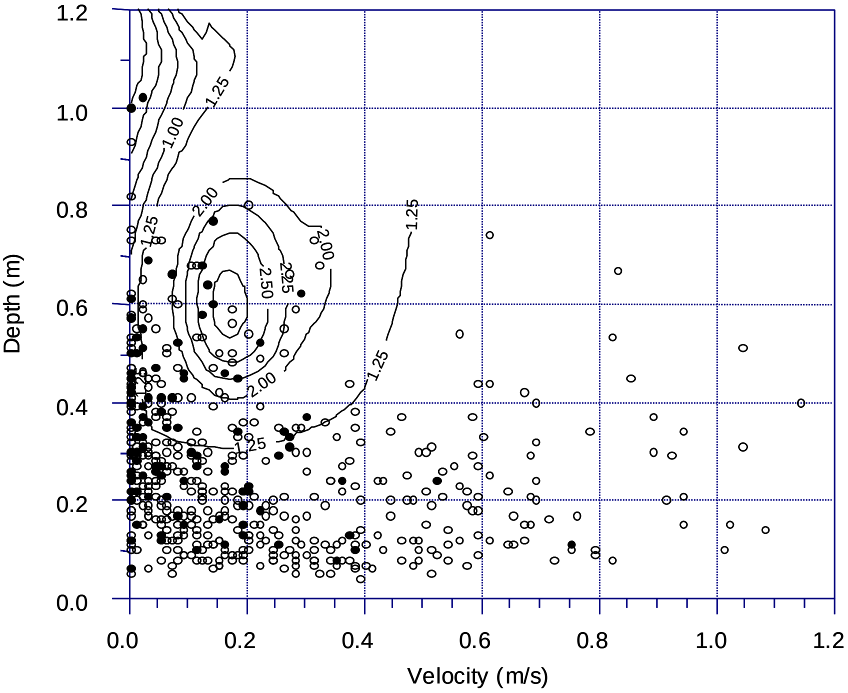


**Figure 4.2.7:** Depth and velocity at all sampling locations, with LOESS contours fitted to eel densities. Locations containing shortfin eels > 300 mm are shown shaded.

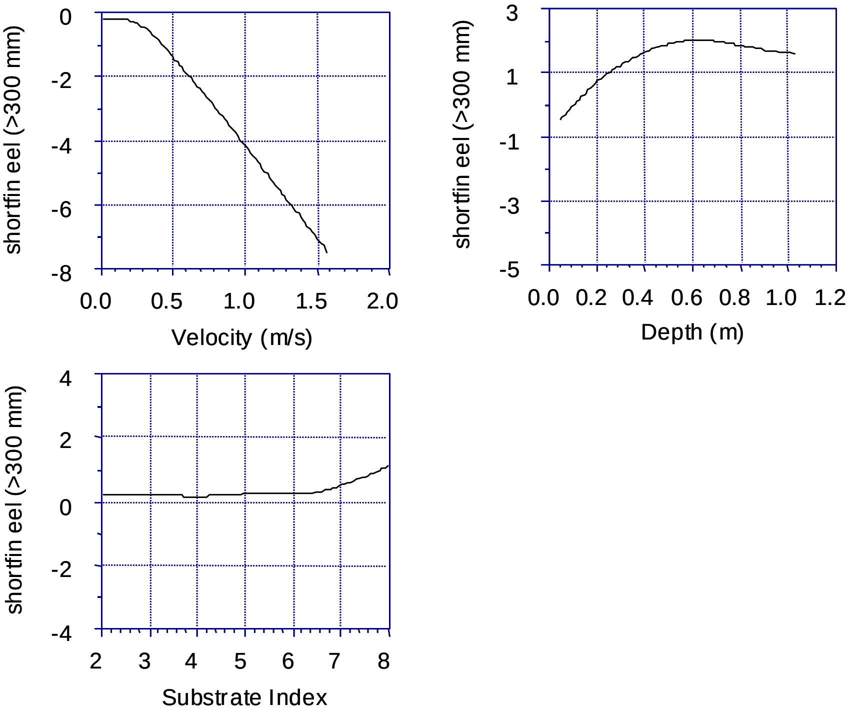


**Figure 4.2.8:** Generalised additive logistic model of shortfin eel > 300 mm probability of use using depth, velocity and substrate index to give 70% correct prediction at a cut level of 0.4.

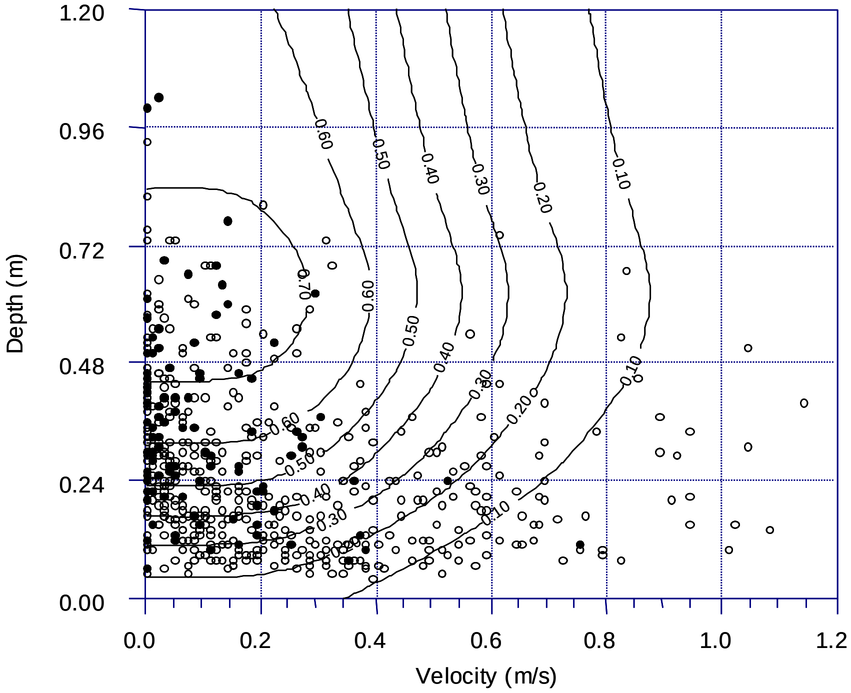


**Figure 4.2.9:** Contour plot of GAM of probability of use using depth and velocity for a substrate index of 5 showing points filled if shortfin eels were present.

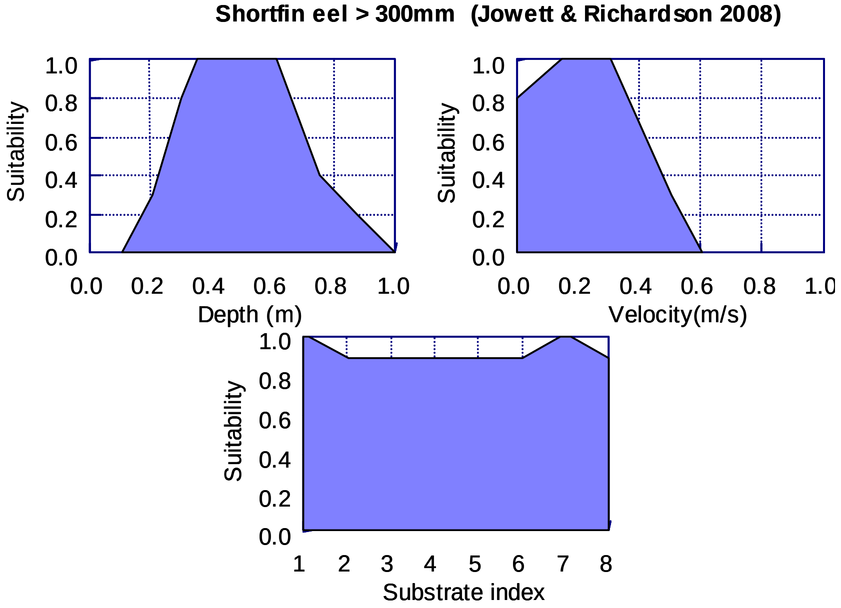


**Figure 4.2.10:** Habitat suitability curves for shortfin eel > 300 mm derived from above analyses.

## 4.3 Longfin eel

Longfin eels are found only in New Zealand, but they have a similar life history to shortfin eels. They are one of our most widespread fish species, found in 70 of the 123 rivers surveyed for this study, and penetrate further inland than shortfin eels. Longfin eels are found in a wide variety of habitats, from lowland pastoral rivers to headwater tributaries of bush streams.

Like the shortfin eels, data for longfin eels larger than 300 mm in length were available within the 549 sites where only eel data were collected. The density of large longfin eels was highly skewed by some dense aggregations (e.g., up to 68 in 5 m$^2$) that were found beneath undercut banks. To avoid these aggregations putting undue weight on habitat preferences, the very high eel densities were reduced to 7 per 10 m$^2$, which was typical of the density associated with good habitat.

The habitat suitability data presented here are based on day observations and during the night small longfin eels are probably to be found in shallower and slower water, as indicated in Table 3.2.1. Although there are no data for large longfin eels, their night habitat is probably similar to that of large shortfin eels (i.e., shallower and swifter water than their day-time habitat).

**Table 4.3.1: Habitat statistics for 1625 longfin eels (<300 mm) caught at 558 of 2641 locations in 70 rivers.**

| | Velocity (m/s) | Depth (m) | Substrate index | Substrate size (mm) |
|---|---|---|---|---|
| Minimum | 0.00 | 0.04 | 2 | 0.01 |
| Maximum | 1.39 | 0.80 | 8 | 288 |
| Average (SD) | 0.40 (0.20) | 0.21 (0.13) | 5.5 (0.1) | 82 (55) |

Small (< 300 mm) longfin eels were found predominately in relatively shallow water with moderate velocities (Table 4.3.1). The preference curves (Fig. 4.3.1), depth/velocity contours (Fig. 4.3.2), and the GAM analysis (Figs 4.3.3 & 4.3.4) all showed a general pattern of preference for moderate velocities (0.2–0.6 m/s) and depths of less than 0.3 m and a preference for gravel or coarser substrate. The velocity at which 82 mm substrate (critical velocity) just begins to move at a depth of 0.21 m is 1.62 m/s.

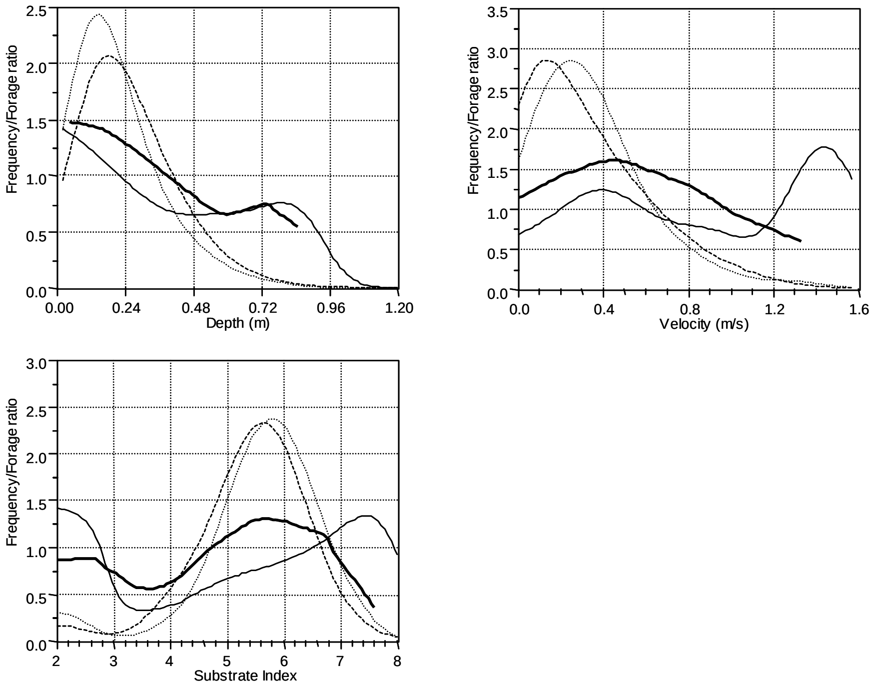


**Figure 4.3.1:** Kernel smoothed frequency of habitat availability (dashed line), use (dotted line), and the preference curves derived from all data (solid thin line) and by averaging preference relationships in each river (solid thick line) for longfin eels < 300 mm.

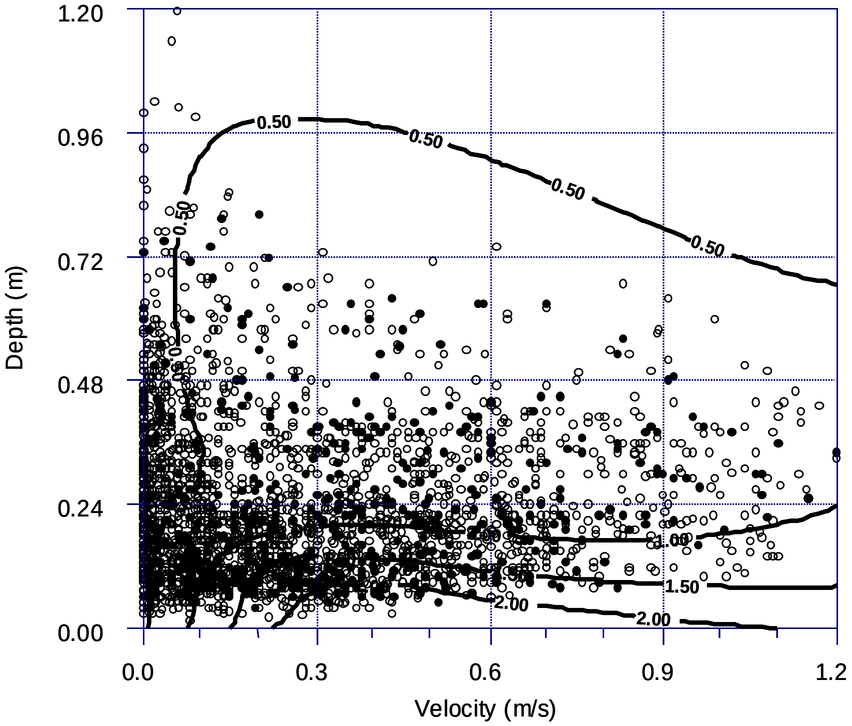


**Figure 4.3.2:** LOESS contours fitted to eel densities and depth and velocity at all sampling locations. Locations containing longfin eels < 300 mm are shown shaded.

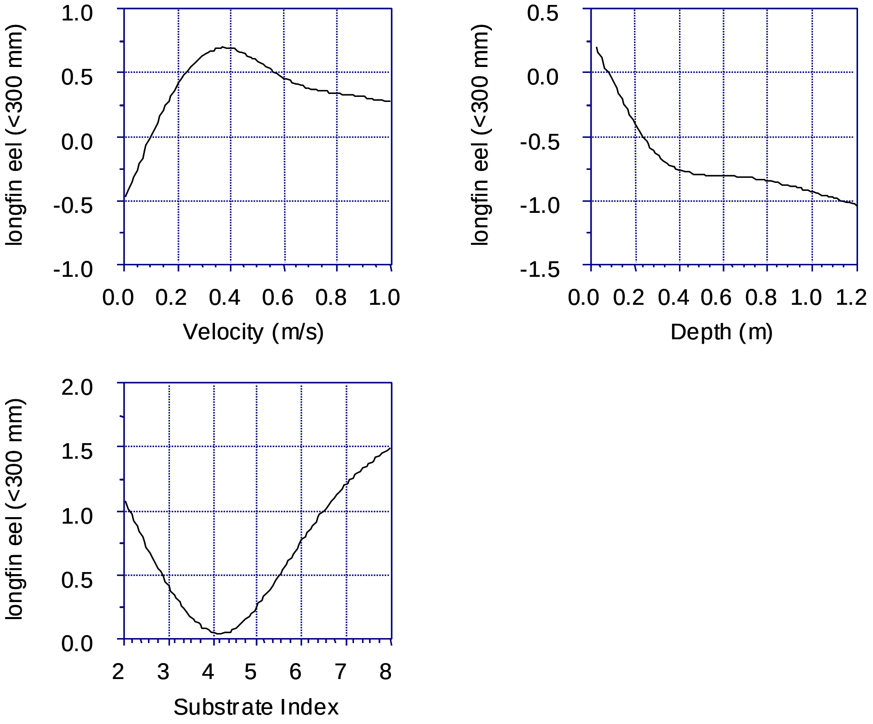


**Figure 4.3.3:** Generalised additive logistic model of longfin eel < 300 mm probability of use using depth, velocity and substrate index excluding velocities >1 m/s to give 63% correct prediction at a cut level of 0.6.

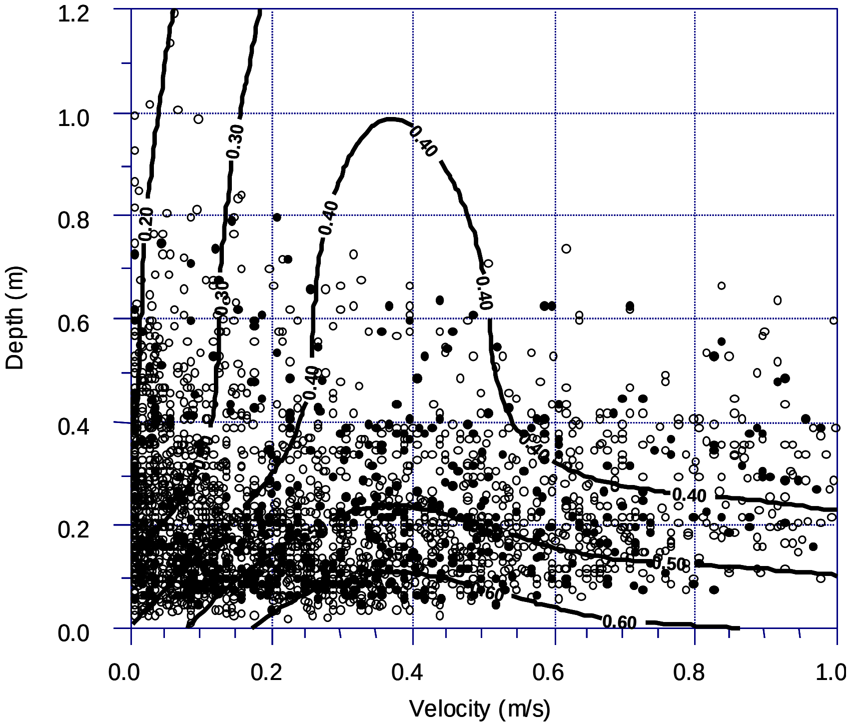
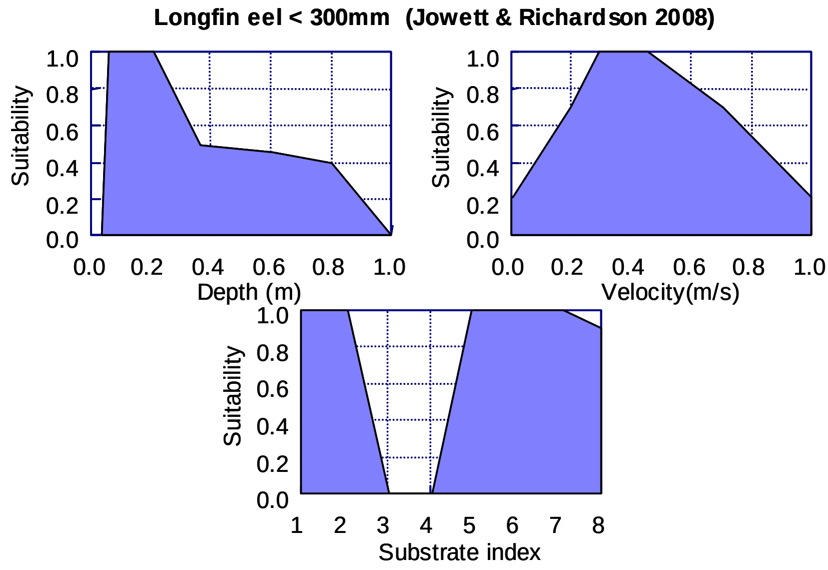


**Figure 4.3.4:** Contour plot of GAM of probability of use using depth and velocity for a substrate index of 5, showing locations sampled with points filled if longfin eels were present.


Longfin eel < 300mm (Jowett & Richardson 2008)

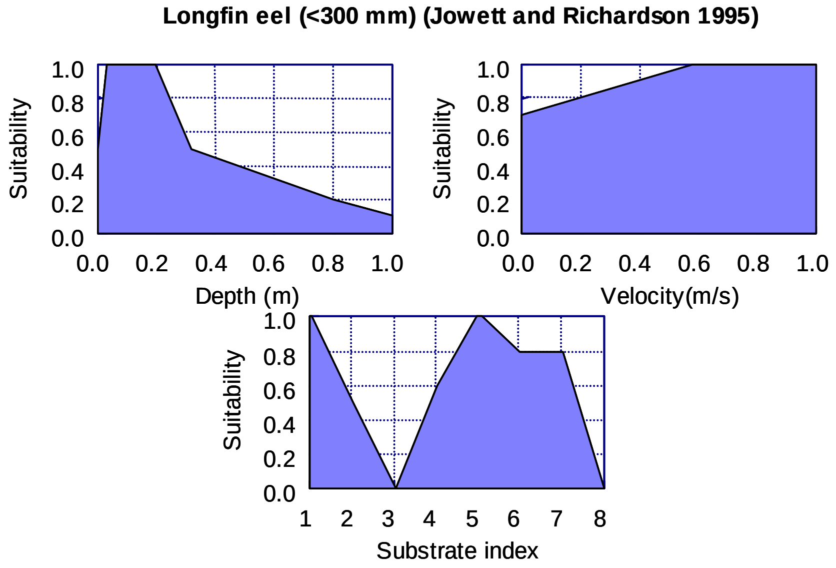

Longfin eel (<300 mm) (Jowett and Richardson 1995)

**Figure 4.3.5:** **Habitat suitability curves for longfin eel < 300 mm derived from above analyses (top) compared with curves based on data from Jowett & Richardson (1995) (bottom).**

**Table 4.3.2:** **Habitat statistics for 389 longfin eels (>300 mm) present at 155 of 549 locations in 4 rivers during the daytime.**

| | Velocity (m/s) | Depth (m) | Substrate index | Substrate size (mm) |
|---|---|---|---|---|
| Minimum | 0.00 | 0.05 | 2 | 0.06 |
| Maximum | 0.67 | 1.02 | 8 | 256 |
| Average (SD) | 0.14 (0.12) | 0.42 (0.20) | 5.6 (1.7) | 127 (99) |

Large longfin eels preferred deep (>0.6 m), slow water (< 0.4 m/s) (Fig. 4.3.6), just like the large shortfin eels. Instream or bank-side cover probably influences the presence of large longfin eels (very high densities were found under some undercut banks). They did not show any strong preference for substrate, although vegetation, large instream debris, and boulders would provide suitable cover for large longfin eels. The velocity at which 127 mm substrate (critical velocity) just begins to move at a depth of 0.42 m is 1.88 m/s. At night, large longfin eels emerge from their daytime refuges and search for food. Casual observations suggest that they feed in a very wide variety of habitats.

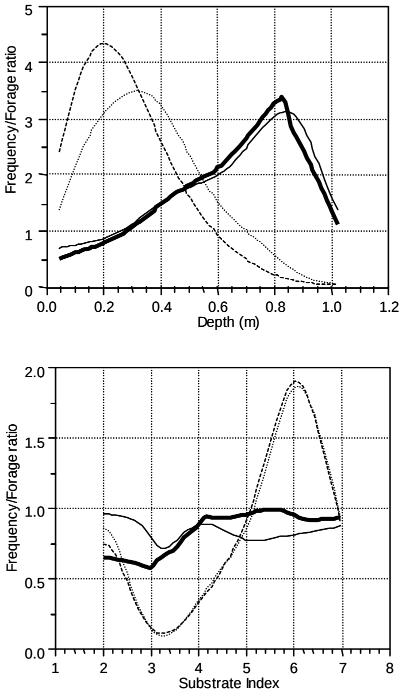


**Figure 4.3.6:** **Kernel smoothed frequency of habitat availability (dashed line), use (dotted line), and the preference curves derived from all data (solid thin line) and by averaging preference relationships in each river (solid thick line) for longfin eels > 300 mm.**

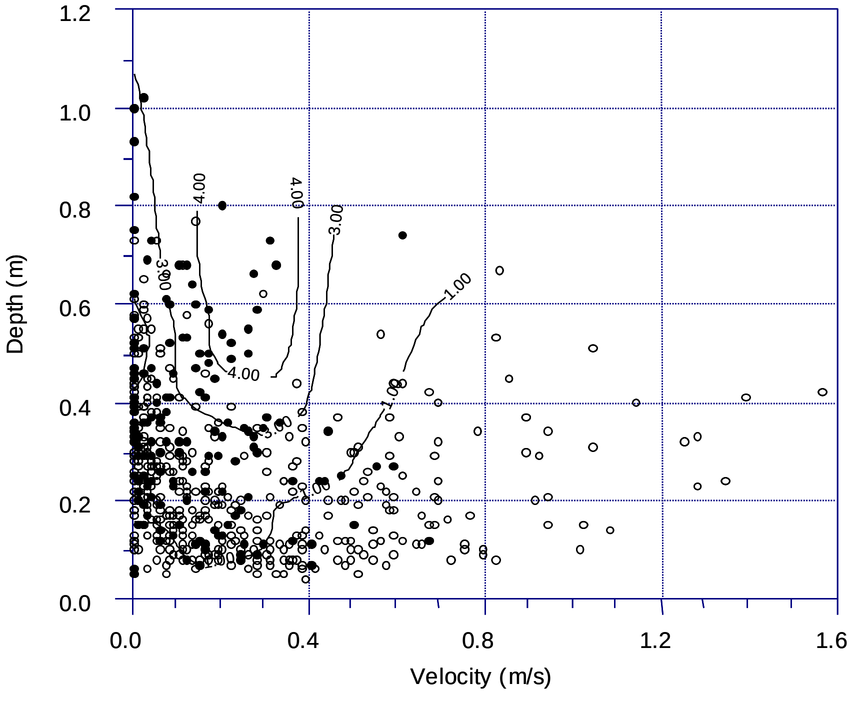


**Figure 4.3.7:** **LOESS contours fitted to eel densities and depth and velocity at all sampling locations. Locations containing longfin eels > 300 mm are shown shaded.**

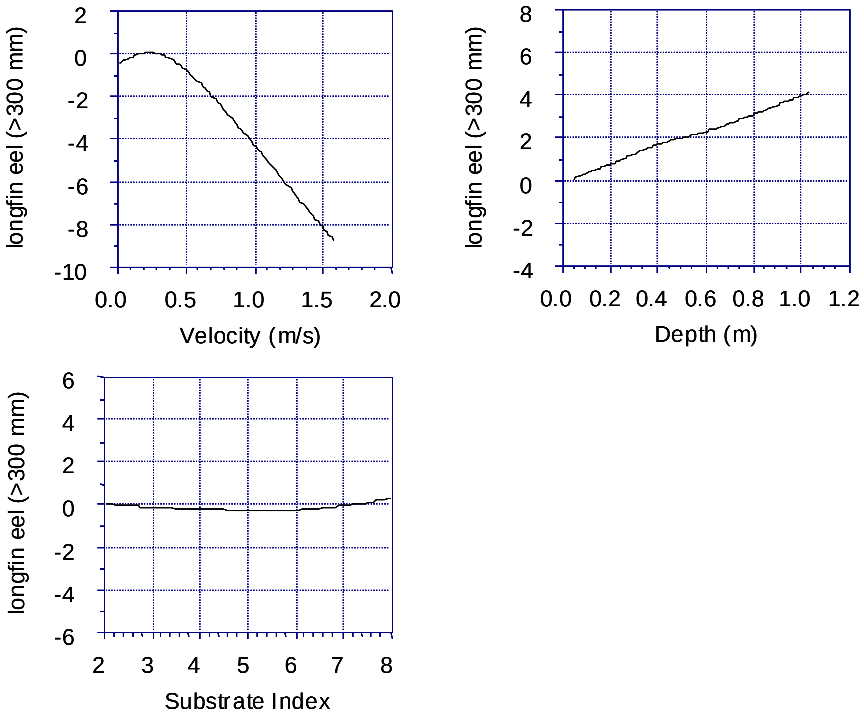


Figure 4.3.8: **Generalised additive logistic model of longfin eel > 300 mm probability of use using depth, velocity and substrate index to give 67% correct prediction at a cut level of 0.7.**

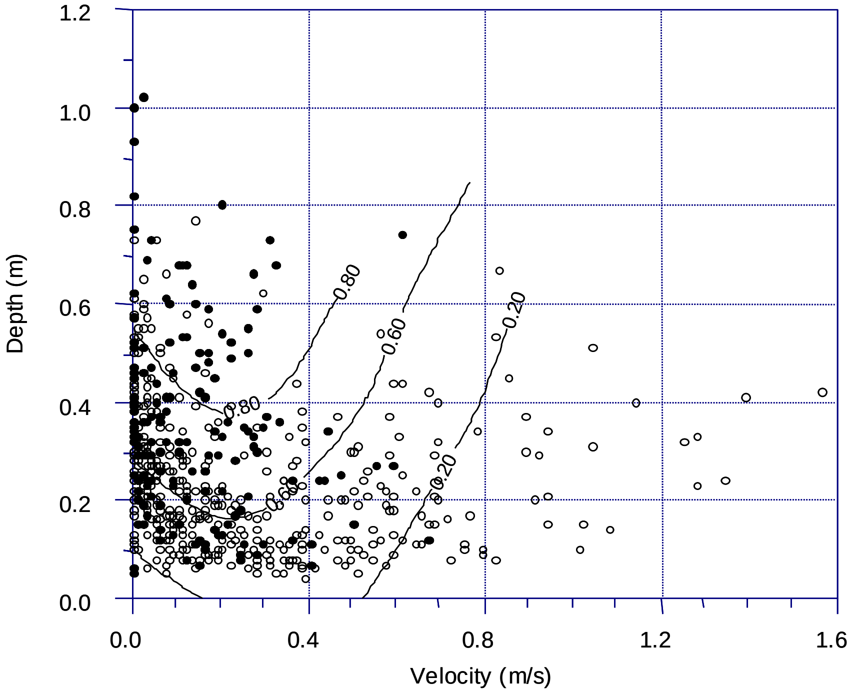


Figure 4.3.9: **Contour plot of GAM of probability of use using depth and velocity for a substrate index of 5 with points filled if longfin eels were present.**

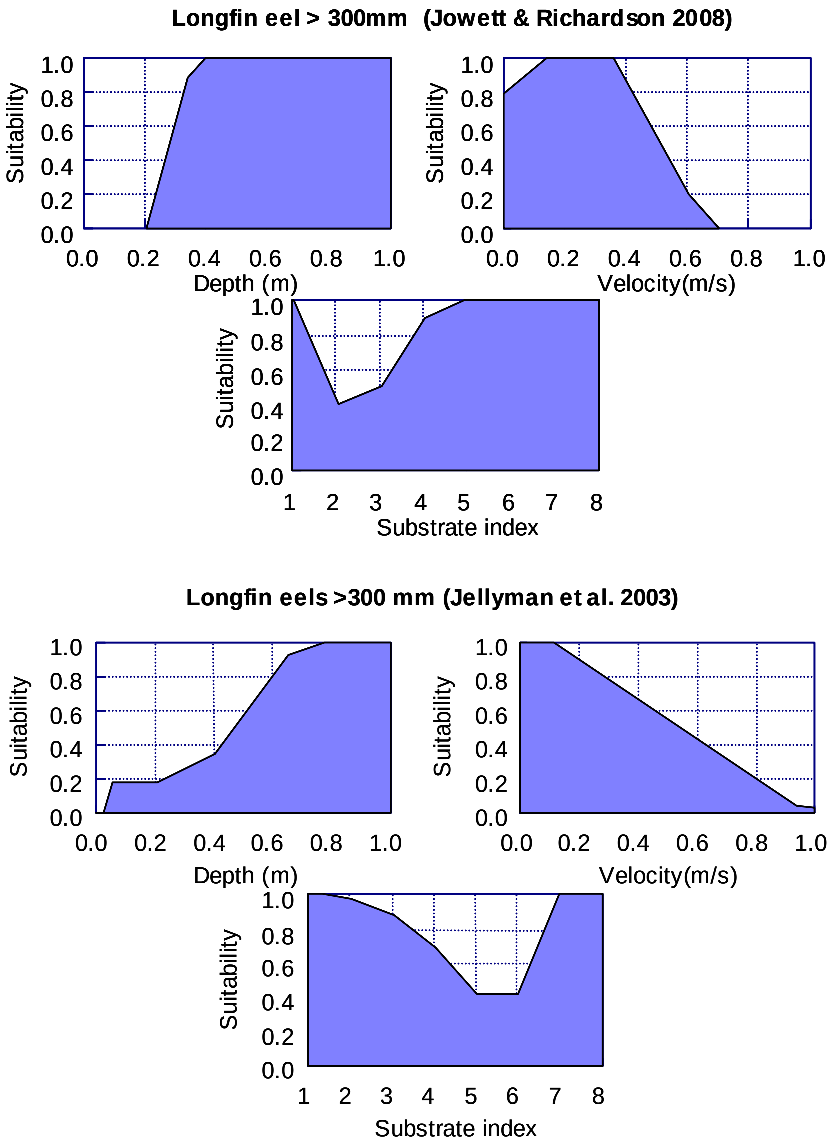


**Figure 4.3.10:** Habitat suitability curves for longfin eel > 300 mm derived from above analyses (top) compared with curves based on data from Jellyman et al. (2003) (bottom)

## 4.4 Torrentfish

Torrentfish are a native diadromous species that prefer swiftly flowing water, and they are generally found in the centre of riffles and rapids in open stony rivers. Although torrentfish are not good climbers, they do penetrate long distances inland, and are believed to undertake spawning migrations between upper and lower river sections over the course of their lifetimes.

Torrentfish are rarely found in small bush streams, preferring mainstems and large tributaries with good access to the sea.

**Table 4.4.1: Habitat statistics for 784 torrentfish present at 200 of 1217 locations in 37 rivers.**

| | Velocity (m/s) | Depth (m) | Substrate Index | Substrate size (mm) |
|---|---|---|---|---|
| Minimum | 0.07 | 0.07 | 4.0 | 8.0 |
| Maximum | 1.24 | 0.72 | 6.7 | 239.0 |
| Average (SD) | 0.72 (0.27) | 0.24 (0.11) | 5.2 (0.6) | 56 (35) |

Torrentfish are usually found in water less than 0.4 m deep and velocities in excess of 0.5 m/s. The average velocity (0.66 m/s) in which they were found was similar to that used by koaro and higher than any of the other species analysed (Table 4.1.2). The preferred velocity of over 1 m/s was almost double the velocity in which they were normally found (Fig. 4.4.1). The velocity at which 56 mm substrate (critical velocity) just begins to move at a depth of 0.24 m is 1.55 m/s. A velocity of 1.3 m/s was taken as the upper limit of habitat suitability and all torrentfish were found in velocities lower than this (Fig. 4.4.2). Torrentfish utilise the substrate as cover, and occupied a relatively narrow range of substrates; fine substrates, boulders and bedrock were avoided by torrentfish.

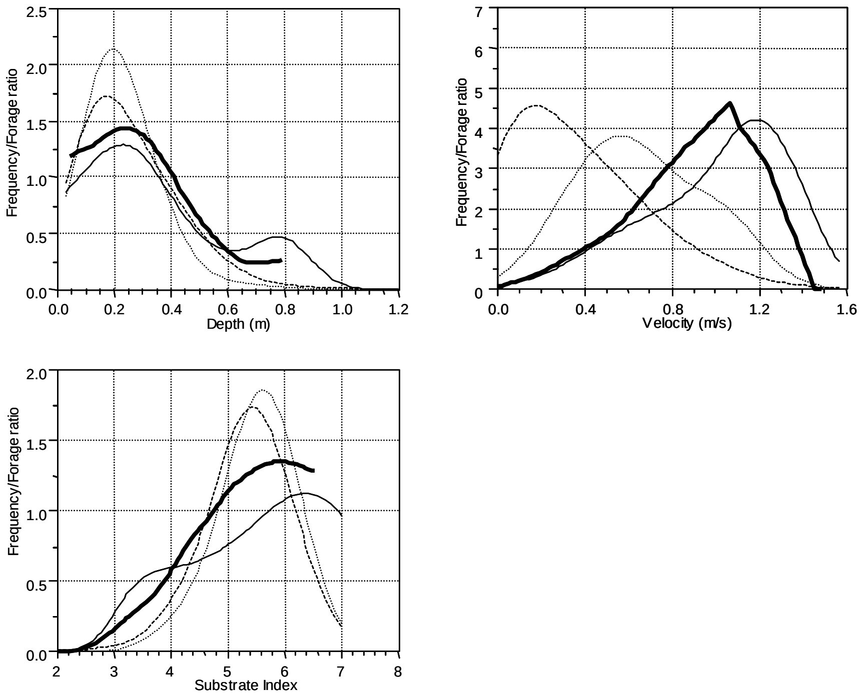


**Figure 4.4.1: Kernel smoothed frequency of habitat availability (dashed line), use (dotted line), and the preference curves derived from all data (solid thin line) and by averaging preference relationships in each river (solid thick line) for torrentfish.**

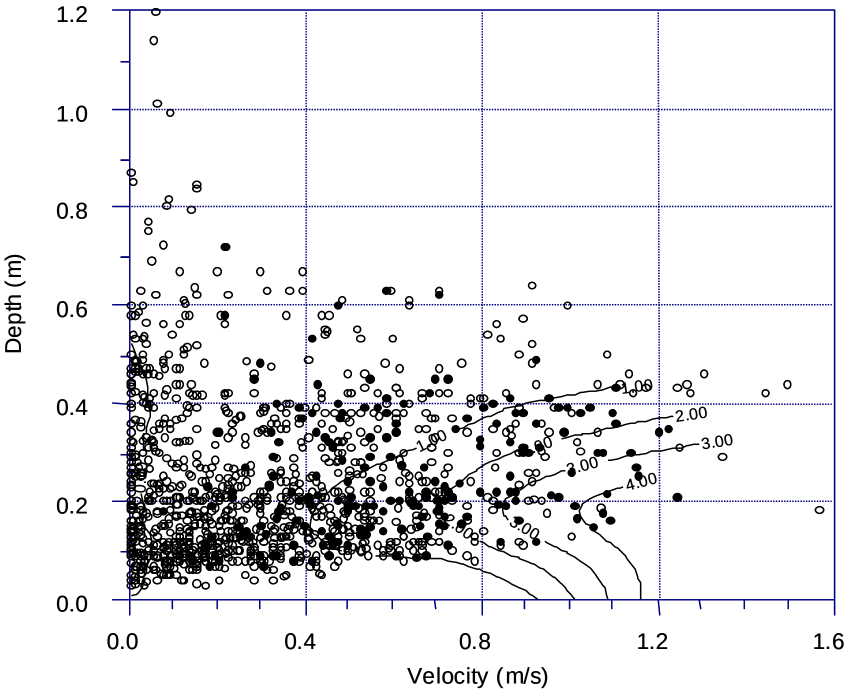


**Figure 4.4.2:** **LOESS contours fitted to torrentfish densities and depth and velocity at all sampling locations. Locations containing torrentfish are shown shaded.**

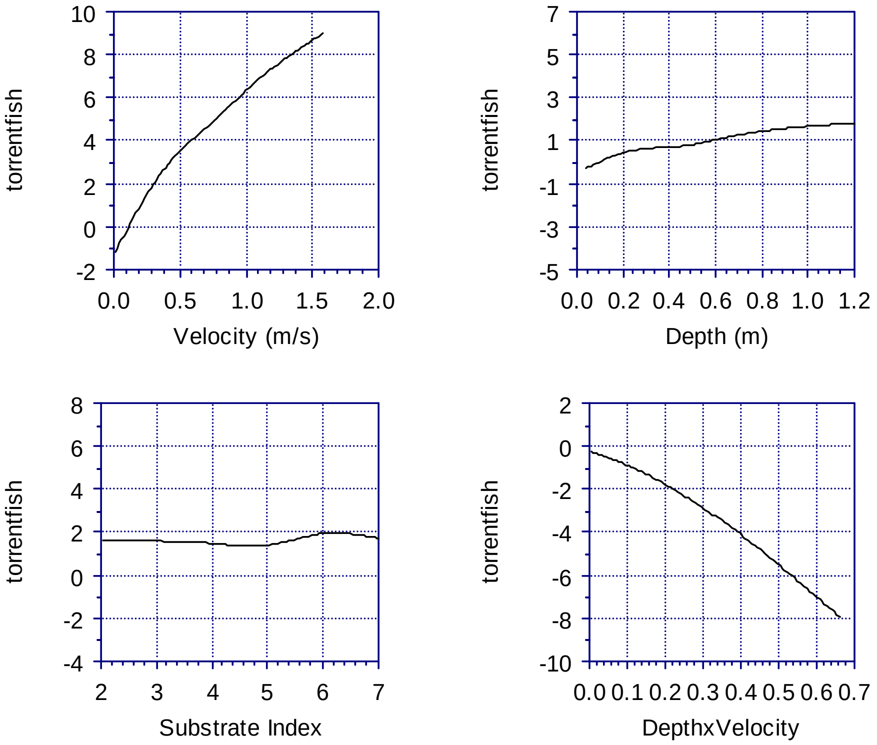


**Figure 4.4.3:** **Generalised additive logistic model of torrentfish probability of use using depth, velocity, substrate index and velocity/depth interaction to give 78% correct prediction at a cut level of 0.5. Velocity/depth interaction significant at $P < 0.001$.**

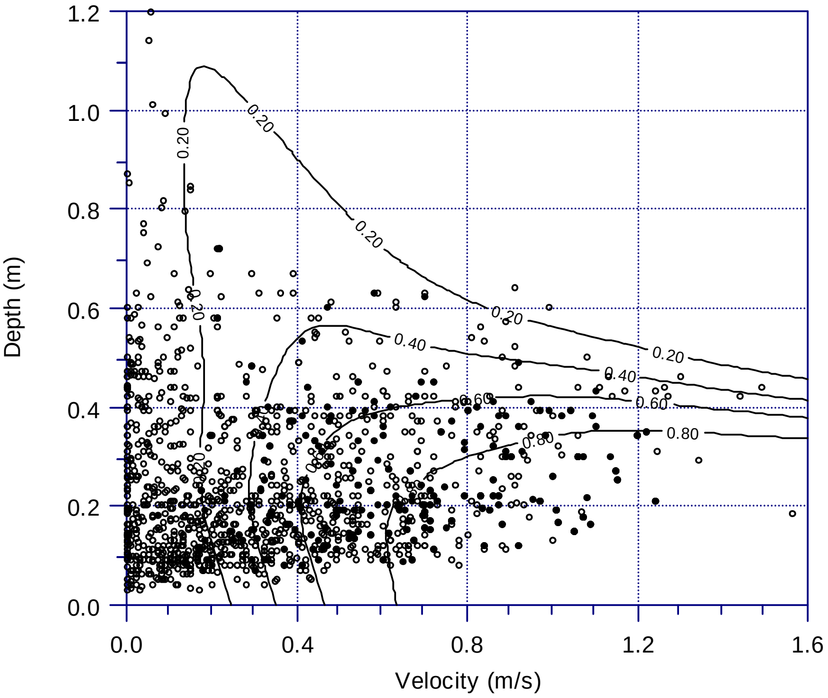


**Figure 4.4.4:** **Contour plot of GAM of probability of use using depth and velocity for a substrate index of 6 with points filled if torrentfish were present.**

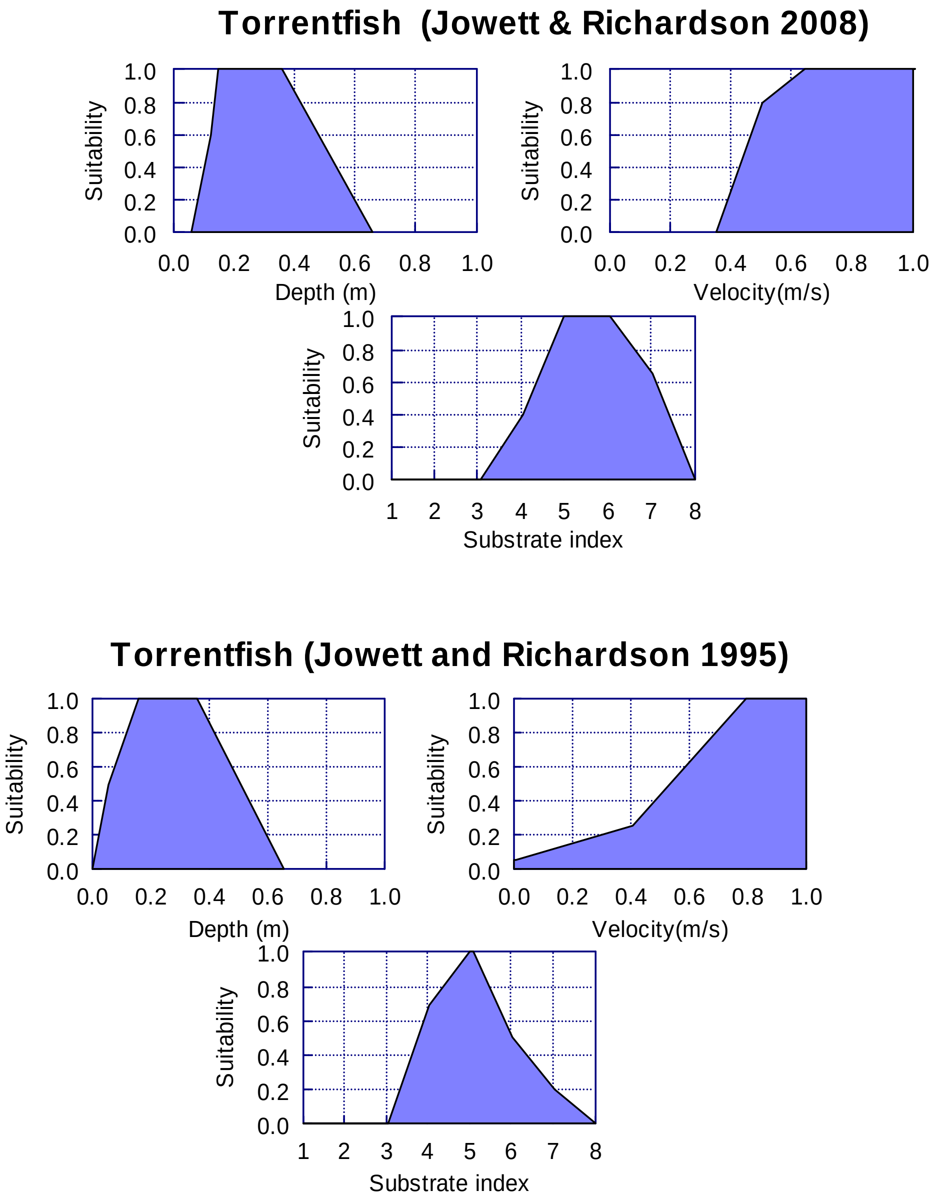


**Figure 4.4.5:** **Habitat suitability curves derived from above analyses (top) compared with curves based on data from Jowett & Richardson (1995) (bottom)**

## 4.5 Koaro

Koaro are one of the diadromous galaxiid species that make up the whitebait catch. They are probably the second most abundant species in the catch after inanga, although this varies from river to river (McDowall 1984). Koaro occur throughout New Zealand and also in eastern Australia and Tasmania.

Although koaro are diadromous, they are excellent climbers, and are able to negotiate cascades and waterfalls that species other than eels cannot. Koaro can also form land-locked populations, using lakes for the normally sea-going stages of the life cycle. In our dataset, koaro were found in 9 of the rivers surveyed, but were only comparatively abundant in two of these, the Onekaka and Ryton. The Onekaka population is diadromous, whereas the Ryton flows into Lake Coleridge, which acts as the “sea” for this land-locked koaro population.

Rocky, tumbling streams are the preferred habitat of koaro, and they are almost always found in streams with native bush catchments, except for tributaries of upland lakes that may be above the bush-line. Studies here and in Australia found that koaro spawned in damp areas along the edges of the streams they lived in, relying on subsequent floods to inundate the eggs for hatching (Allibone & Caskey 2000; O’Connor & Koehn 1998). This requirement could explain their preference for forested streams, which may provide more humid conditions for the incubating eggs than more exposed sites.

Koaro are generally assumed to prefer relatively deep swift habitats, but this might be related to the presence of other fish (Hayes 1995). Additional habitat measurements were carried out for koaro in Lake Chalice tributaries, where koaro are the only species present. These measurements showed a preference for lower velocity water and a much wider depth range than koaro in the Onekaka or Ryton. However, there was little difference in the preferred substrate. Because most flow assessments are likely to occur where there is a mixed population of fish, we present the habitat suitability curves for koaro developed from data from the Onekaka and Ryton rivers, where there were sufficient data.

**Table 4.5.1: Habitat statistics for 286 koaro present in the Ryton and Onekaka and at 153 of 832 locations in 9 rivers.**

| | Velocity (m/s) | | Depth (m) | | Substrate index | | Substrate (mm) | |
|---|---|---|---|---|---|---|---|---|
| | 9 rivers | Ryton, Onekaka | 9 rivers | Ryton, Onekaka | 9 rivers | Ryton, Onekaka | 9 rivers | Ryton, Onekaka |
| Minimum | 0.00 | 0.00 | 0.04 | 0.04 | 4.3 | 4.9 | 16 | 24 |
| Maximum | 1.42 | 1.42 | 0.49 | 0.42 | 7 | 6.6 | 272 | 247 |
| Average (SD) | 0.64 (0.30) | 0.70 (0.29) | 0.20 (0.08) | 0.21 (0.08) | 5.6 (0.4) | 5.7 (0.37) | 81 (31) | 85 (31) |

Koaro were found in velocities and depths that were similar to those used by torrentfish. Preferred depths were 0.1–0.4 m in velocities exceeding 0.5 m/s (Fig. 4.5.1). Most (77%) koaro were found in velocities of 0.4–1 m/s. Under these high velocity conditions, boulders and cobbles are the predominant substrate type. The velocity at which 81 mm substrate (critical velocity) just begins to move at a depth of 0.20 m is 1.61 m/s. A velocity of 1.6 m/s was used as the upper limit of habitat suitability. The multivariate analyses also showed that there was a tendency for preferred velocity to increase with depth, at least up to a depth of about 0.6 m.

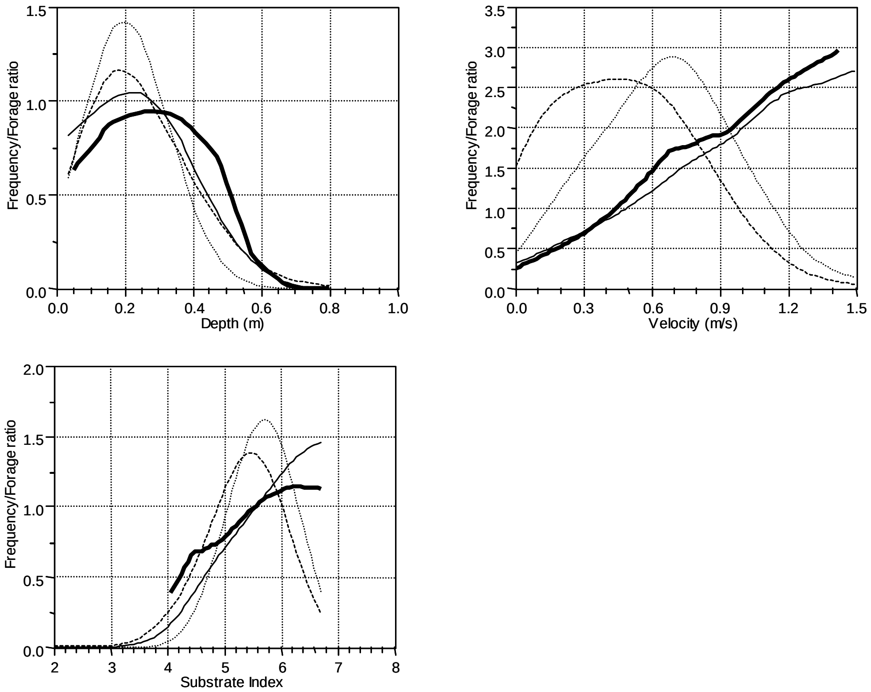


**Figure 4.5.1:** Kernel smoothed frequency of habitat availability (dashed line), use (dotted line), and the preference curves derived from all data (solid thin line) and by averaging preference relationships in each river (solid thick line) for koaro.

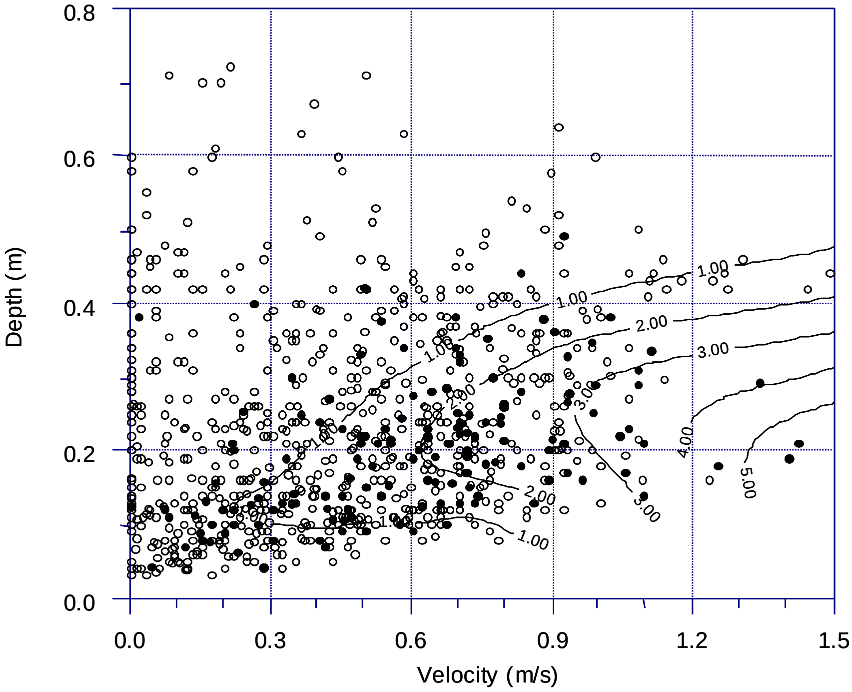


**Figure 4.5.2:** LOESS contours fitted to koaro densities and depth and velocity at all sampling locations. Locations containing koaro are shown shaded.

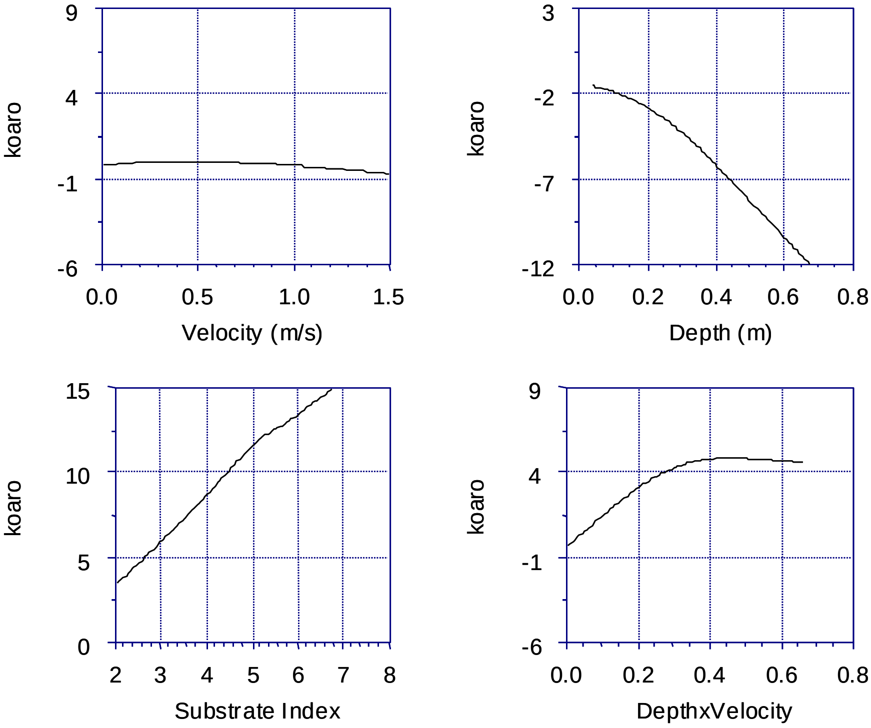


**Figure 4.5.3:** **Generalised additive logistic model of koaro probability of use using depth, velocity, substrate index and depth/velocity interaction to give 77% correct prediction at a cut level of 0.5. Depth/velocity interaction significant *P* < 0.001.**

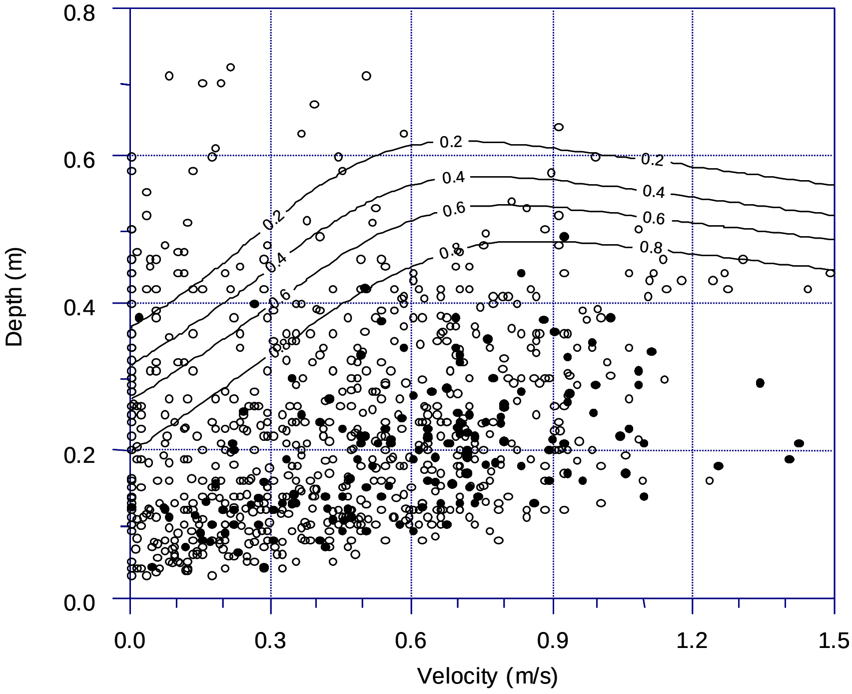


**Figure 4.5.4:** **Contour plot of GAM of probability of use using depth and velocity for a substrate index of 7 with points filled if koaro were present.**

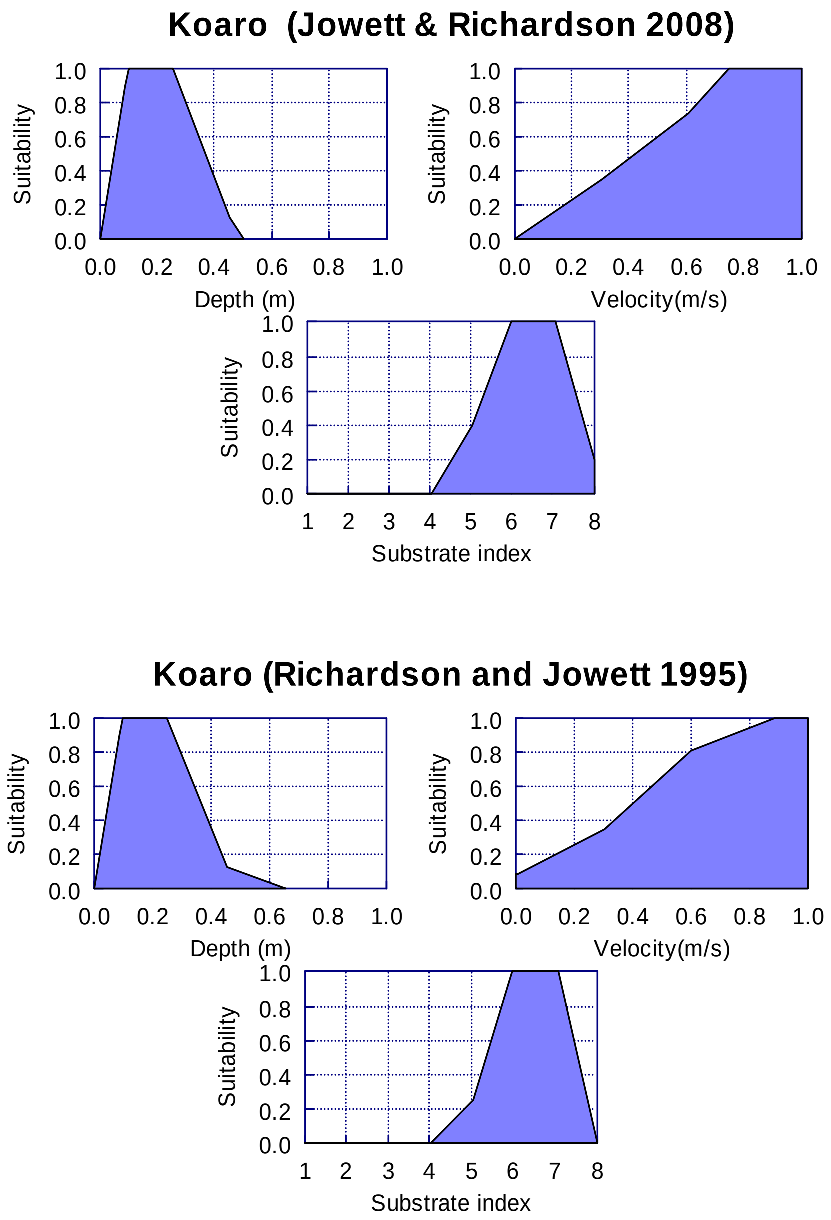


**Figure 4.5.5:** Habitat suitability curves for koaro derived from above analyses (top) compared with curves based on data from Richardson & Jowett (1995) (bottom).

## 4.6 Roundhead galaxias

The roundhead galaxias is a non-diadromous member of the Galaxiidae family that is found only in Otago, mainly in the Taieri and Clutha catchments. They occupy a diverse range of low gradient streams, from small weedy drains to braided cobble streams. The roundhead is tolerant of high water temperatures and low flows, surviving droughts by living in remnant pools that remain in ephemeral streams. The collection of data is described in Baker et al. (2003). Data for adult (≥50 mm length) and juvenile roundhead galaxias were analysed separately. Juvenile roundhead galaxias were often observed in large schools. The maximum density of these schools was limited to 10 fish per 10 $m^2$ to avoid undue bias on the analysis.

**Table 4.6.1: Habitat statistics for 2405 juvenile (<50mm length) roundhead galaxias present at 217 of 528 locations in 5 rivers.**

| | Velocity (m/s) | Depth (m) | Substrate index | Substrate size (mm) |
|---|---|---|---|---|
| Minimum | 0.00 | 0.02 | 2.5 | 2.0 |
| Maximum | 1.02 | 0.86 | 7.0 | 300 |
| Average (SD) | 0.03 (0.07) | 0.26 (0.14) | 3.7 (1.3) | 20 (36) |

Juvenile roundhead galaxias have a strong preference for low velocity and moderately deep water, which is usually found in small backwaters (Fig. 4.6.1), although this was not so obvious when data were averaged over all rivers. The substrate at juvenile locations was smaller in size than that of adults. The velocity at which 20 mm substrate (critical velocity) just begins to move at a depth of 0.26 m is 1.15 m/s.

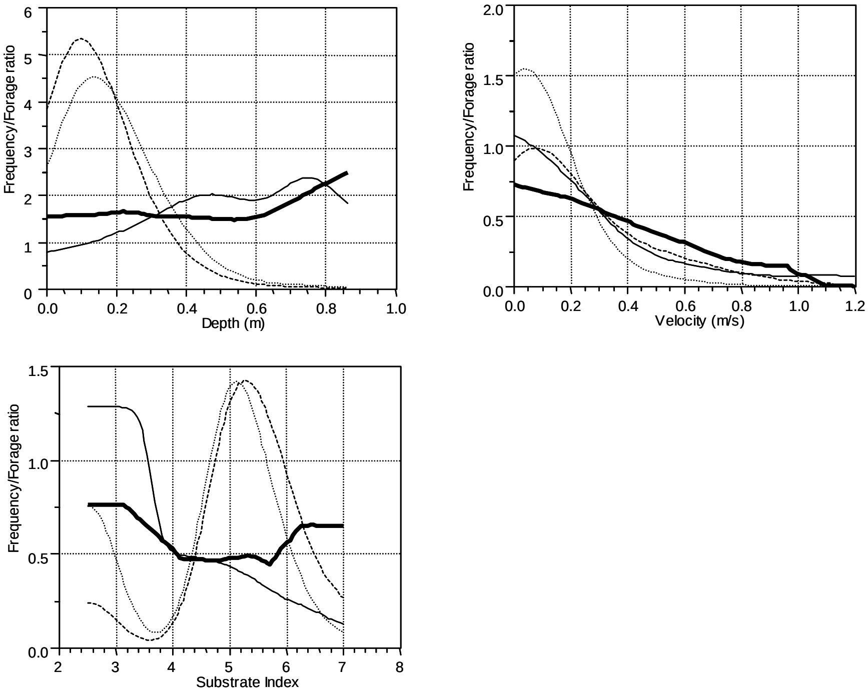


**Figure 4.6.1: Kernel smoothed frequency of habitat availability (dashed line), use (dotted line), and the preference curves derived from all data (solid thin line) and by averaging preference relationships in each river (solid thick line) for juvenile roundhead galaxias.**

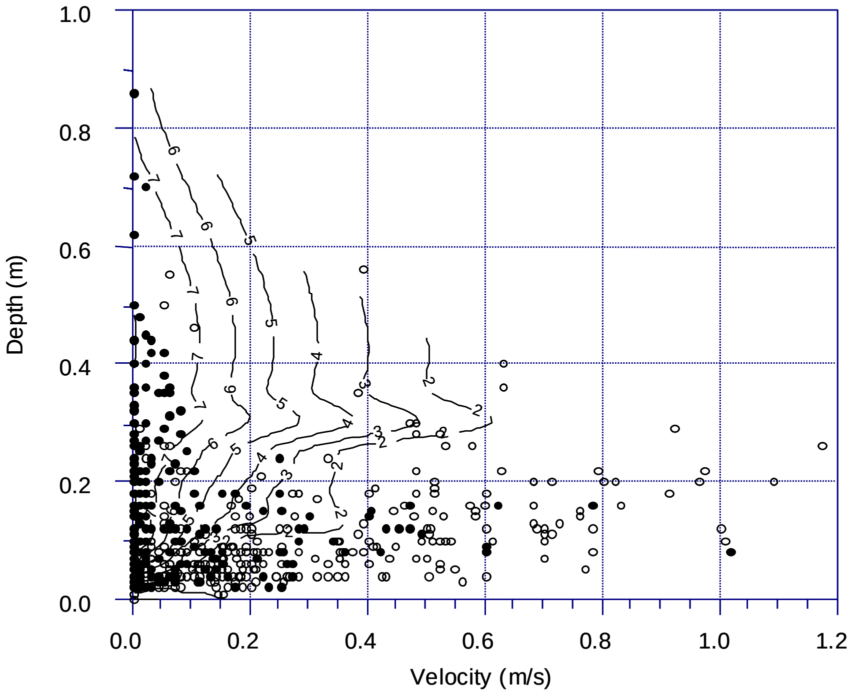


**Figure 4.6.2:** **LOESS contours fitted to juvenile roundhead galaxias densities and depth and velocity at all sampling locations. Locations containing juvenile roundhead galaxias are shown shaded.**

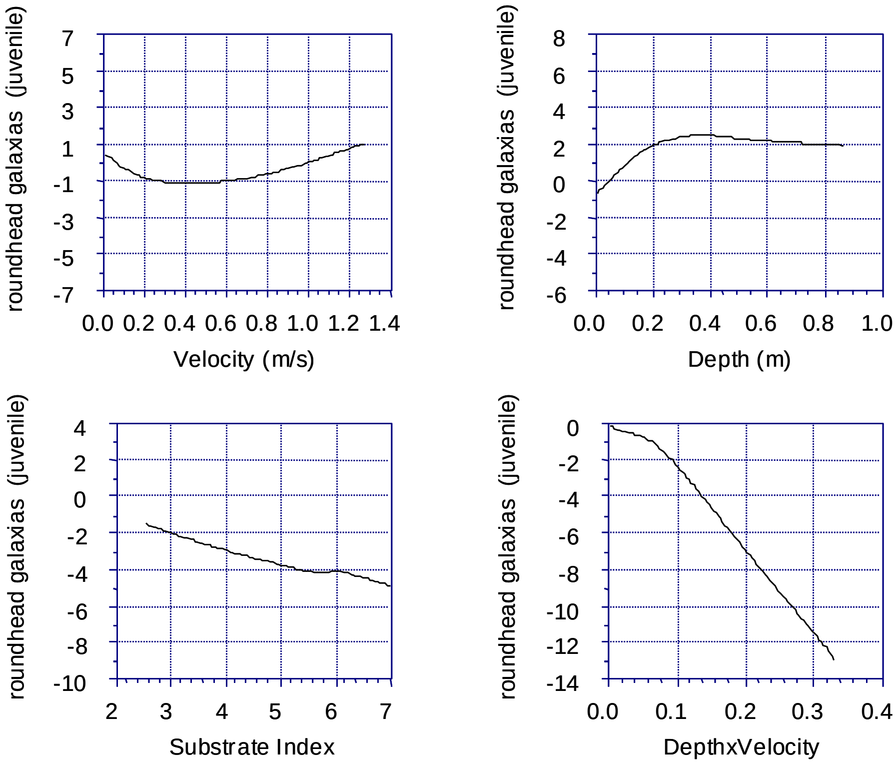


**Figure 4.6.3:** **Generalised additive logistic model of juvenile roundhead galaxias probability of use using depth, velocity, substrate index, and depth/velocity interaction to give 87% correct prediction at a cut level of 0.7. The depth/velocity interaction term was significant (*P* < 0.001).**

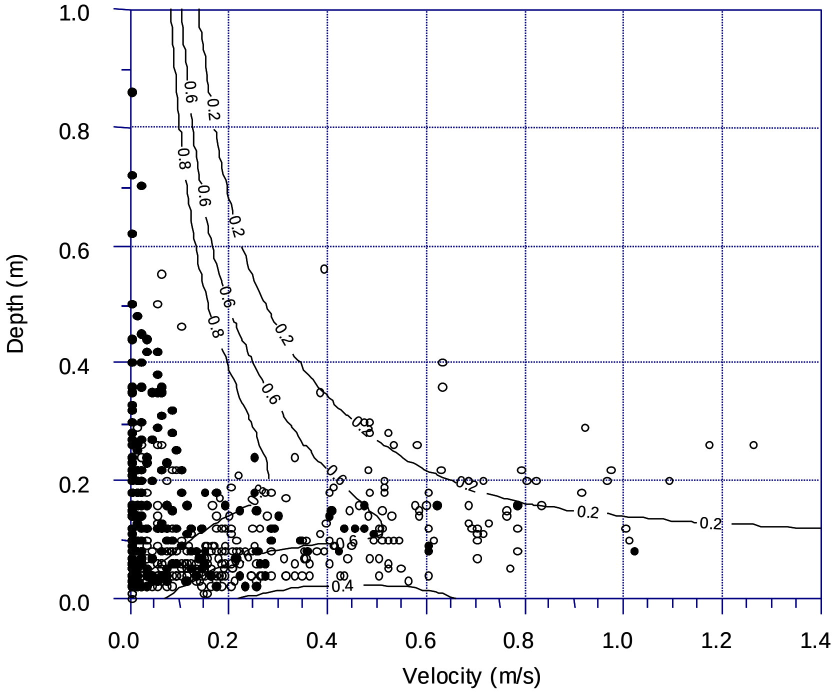


**Figure 4.6.4:** **Contour plot of GAM of probability of use using depth and velocity for a substrate index of 5 with points filled if juvenile roundhead galaxias were present.**

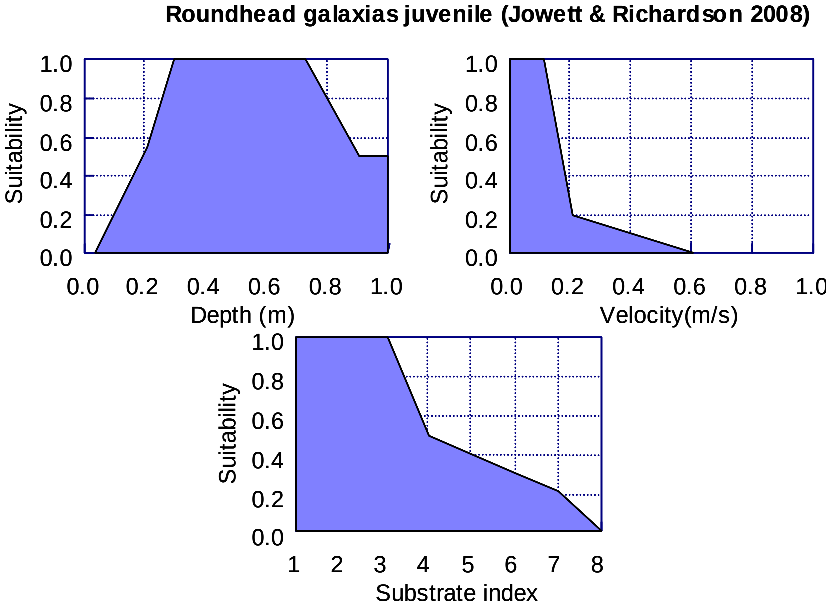


**Figure 4.6.5:** **Habitat suitability curves for juvenile roundhead galaxias derived from above analyses.**

**Table 4.6.2: Habitat statistics for 358 adult (≥50 mm length) roundhead galaxias present at 132 of 528 locations in 5 rivers.**

| | Velocity (m/s) | Depth (m) | Substrate index | Substrate size (mm) |
|---|---|---|---|---|
| Minimum | 0.00 | 0.00 | 5.0 | 20.5 |
| Maximum | 1.17 | 0.86 | 7.0 | 300 |
| Average (SD) | 0.17 (0.16) | 0.11 (0.10) | 6.0 (0.8) | 158 (114) |

Adult roundhead galaxias preferred shallow water and low to moderate velocities (Fig. 4.6.1), but tolerated a wide range, with 97.5% of fish found in velocities of 0 to 0.8 m/s. Their substrate preference was for cobble-sized particles that they utilize for cover. The velocity at which 158 mm substrate (critical velocity) just begins to move at a depth of 0.11 m is 1.51 m/s. Night observations of adult roundhead galaxias indicated that they occupy the same run habitat day and night (Baker et al. 2003).

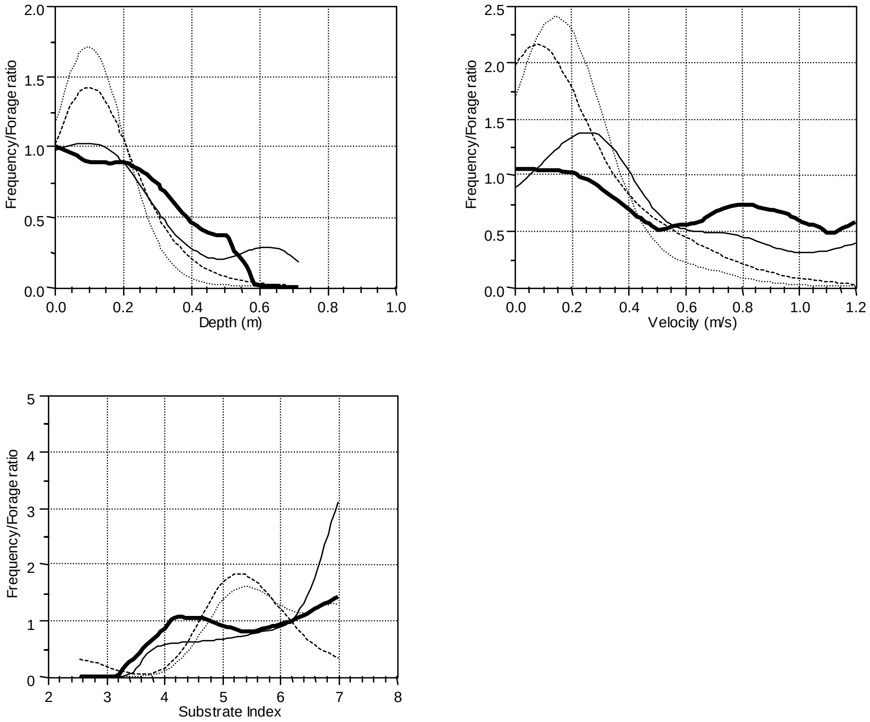


**Figure 4.6.6: Kernel smoothed frequency of habitat availability (dashed line), use (dotted line), and the preference curves derived from all data (solid thin line) and by averaging preference relationships in each river (solid thick line) for adult roundhead galaxias.**

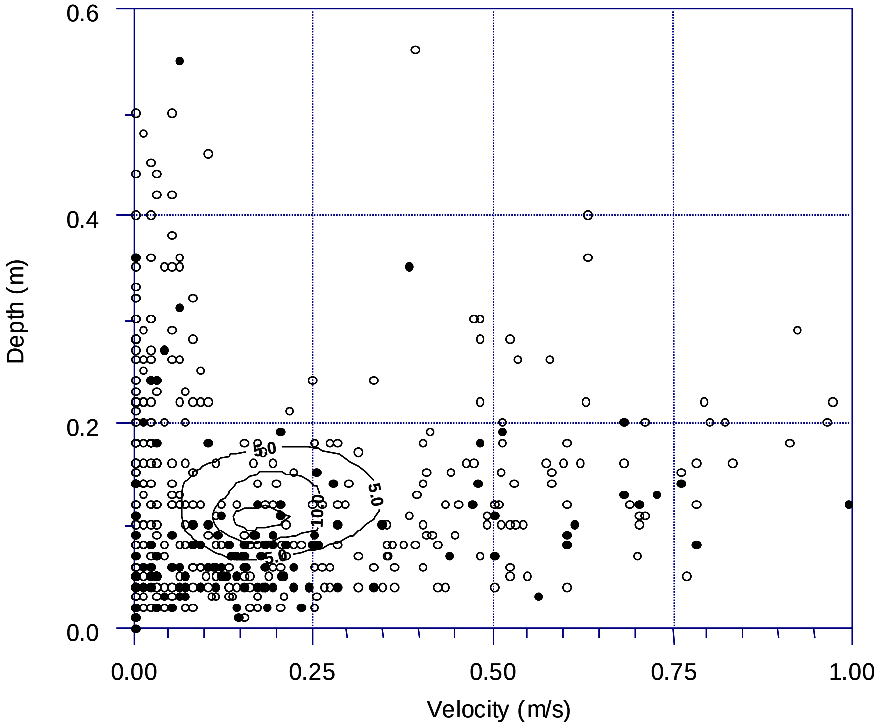


**Figure 4.6.7:** LOESS contours fitted to adult roundhead galaxias densities and depth and velocity at all sampling locations. Locations containing adult roundhead galaxias are shown shaded.

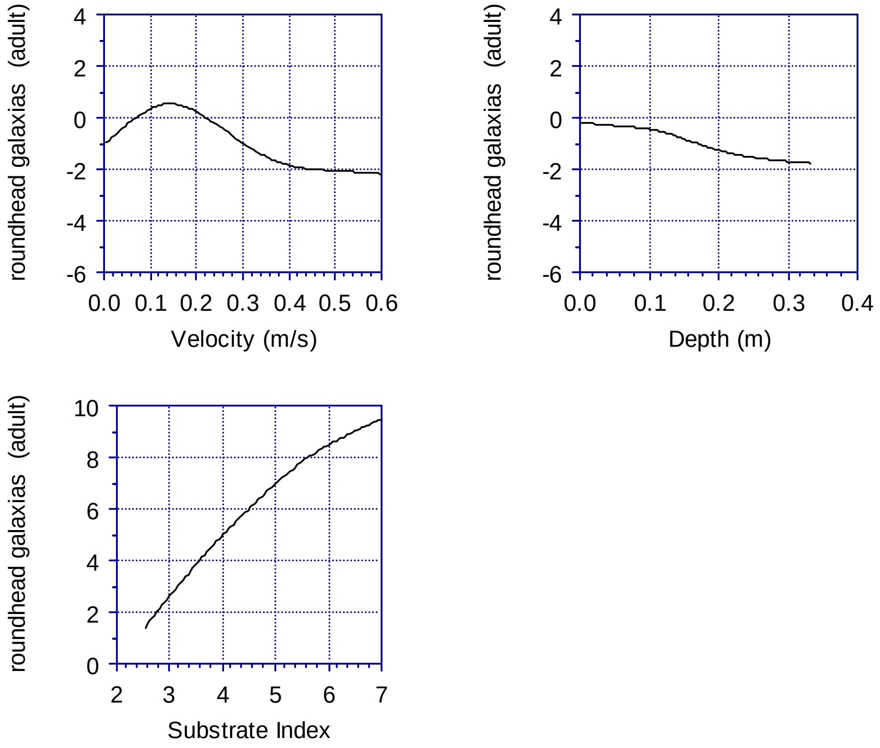


**Figure 4.6.8:** Generalised additive logistic model of adult roundhead galaxias probability of use using depth, velocity and substrate index to give 84% correct prediction at a cut level of 0.7.

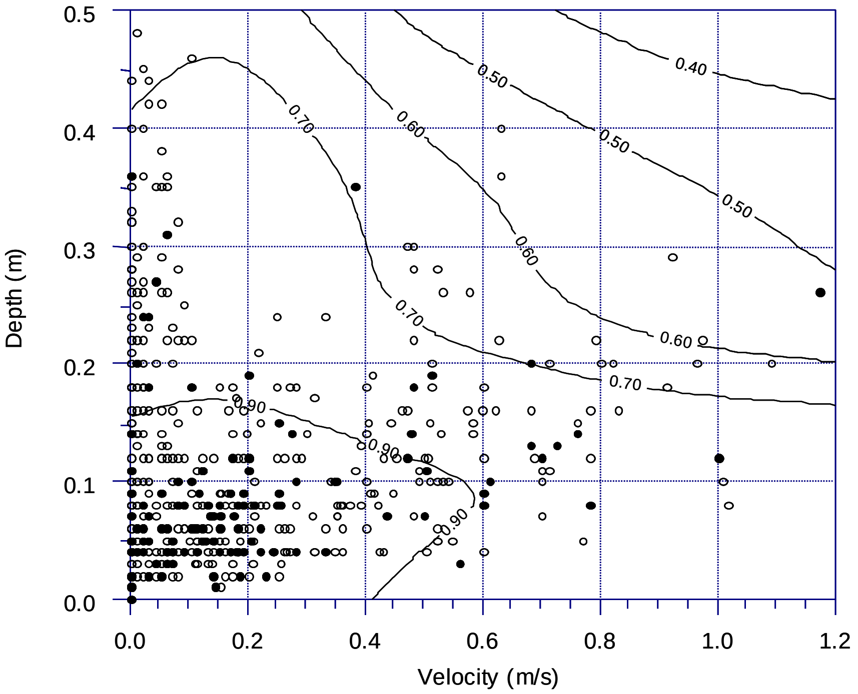
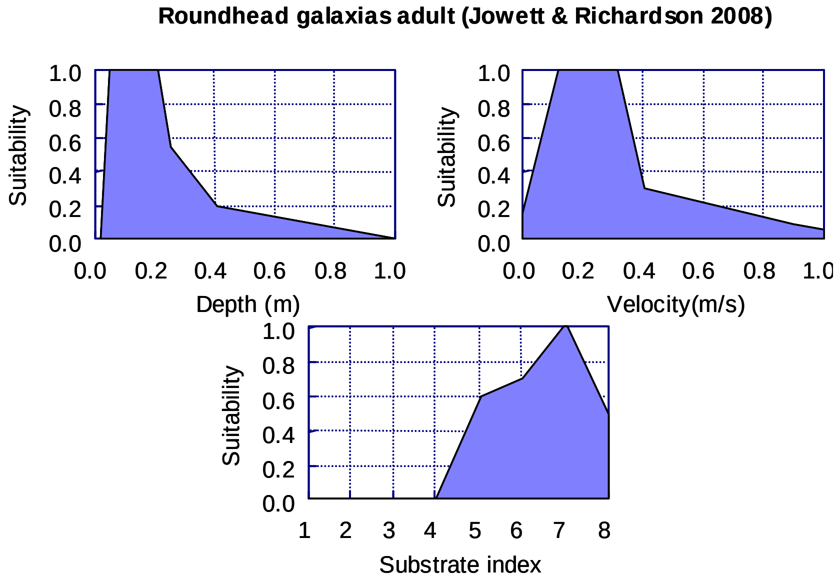
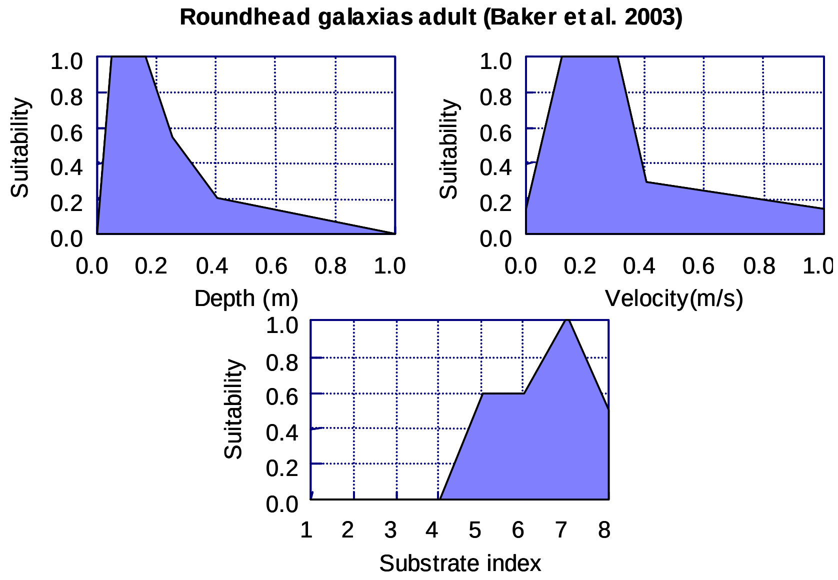


**Figure 4.6.9:** **Contour plot of GAM of probability of use using depth and velocity for a substrate index of 5 with points filled if adult roundhead galaxias were present.**



Roundhead galaxias adult (Jowett & Richardson 2008)



Roundhead galaxias adult (Baker et al. 2003)

**Figure 4.6.10:** **Habitat suitability curves for adult roundhead galaxias derived from above analyses (top) compared with curves based on data from Baker et al. (2003) (bottom).**

## 4.7 Lowland longjaw galaxias

The lowland longjaw galaxias was first described from specimens caught in the Kauru River, a tributary of the Kakanui River in North Otago. Previously, these longjaw populations were thought to be disjunct, lowland populations of *Galaxias prognathus*, the upland longjaw. However, DNA sequencing studies at Otago University showed that the Kauru River fish were highly divergent from the other longjaw galaxias, and this prompted a closer examination of the Kauru fish, revealing a distinct species. Recent surveys have shown that this fish also occurs in parts of the upper Waitaki catchment.

Data for adult (≥50 mm in length) and juvenile fish were analysed separately. Adult fish occur in the margins of riffles and runs, but in daylight are usually hidden under rocks and stones up to large cobble size. They avoided both deep and swift habitats.

Juvenile longjaw galaxias, who lack the distinctly protruding jaw that adults develop, are readily visible from October to January in backwaters and side braids often associated with groundwater up-wellings. The habitat utilized in these areas by the pelagic juveniles is relatively deep, with low velocity and fine substrate.

**Table 4.7.1: Habitat statistics for 80 juvenile (<50 mm) lowland longjaw galaxias caught at 19 out of 469 locations in 2 rivers.**

| | Velocity (m/s) | Depth (m) | Substrate index | Substrate size (mm) |
|---|---|---|---|---|
| Minimum | 0.01 | 0.06 | 3.0 | 2.0 |
| Maximum | 0.48 | 0.32 | 5.5 | 90 |
| Average (SD) | 0.06 (0.07) | 0.21 (0.05) | 4.0 (1.0) | 14 (18) |

Juvenile lowland longjaw galaxias showed a clear preference for water depths of 0.2–0.3 m (Fig. 4.7.1), which is relatively deep for the size of streams in which they are found. As with most juvenile galaxiids, preferred water velocities were low (<0.1 m/s) and fine substrate was the dominant substrate in this pool habitat. The velocity at which 14 mm substrate (critical velocity) just begins to move at a depth of 0.21 m is 0.96 m/s and juvenile velocity preferences were less than this.

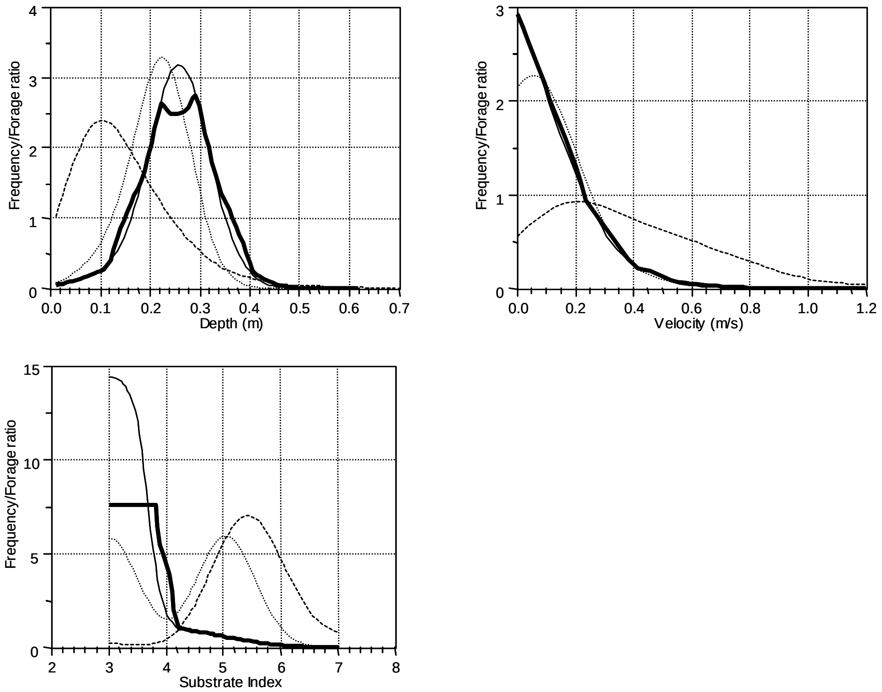


**Figure 4.7.1:** Kernel smoothed frequency of habitat availability (dashed line), use (dotted line), and the preference curves derived from all data (solid thin line) and by averaging preference relationships in each river (solid thick line) for juvenile lowland longjaw galaxias.

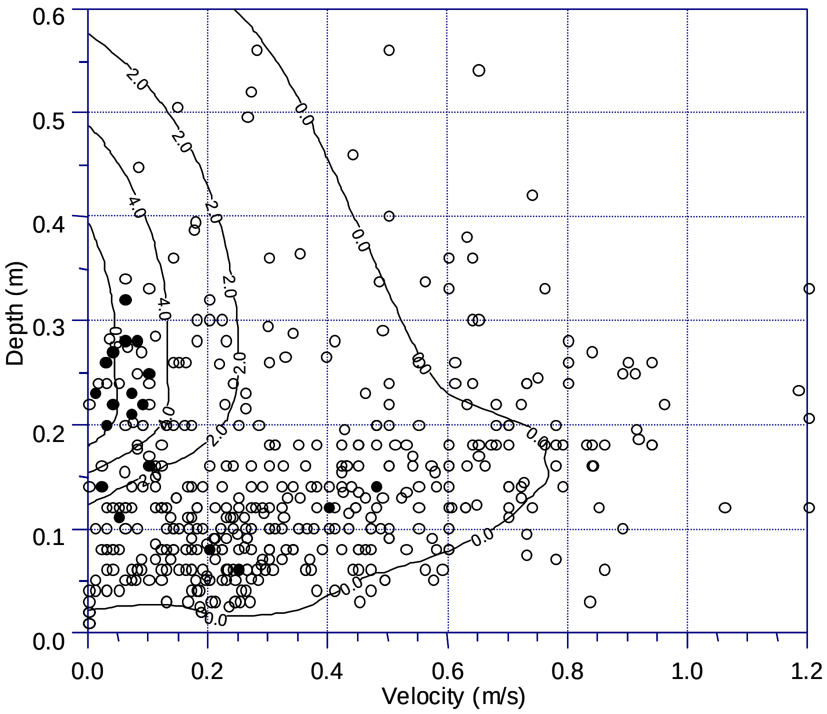


**Figure 4.7.2:** LOESS contours fitted to juvenile lowland longjaw galaxias densities and depth and velocity at all sampling locations. Locations containing lowland longjaw galaxias are shown shaded.

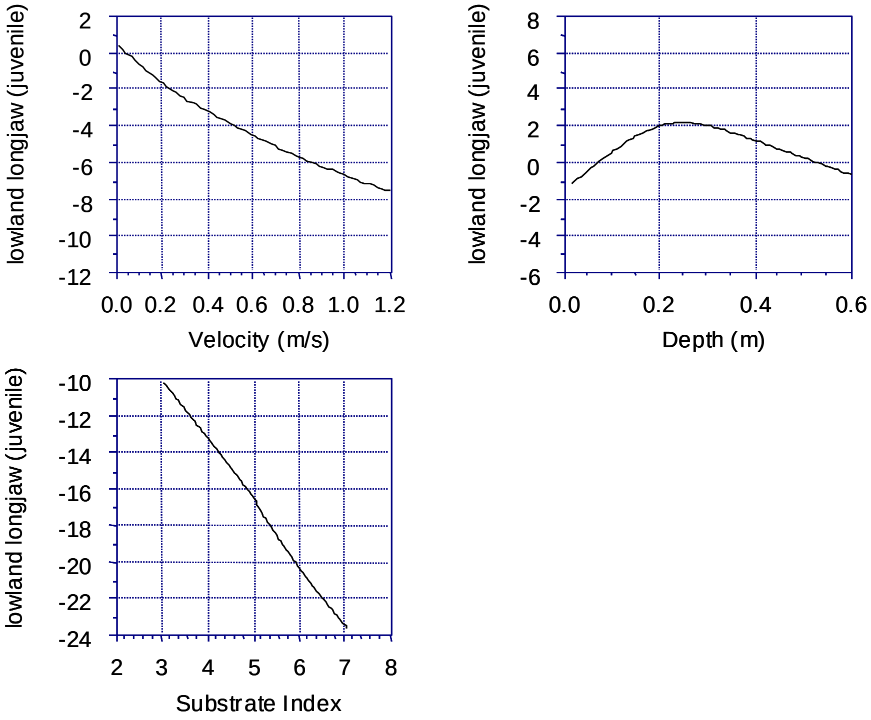


**Figure 4.7.3:** Generalised additive logistic model of juvenile lowland longjaw galaxias probability of use using depth, velocity and substrate index to give 77% correct prediction at a cut level of 0.5.

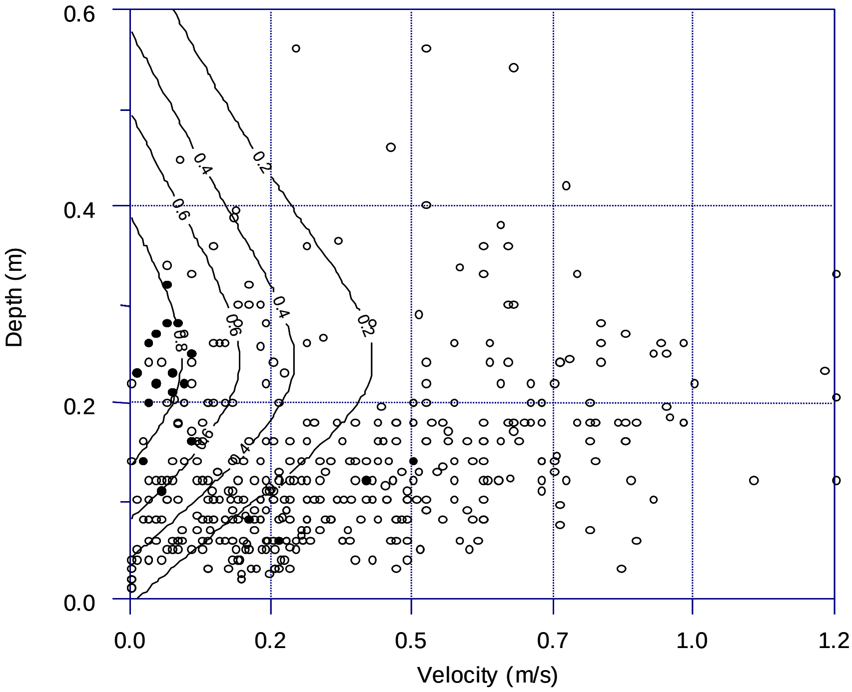


**Figure 4.7.4:** Contour plot of GAM of probability of use using depth and velocity for a substrate index of 5 with points filled if juvenile lowland longjaw galaxias were present.

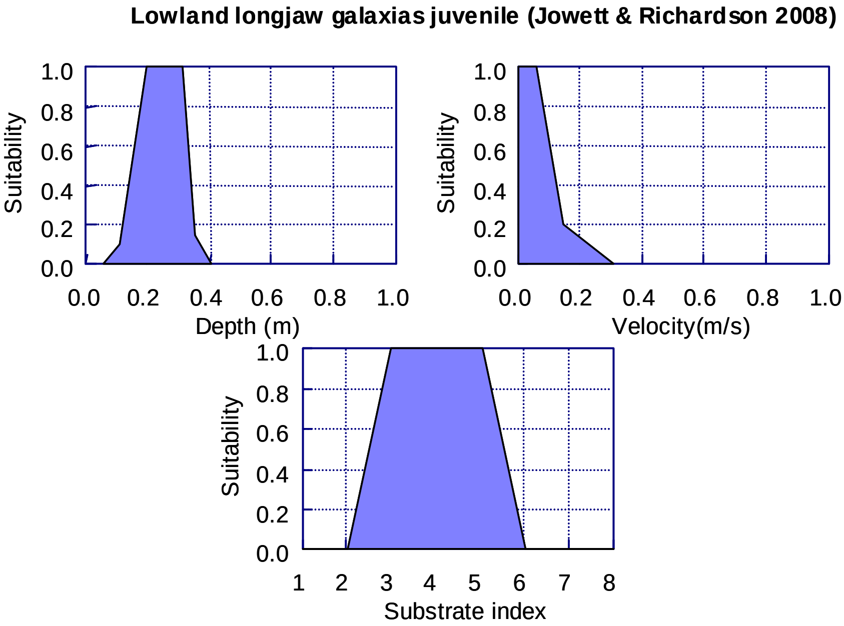


**Figure 4.7.5:** **Habitat suitability curves for juvenile lowland longjaw galaxias derived from above analyses.**

**Table 4.7.2:** **Habitat statistics for 109 adult (≥50 mm) lowland longjaw galaxias caught at 83 out of 399 locations in the Kauru River.**

| | Velocity (m/s) | Depth (m) | Substrate index | Substrate size (mm) |
|---|---|---|---|---|
| Minimum | 0.00 | 0.01 | 5.0 | 20.5 |
| Maximum | 0.90 | 0.33 | 7.0 | 300 |
| Average (SD) | 0.31 (0.21) | 0.11 (0.06) | 5.5 (0.4) | 84 (57) |

Adult longjaw galaxias preferred shallow water and moderate (0.2–0.5 m/s) velocities (Fig. 4.7.1). The velocity at which 84 mm substrate (critical velocity) just begins to move at a depth of 0.11 m is 1.46 m/s. This is less than the highest velocity (0.9 m/s) in which adult longjaw have been found and 0.9 m/s was taken as the upper limit of velocity preference.

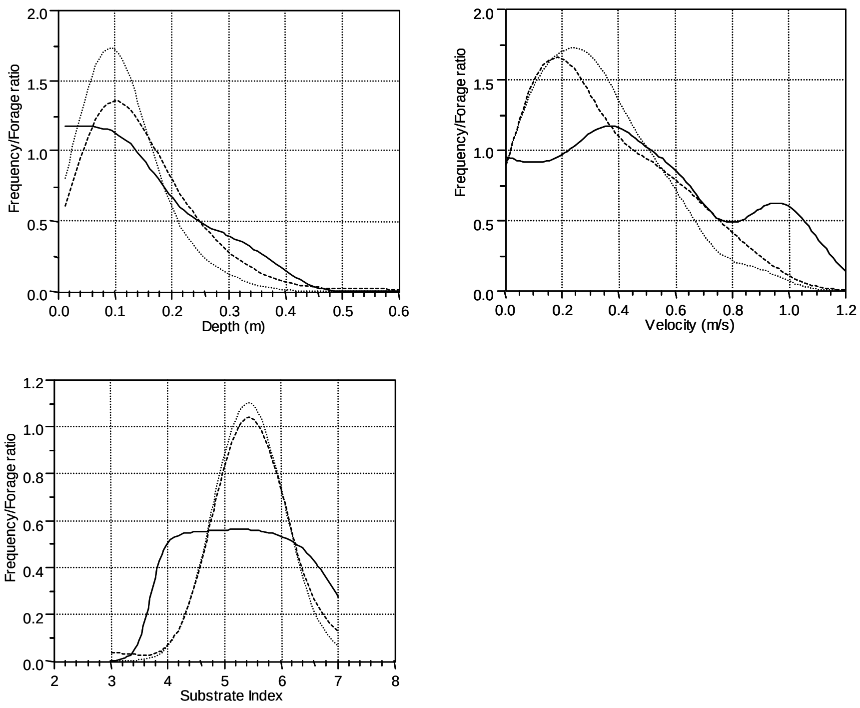


Figure 4.7.6: **Kernel smoothed frequency of habitat availability (dashed line), use (dotted line), and the preference curve (solid line) derived from the Kauru River for adult lowland longjaw galaxias.**

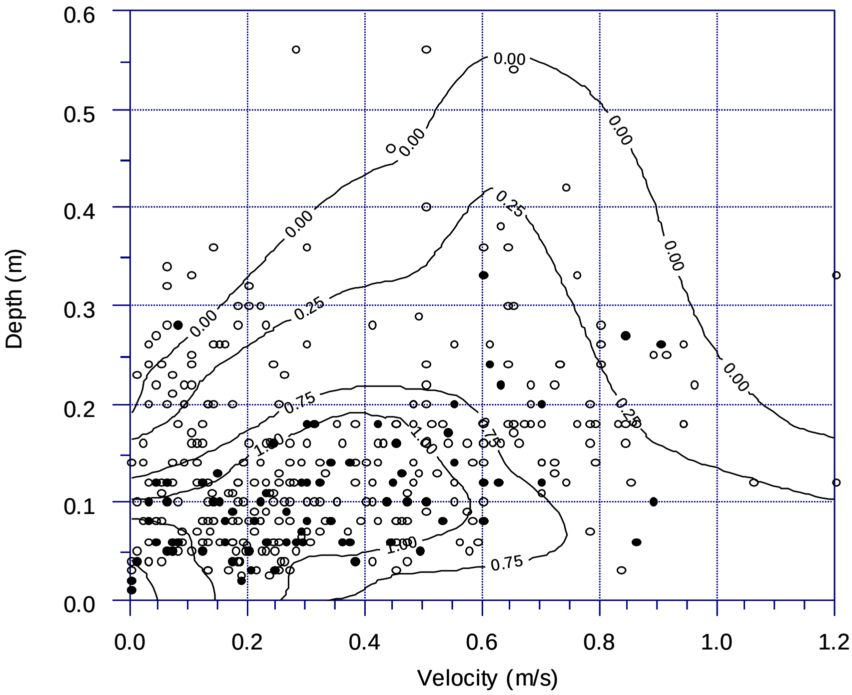


Figure 4.7.7: **LOESS contours fitted to adult lowland longjaw galaxias densities and depth and velocity at all sampling locations. Locations containing adult lowland longjaw galaxias are shown shaded.**

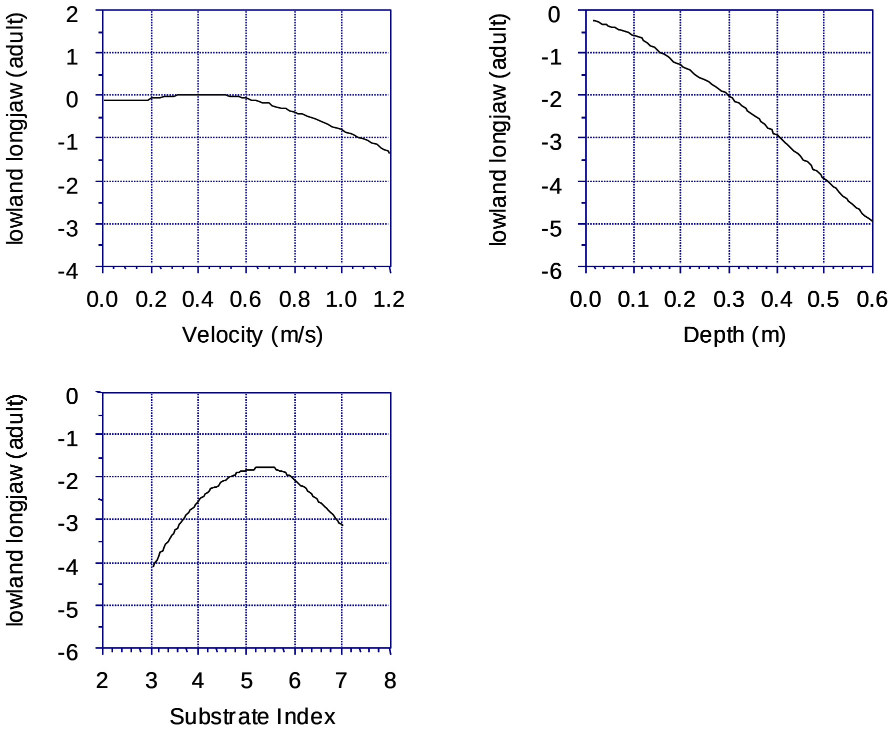


**Figure 4.7.8:** **Generalised additive logistic model of adult lowland longjaw galaxias probability of use using depth, velocity and substrate index to give 77% correct prediction at a cut level of 0.5.**

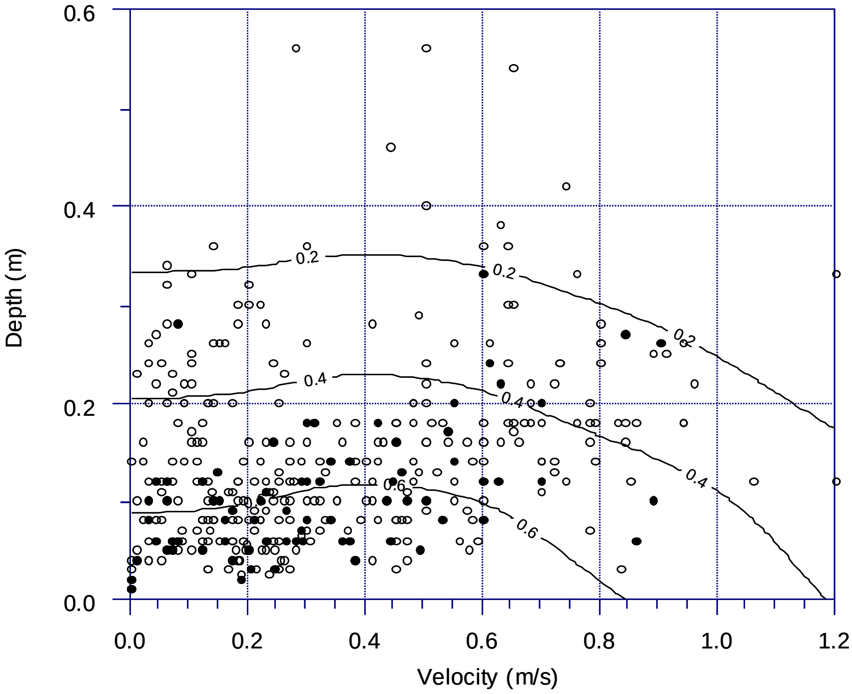
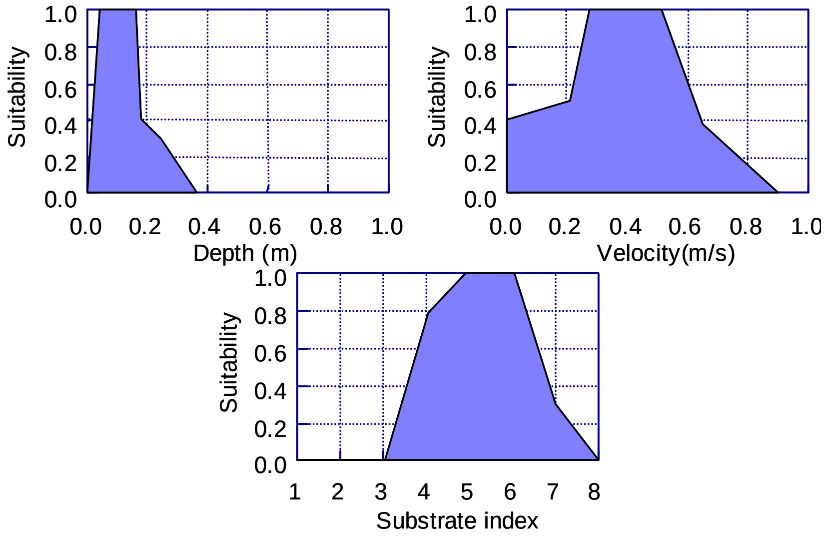


**Figure 4.7.9:** **Contour plot of GAM of probability of use using depth and velocity for a substrate index of 5 with points filled if adult lowland longjaw galaxias were present.**

Lowland longjaw galaxias adult (Jowett & Richardson 2008)



Lowland longjaw galaxias adult (Baker et al. 2003)

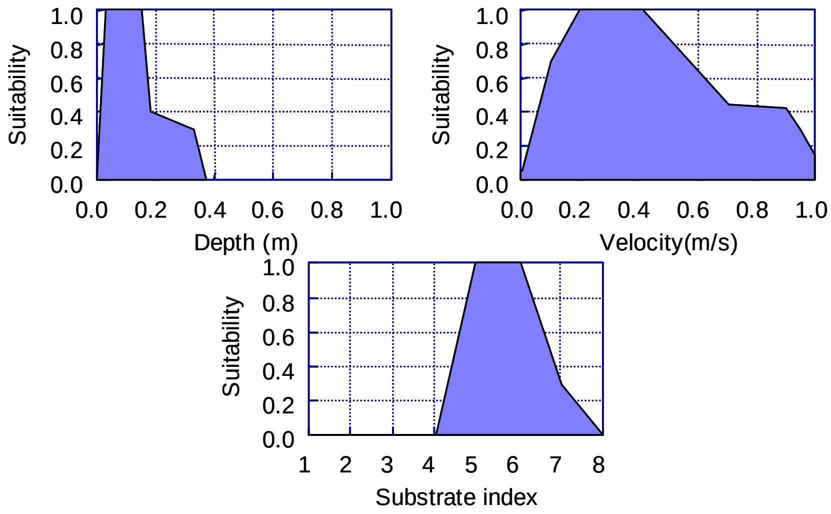


**Figure 4.7.10:** **Habitat suitability curves for adult lowland longjaw galaxias derived from above analyses (top) compared with curves based on data from Baker et al. (2003) (bottom).**

## 4.8 Flathead galaxias

The flathead galaxias is another of the recently discovered non-diadromous Galaxiidae that are only found in Otago. At present, this species of flathead galaxias (there could be up to three others) is known mainly from streams in the Taieri catchment, but also the Shag, Waikouaiti and some coastal streams south of the Taieri. The distribution of the flathead galaxias is quite fragmented, possibly a consequence of impacts from the introduced brown trout. The preferred habitat for this species is cobble/boulder streams in tussock grasslands, and most populations occur above large waterfalls. Data for adult and juvenile flathead galaxias were analysed separately.

**Table 4.8.1: Habitat statistics for 41 juvenile (<50 mm length) flathead galaxias caught at 11 out of 233 locations in 4 rivers.**

| | Velocity (m/s) | Depth (m) | Substrate index | Substrate size (mm) |
|---|---|---|---|---|
| Minimum | 0.00 | 0.05 | 5.0 | 20.5 |
| Maximum | 0.27 | 0.36 | 8.0 | 300 |
| Average (SD) | 0.06 (0.08) | 0.18 (0.12) | 6.3 (1.1) | 175 (117) |

As with most juvenile galaxiids, juvenile (<50 mm) flatheads preferred very low velocity water, depths >0.2 m, and fine gravel substrate (Fig. 4.8.1), although they were found most commonly with cobble/gravel substrate (Table 4.8.1). The velocity at which 175 mm substrate (critical velocity) just begins to move at a depth of 0.18 m is 1.63 m/s, and juvenile velocity preferences were well below this.

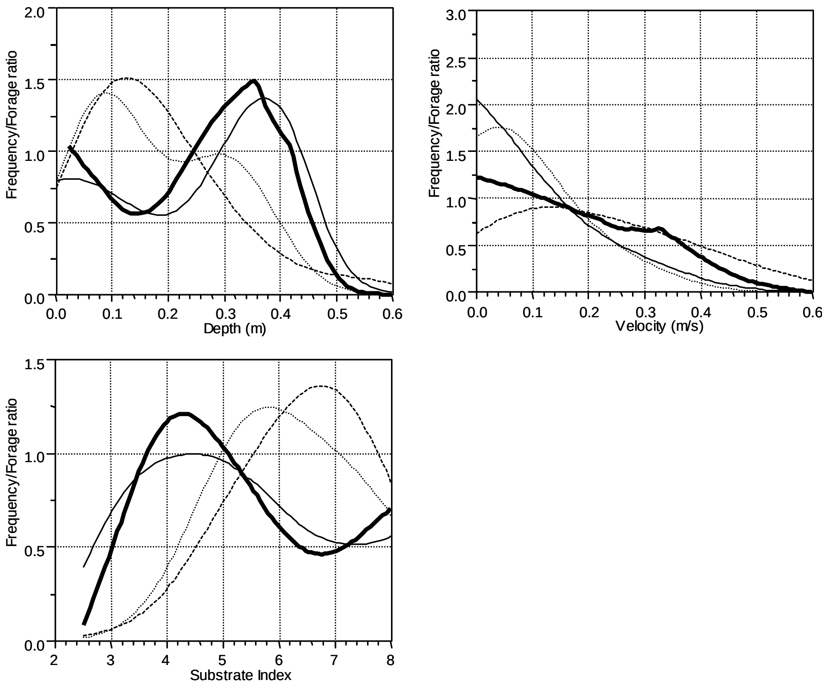


**Figure 4.8.1: Kernel smoothed frequency of habitat availability (dashed line), use (dotted line), and the preference curves derived from all data (solid thin line) and by averaging preference relationships in each river (solid thick line) for juvenile flathead galaxias.**

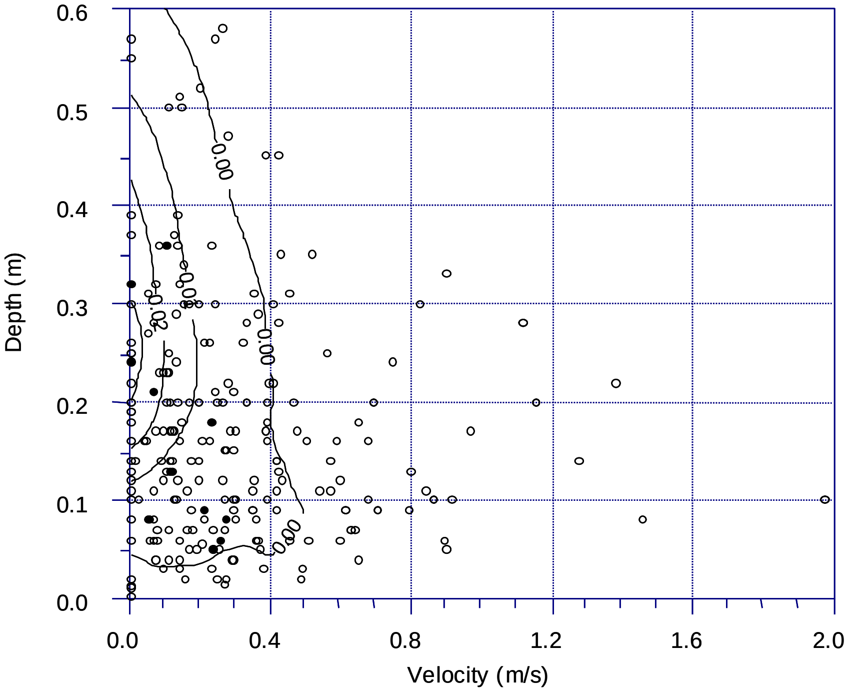


**Figure 4.8.2:** **LOESS contours fitted to juvenile flathead galaxias densities and depth and velocity at all sampling locations. Locations containing juvenile flathead galaxias are shown shaded.**

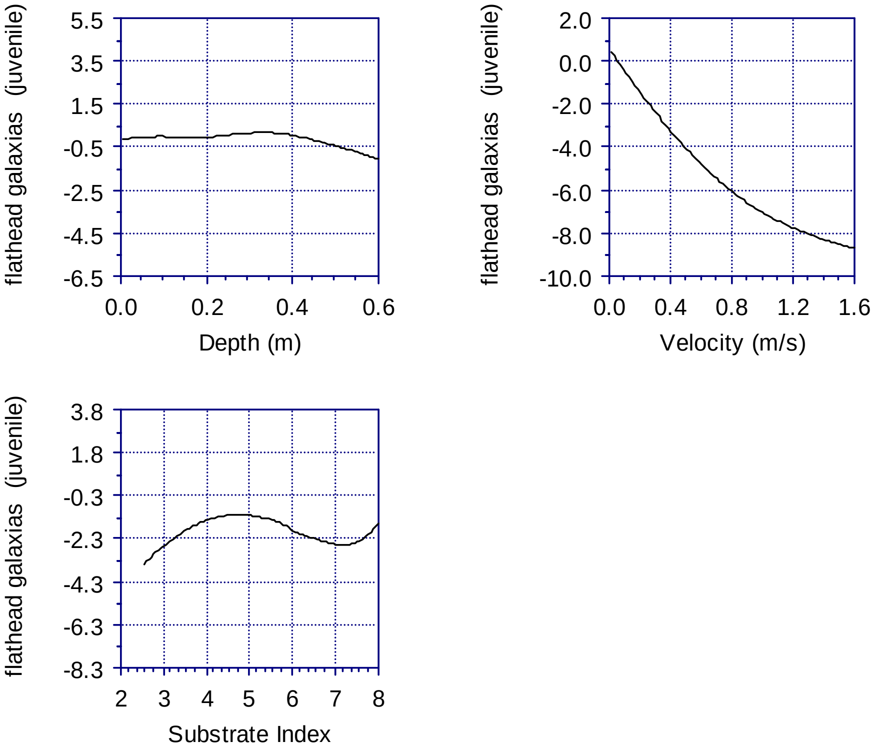


**Figure 4.8.3:** **Generalised additive logistic model of juvenile flathead galaxias probability of use using depth, velocity and substrate index to give 87% correct prediction at a cut level of 0.6.**

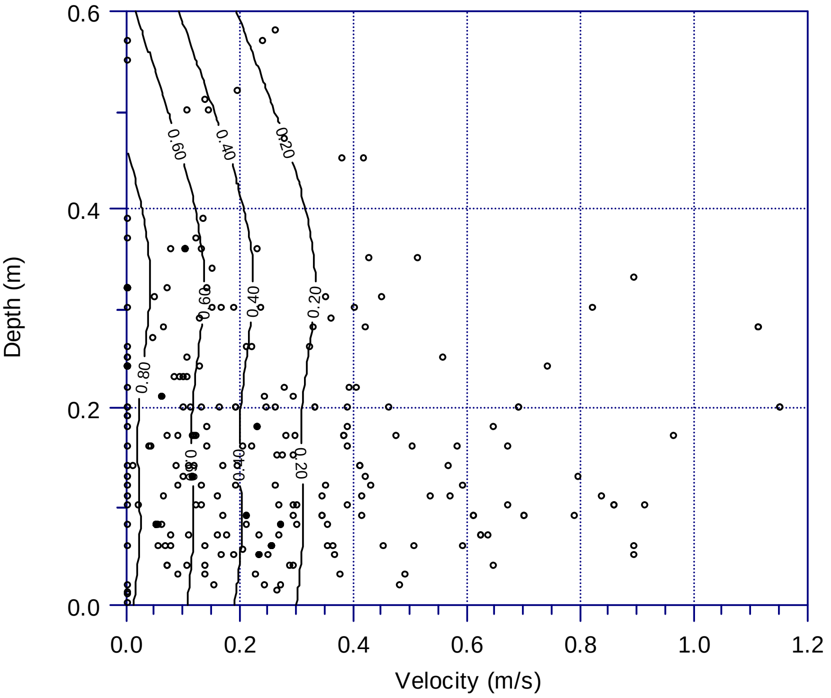


**Figure 4.8.4:** **Contour plot of GAM of probability of use using depth and velocity for a substrate index of 4 with points filled if juvenile flathead galaxias were present.**

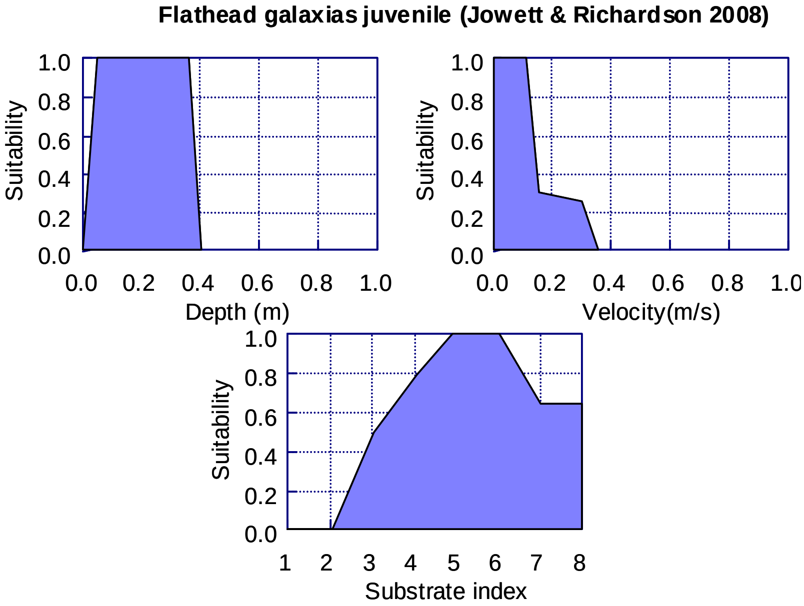

Flathead galaxias juvenile (Jowett & Richardson 2008)

**Figure 4.8.5:** **Habitat suitability curves for juvenile flathead galaxias derived from above analyses.**

**Table 4.8.2: Habitat statistics for 160 adult (≥50 mm length) flathead galaxias caught at 91 out of 233 locations in 4 rivers.**

|  | Velocity (m/s) | Depth (m) | Substrate index | Substrate size (mm) |
|---|---|---|---|---|
| Minimum | 0.00 | 0.00 | 5.0 | 20.5 |
| Maximum | 1.45 | 0.57 | 8.0 | 300 |
| Average (SD) | 0.39 (0.38) | 0.13 (0.10) | 6.5 (0.9) | 225 (113) |

Adult (≥50 mm) flathead galaxias preferred large substrate (Fig. 4.8.5); the average substrate size of 225 mm was the largest of all the species analysed (Table 4.1.2). A wide range of velocities appeared to be suitable for adult flatheads, although they were most commonly found in a depth of about 0.12 m and velocity of 0.3 m. Although the preference curve (Fig. 4.8.6) shows an increasing preference for velocities over 0.6 m/s, only 15% of adult flathead galaxias were found at higher velocities and only 4% were in velocities higher than 0.8 m/s. The velocity at which 225 mm substrate (critical velocity) just begins to move at a depth of 0.13 m is 1.51 m/s. The maximum suitable velocity was taken to be 1.5 m/s.

Figure 4.8.6 shows that there were few measurements at velocities exceeding 0.7 m/s and that flathead galaxias were often present at these velocities. The derivation of habitat preference excluded data collected at velocities greater than 0.7 m/s because of the distortion it introduced, but the preference for high velocities was recognised in the suitability curve (Fig. 4.8.10).

The analyses presented here are based on measurements carried out in areas of streams with and without trout. Baker et al. (2003) compared habitat use by adult flathead galaxias in areas with and without brown trout and suggested that the absence of trout might allow flathead galaxias to utilise a greater range of habitats.

**Kernel smoothed frequency of habitat availability (dashed line), use (dotted line), and the preference curves derived from all data (solid thin line) and by averaging preference relationships in each river (solid thick line) for adult flathead galaxias.**

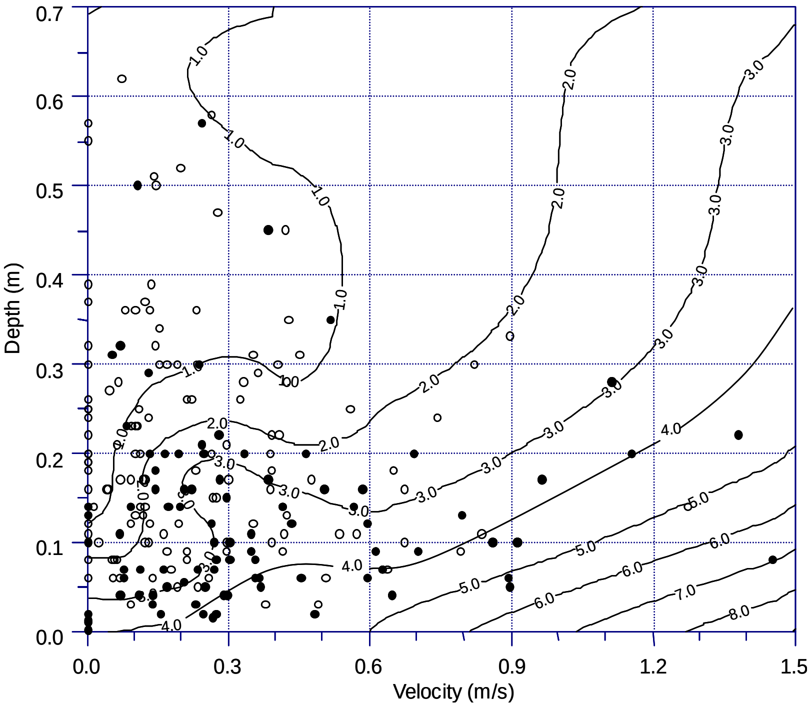


**Figure 4.8.7: LOESS contours fitted to adult flathead galaxias densities and depth and velocity at all sampling locations. Locations containing adult flathead galaxias are shown shaded.**

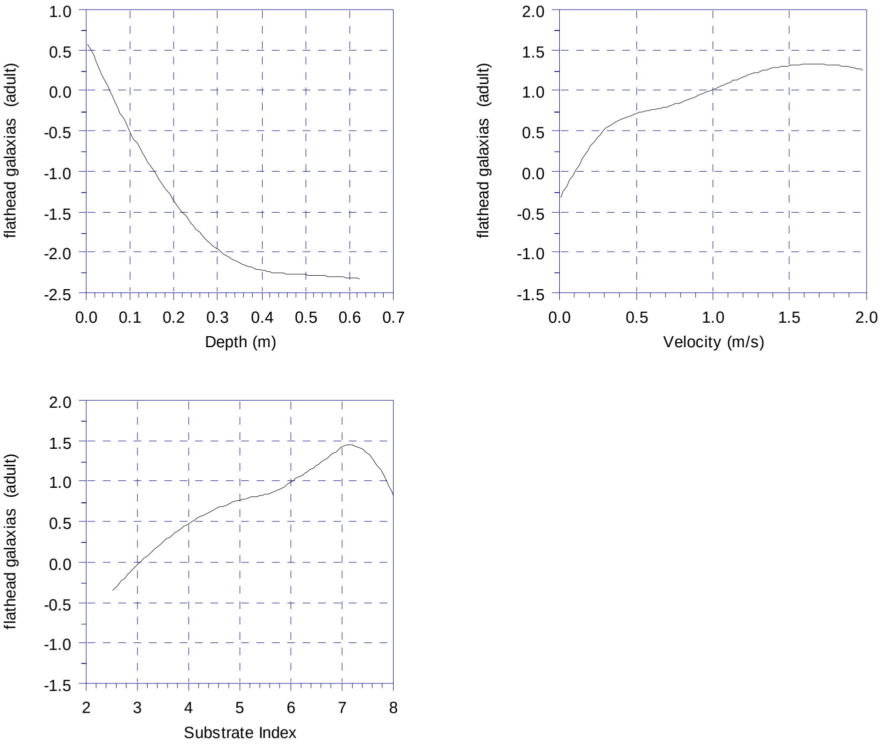


**Figure 4.8.8:** Generalised additive logistic model of adult flathead galaxias probability of use using depth, velocity and substrate index to give 81% correct prediction at a cut level of 0.7.

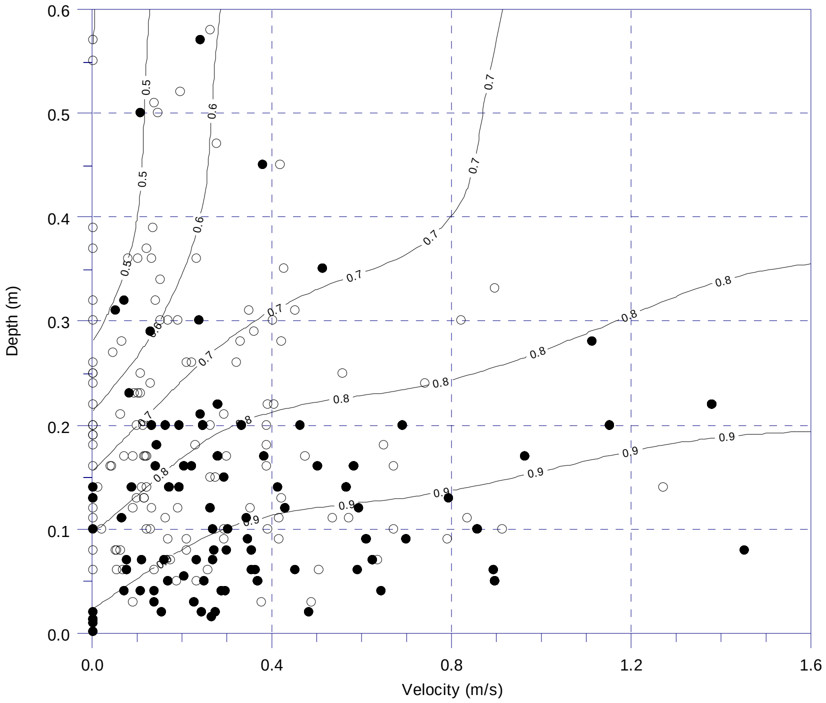
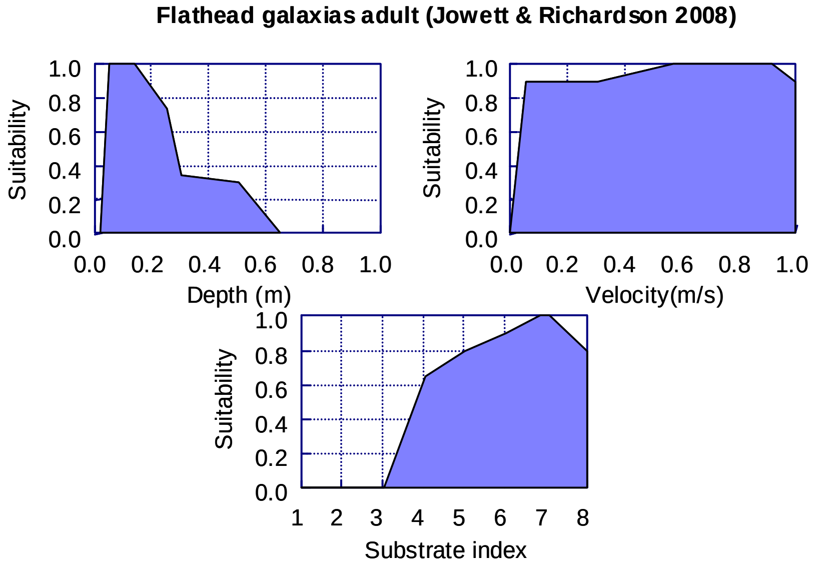
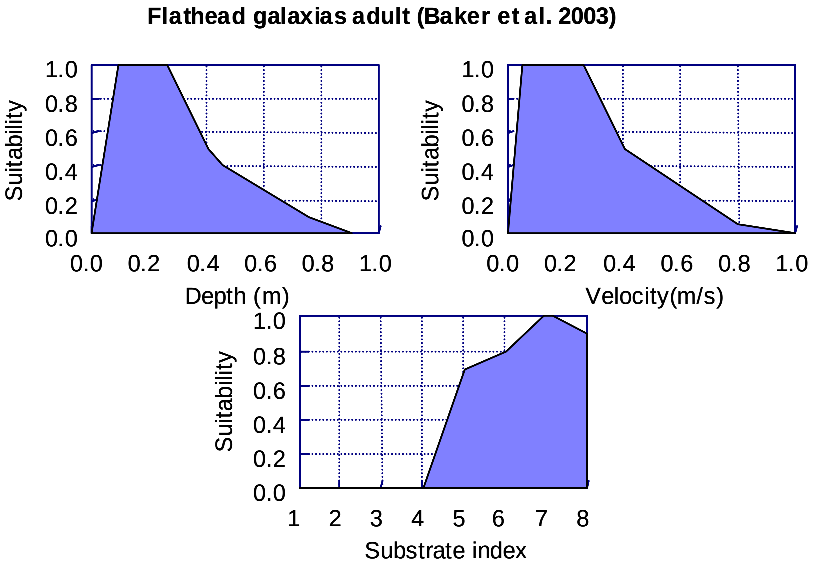


**Figure 4.8.9:** **Contour plot of GAM of probability of use using depth and velocity for a substrate index of 7 with points filled if adult flathead galaxias were present.**



Flathead galaxias adult (Jowett & Richardson 2008)



Flathead galaxias adult (Baker et al. 2003)

**Figure 4.8.10:** **Habitat suitability curves for adult flathead galaxias derived from above analyses (top) compared with curves based on data from Baker et al. (2003) (bottom).**

## 4.9 Dwarf galaxias

Of the non-diadromous members of the Galaxiidae family, the dwarf galaxias has the widest distribution, although populations are extremely fragmented. In the North Island, dwarf galaxias occur in the headwaters of the Waihou River near Putaruru, at a few sites in the Rangitaiki River near Galatea, in Hawkes Bay and the Wellington region. In the South Island, it occurs in Marlborough and Nelson, and on the west coast as far south as the Hokitika River. Recent studies show there are some genetic differences between the populations, but probably not enough to warrant a separate species. Habitat suitability data for this species were collected mainly from targeted waterways in Marlborough and Hawkes Bay.

**Table 4.9.1: Habitat statistics for 159 dwarf galaxias present at 64 of 467 locations in 8 rivers.**

| | Velocity (m/s) | Depth (m) | Substrate index | Substrate size (mm) |
|---|---|---|---|---|
| Minimum | 0.01 | 0.03 | 4.2 | 8.0 |
| Maximum | 1.10 | 0.38 | 6.3 | 179 |
| Average (SD) | 0.43 (0.29) | 0.12 (0.05) | 5.3 (0.6) | 52 (26) |

The habitat preference curves for dwarf galaxias showed they prefer shallow, moderately swift water (c. 0.5 m/s Fig. 4.9.1), with a few found in velocities between 0.9 m/s and 1.1 m/s (Fig. 4.9.2). Although the average substrate particle size used was about 50 mm, there was a preference for larger substrate in most rivers, and this is consistent with their preference for moderate to high water velocities. The velocity at which 52 mm substrate (critical velocity) just begins to move at a depth of 0.12 m is 1.36 m/s, and a velocity of 1.2 m/s was considered to be a maximum velocity for habitat suitability. Generally, dwarf galaxias were more abundant in single channel tributary streams than in large braided mainstems.

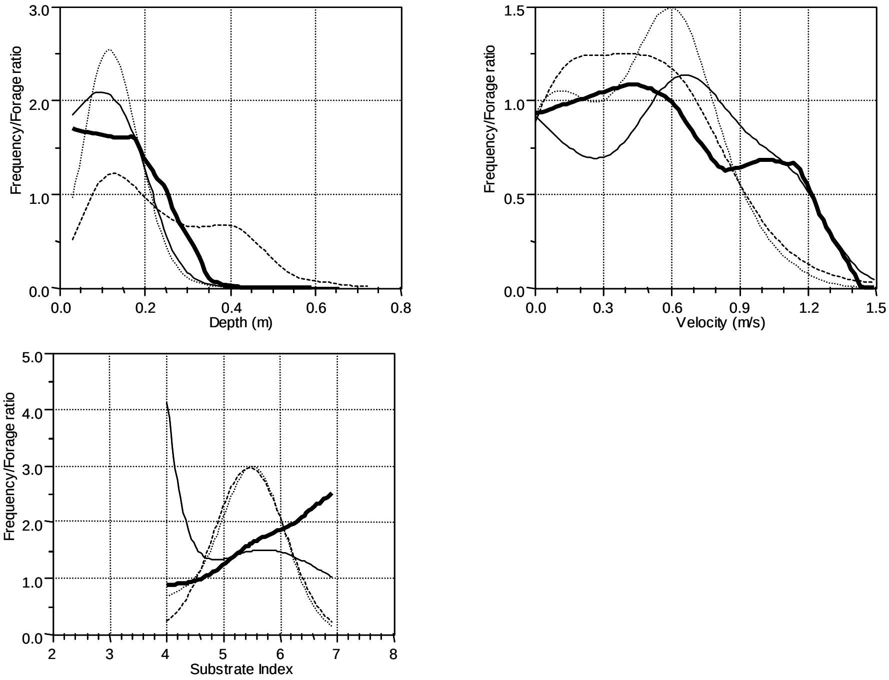


**Figure 4.9.1: Kernel smoothed frequency of habitat availability (dashed line), use (dotted line), and the preference curves derived from all data (solid thin line) and by averaging preference relationships in each river (solid thick line) for dwarf galaxias.**

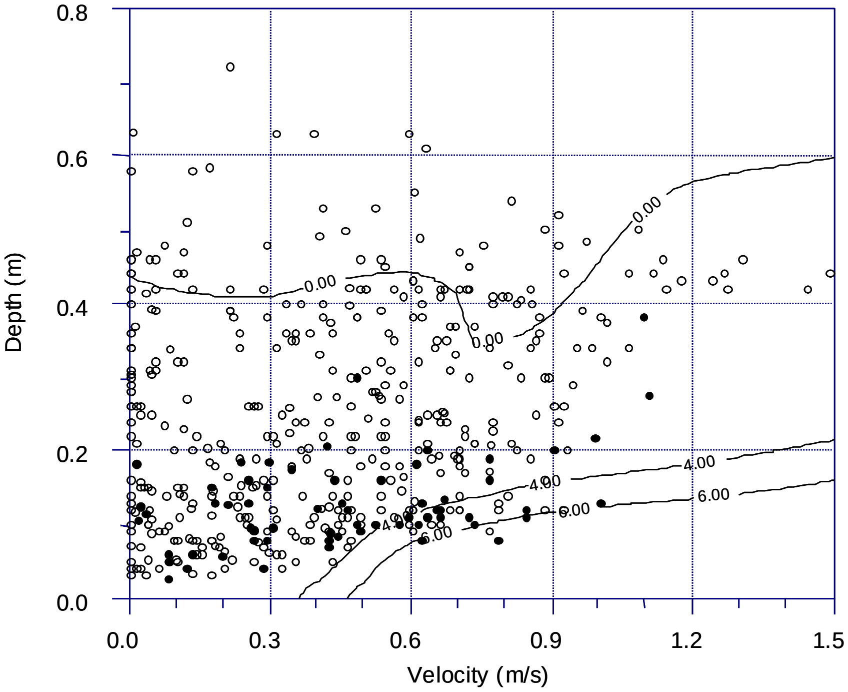


**Figure 4.9.2:** **LOESS contours fitted to dwarf galaxias densities and depth and velocity at all sampling locations. Locations containing dwarf galaxias are shown shaded.**

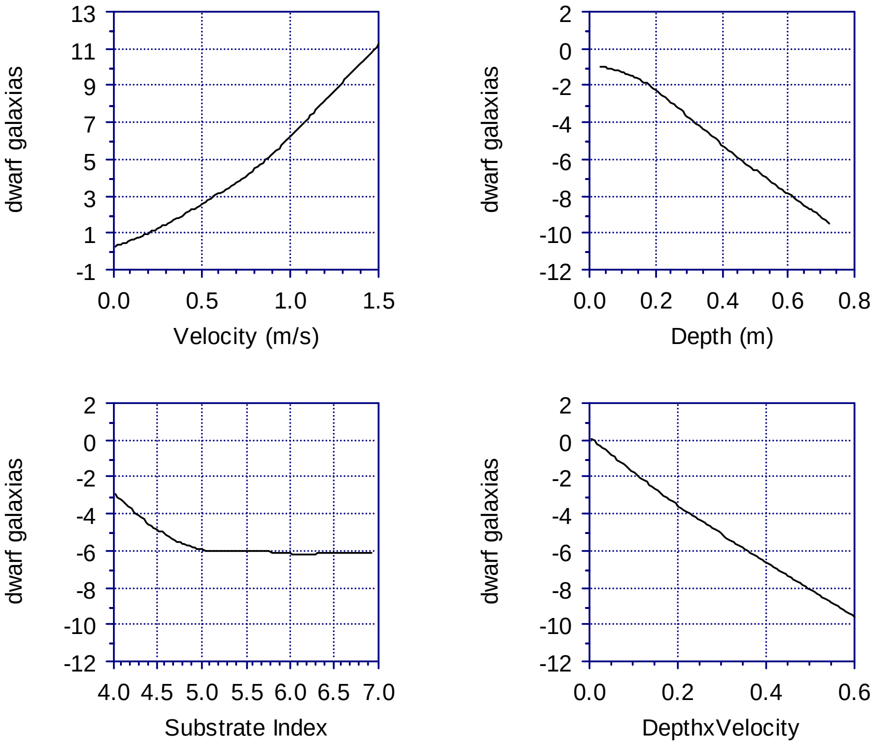


**Figure 4.9.3:** **Generalised additive logistic model of dwarf galaxias probability of use using depth, velocity, substrate index and velocity/depth interaction to give 81% correct prediction at a cut level of 0.6. Velocity/depth interaction significant (*P* < 0.001),**

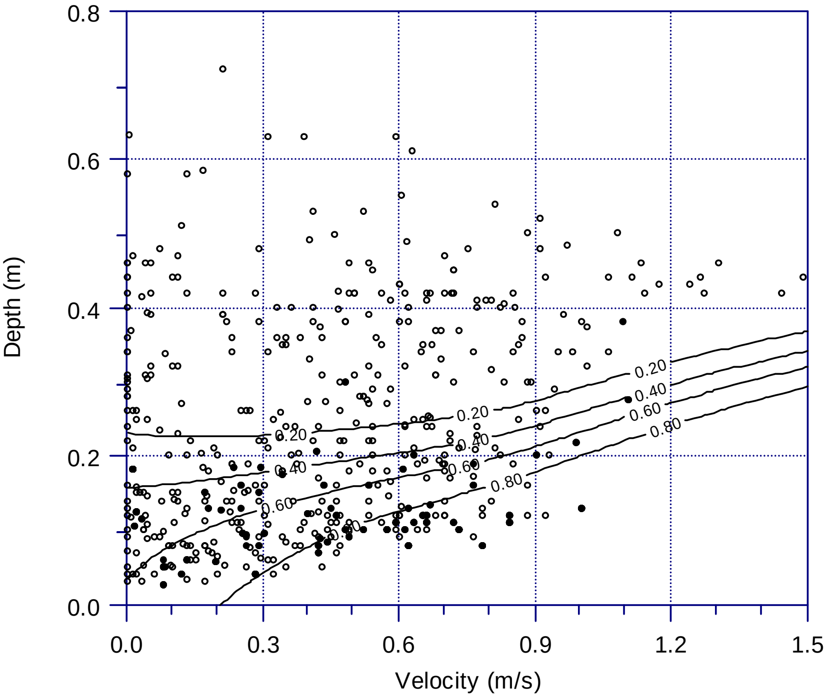
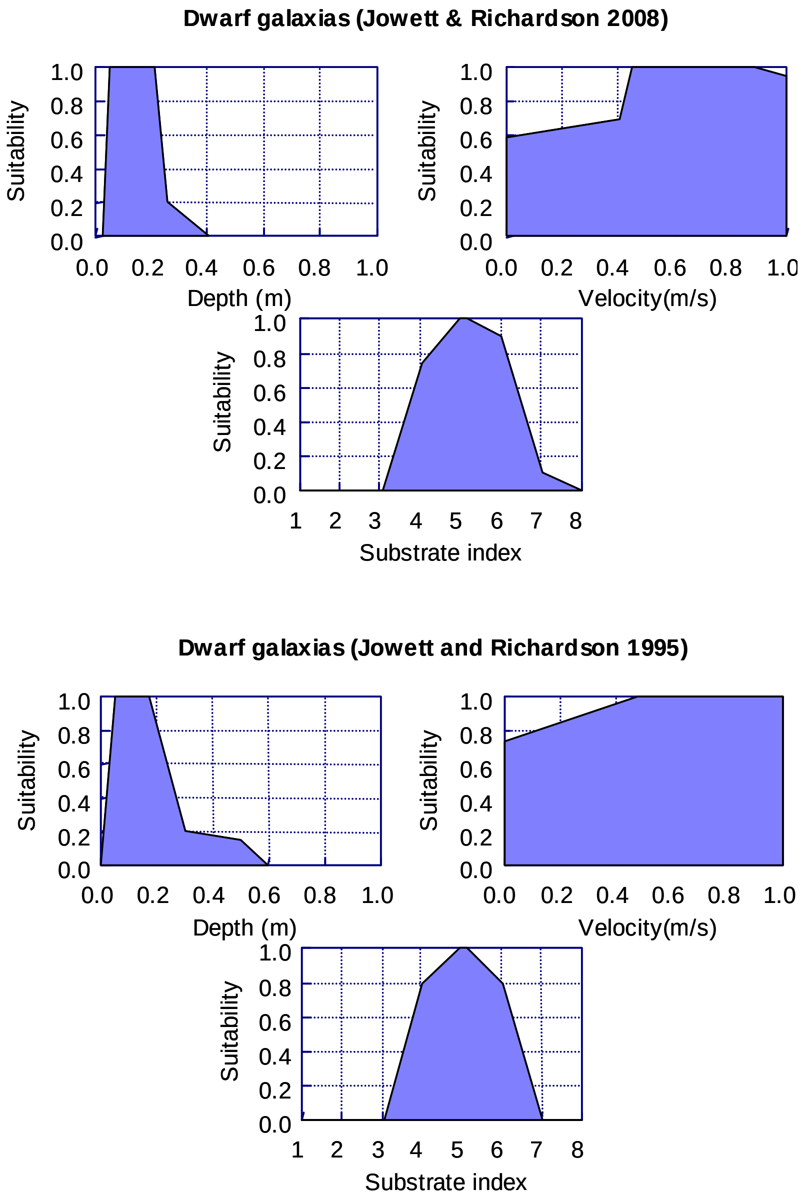


**Figure 4.9.4:** **Contour plot of GAM of probability of use using depth and velocity for a substrate index of 5 with points filled if dwarf galaxias were present.**


Dwarf galaxias (Jowett & Richardson 2008)

Dwarf galaxias (Jowett and Richardson 1995)

**Figure 4.9.5:** **Habitat suitability curves for dwarf galaxias derived from above analyses (top) compared with curves based on data from Jowett & Richardson (1995) (bottom).**

## 4.10 Banded kokopu

Banded kokopu are one of the diadromous galaxiids that form part of the whitebait fishery. Generally, they are less abundant in the whitebait catch than inanga or koaro, but depending on the river, can sometimes be the dominant species, particularly during October. Small shady tributaries are the preferred habitat of banded kokopu, but they adapt well to urban environments and pine forestation so long as there is riparian vegetation that shades the streams.

Only 26 banded kokopu were caught during the electric fishing surveys that were part of habitat suitability studies. During the day, banded kokopu were captured under cover such as instream debris or undercut banks. The average depth and velocity for the 26 daytime banded kokopu locations were 0.19 m and 0.07 m/s, respectively. McCullough (1998) observed banded kokopu by spotlight at night (when banded kokopu are most active) in streams in Coromandel, West Auckland and the Hakarimata Range, and these data were used to develop the habitat suitability curves presented here.

Working in an upstream direction, McCullough (1998) marked the positions of what he determined were undisturbed banded kokopu after identifying the fish as juvenile (<80 mm in length) or adult (≥80 mm length). The next day, velocity, depth, and substrate (percent composition) were measured at each site where a banded kokopu had been. In addition, the available habitat within each stream was sampled proportionally to the number of used samples within the sample reach, the reach length and the reach width. This gave data for 204 adult and 87 juvenile banded kokopu from 575 sites in total.

**Table 4.10.1: Habitat statistics for 87 juvenile (<80 mm) banded kokopu present at 87 out of 575 locations in 5 rivers.**

| | Velocity (m/s) | Depth (m) | Substrate index | Substrate size (mm) |
|---|---|---|---|---|
| Minimum | 0.00 | 0.02 | 2.0 | 0.2 |
| Maximum | 0.22 | 0.64 | 8.0 | 305 |
| Average (SD) | 0.04 (0.04) | 0.15 (0.11) | 4.5 (1.5) | 58 (89) |

**Table 4.10.2: Habitat statistics for 204 adult (≥80 mm) banded kokopu present at 204 out of 575 locations in 5 rivers.**

| | Velocity (m/s) | Depth (m) | Substrate index | Substrate size (mm) |
|---|---|---|---|---|
| Minimum | 0.00 | 0.10 | 2.0 | 0.02 |
| Maximum | 0.20 | 0.80 | 8.0 | 305 |
| Average (SD) | 0.03 (0.04) | 0.18 (0.13) | 4.3 (1.6) | 49 (84) |

Adult banded kokopu preferred very low velocity water over a range of depths more than 0.2 m deep, both during the day and night. There was a slight preference for fine substrate consistent with low velocities (Fig. 4.10.1). Juvenile fish occupied areas of similar water velocity and depth. Although there did not appear to be a preference for shallow water, 96% of juvenile banded kokopu were found in depths of less than 0.4 m because the majority of water sampled was in this range. Substrate also had little influence on the habitat chosen by juvenile banded kokopu. A preference for very low velocity water may be related to the feeding habits of banded kokopu (McCullough 1998). Terrestrial insects comprise the dominant proportion of banded kokopu diets (West et al. 2005), and fish may only be able to detect these when they fall into relatively still water.

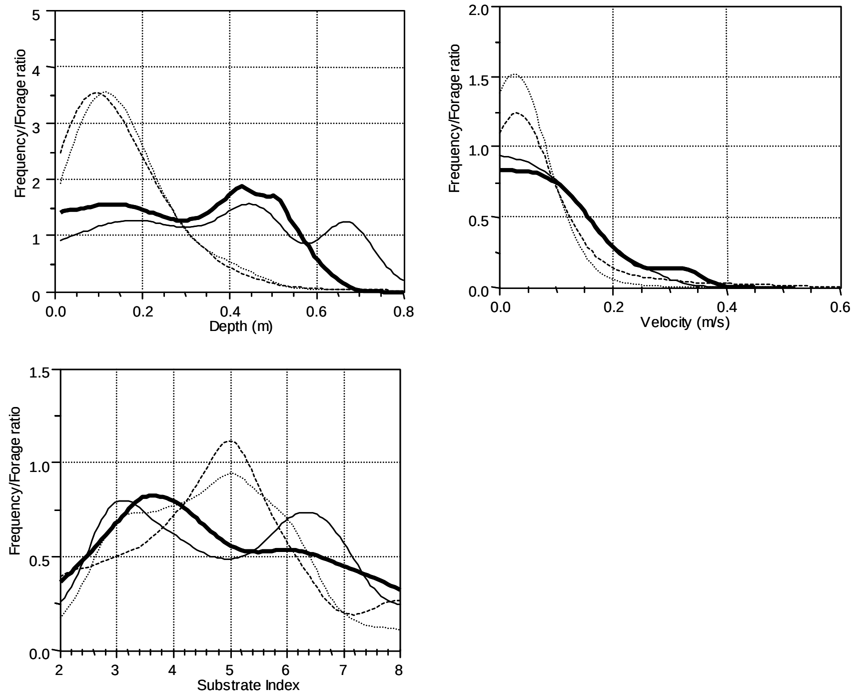


**Figure 4.10.1:** Kernel smoothed frequency of habitat availability (dashed line), use (dotted line), and the preference curves derived from all data (solid thin line) and by averaging preference relationships in each river (solid thick line) for juvenile banded kokopu.

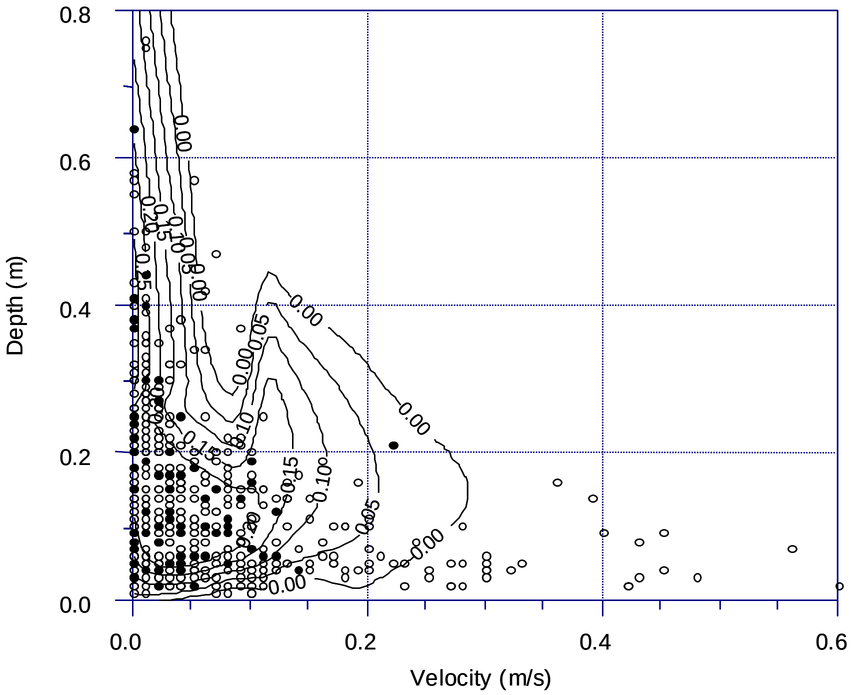


**Figure 4.10.2:** LOESS contours fitted to juvenile banded kokopu densities and depth and velocity at all sampling locations. Locations containing juvenile banded kokopu are shown shaded.

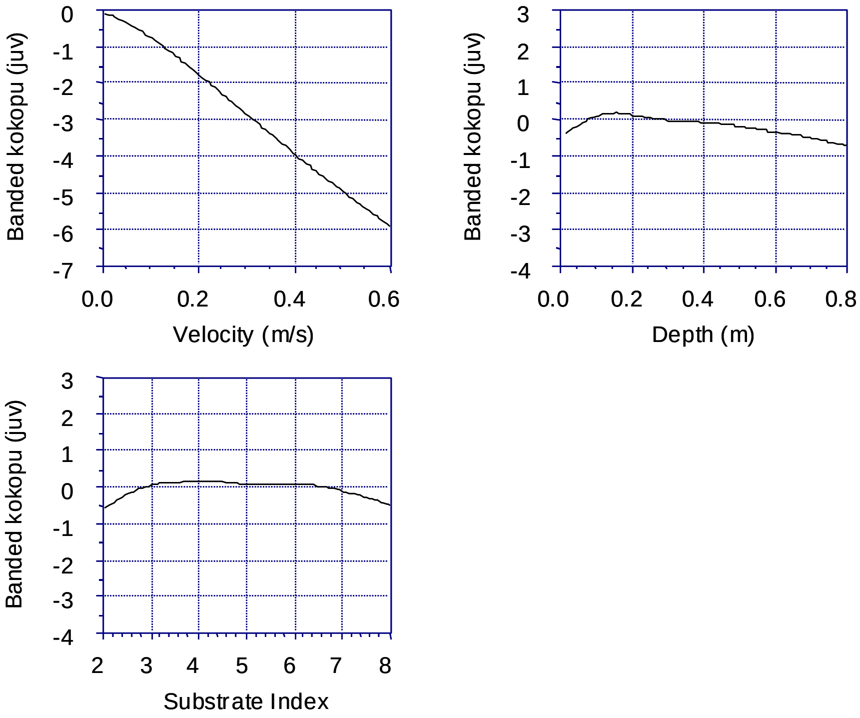


**Figure 4.10.3:** Generalised additive logistic model of juvenile banded kokopu probability of use using depth, velocity and substrate index to give 58% correct prediction at a cut level of 0.2.

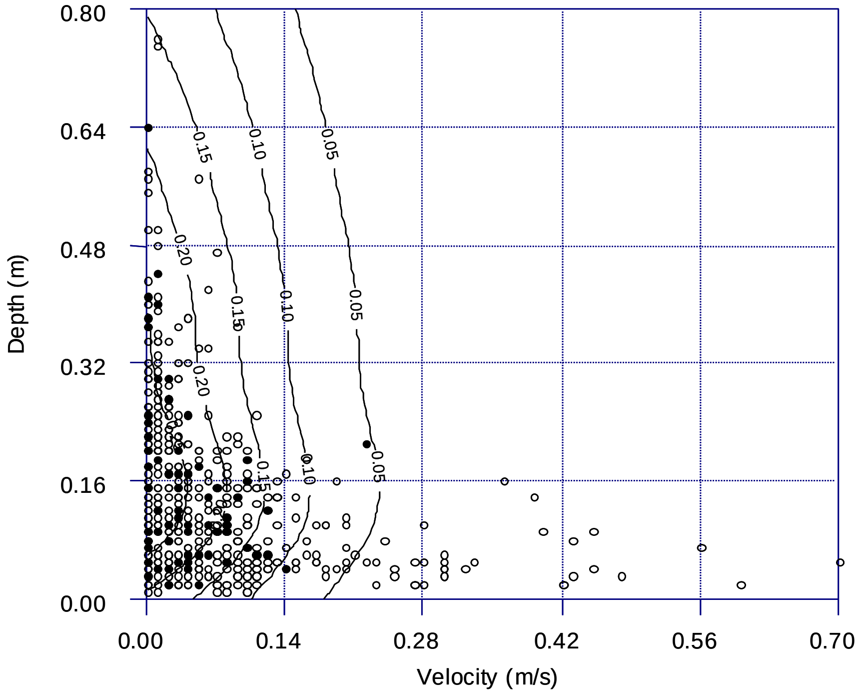
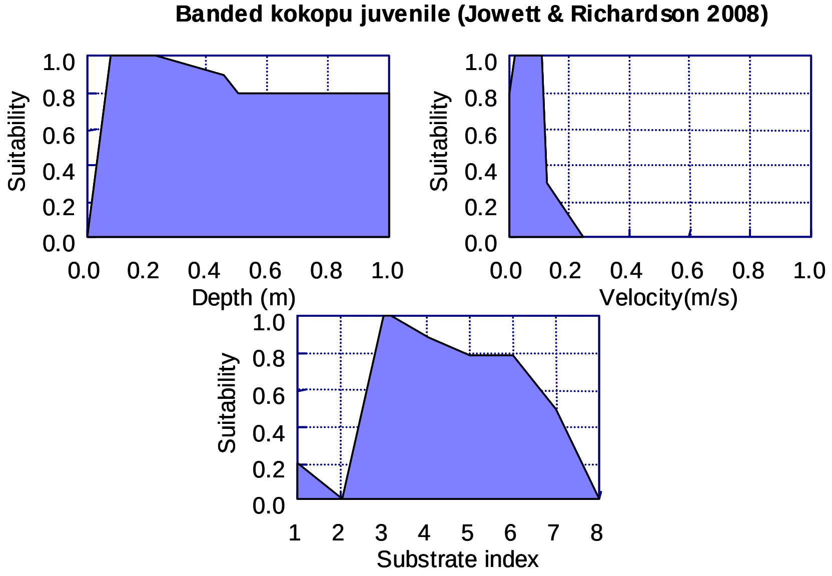


**Figure 4.10.4:** Contour plot of GAM of probability of use using depth and velocity for a substrate index of 3 with points filled if juvenile banded kokopu were present.


Banded kokopu juvenile (Jowett & Richardson 2008)

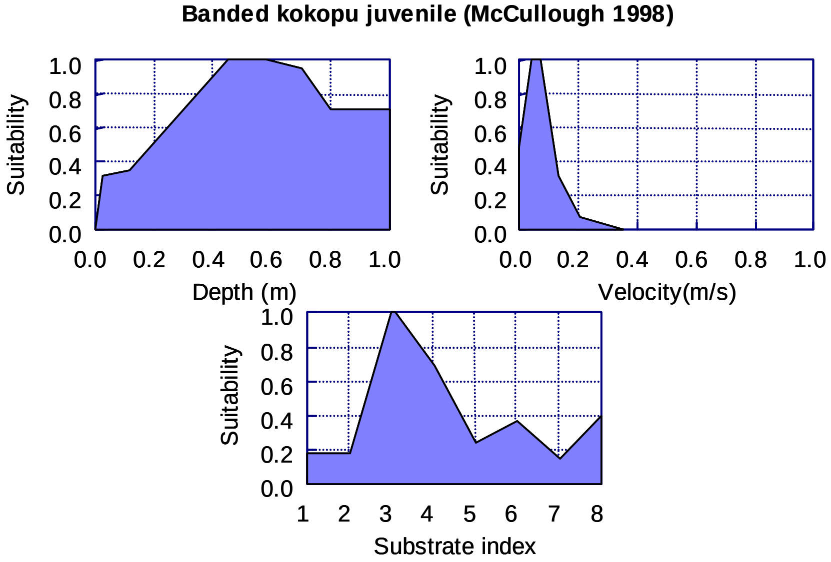

Banded kokopu juvenile (McCullough 1998)

**Figure 4.10.5:** **Habitat suitability curves for juvenile banded kokopu derived from above analyses (top) compared with curves developed previously (bottom).**

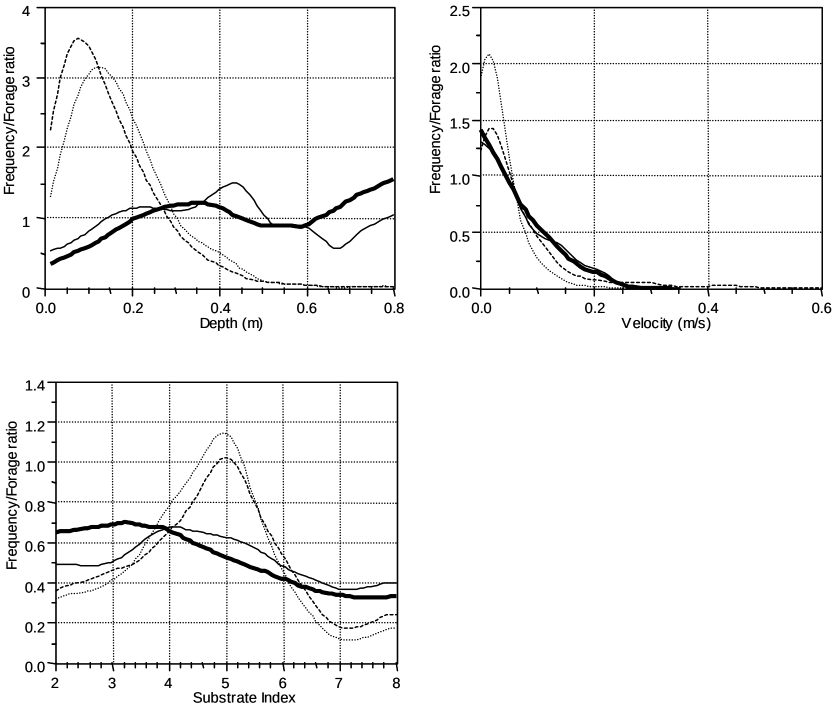


**Figure 4.10.6:** Kernel smoothed frequency of habitat availability (dashed line), use (dotted line), and the preference curves derived from all data (solid thin line) and by averaging preference relationships in each river (solid thick line) for adult banded kokopu.

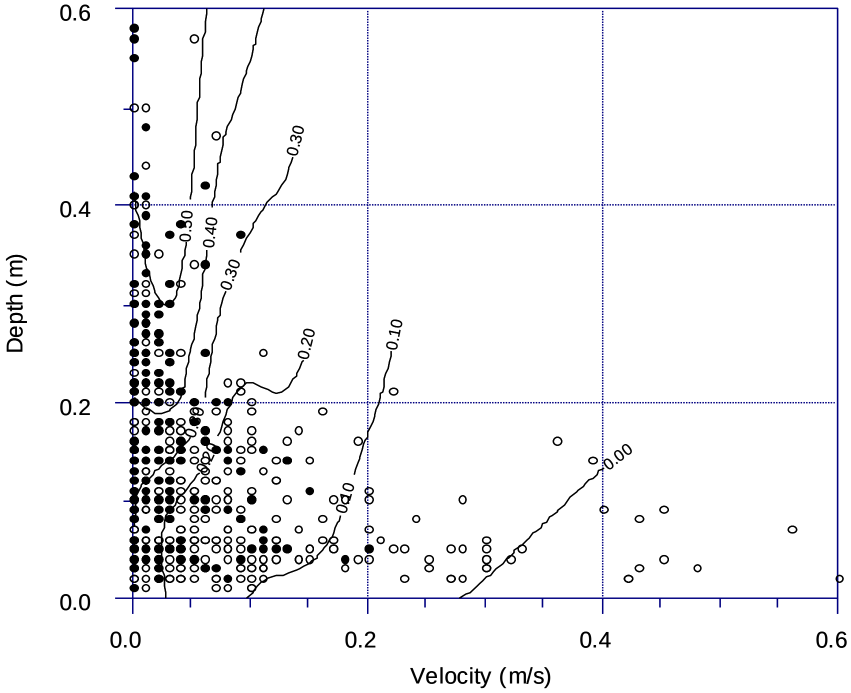


**Figure 4.10.7:** LOESS contours fitted to adult banded kokopu densities and depth and velocity at all sampling locations. Locations containing adult banded kokopu are shown shaded.

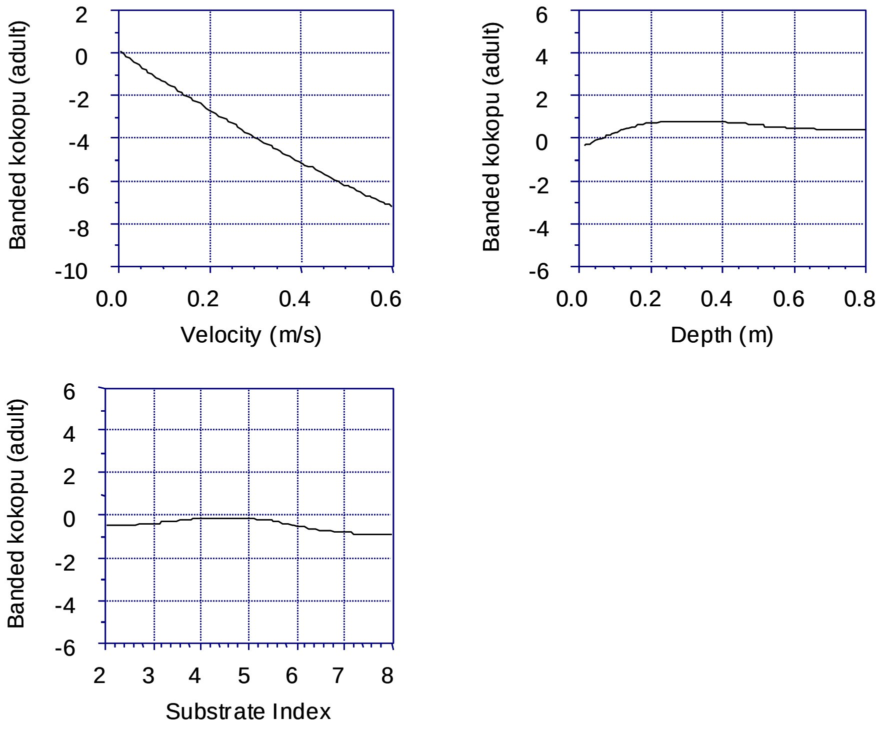


**Figure 4.10.8:** Generalised additive logistic model of adult banded kokopu probability of use using depth, velocity and substrate index to give 69% correct prediction at a cut level of 0.5.

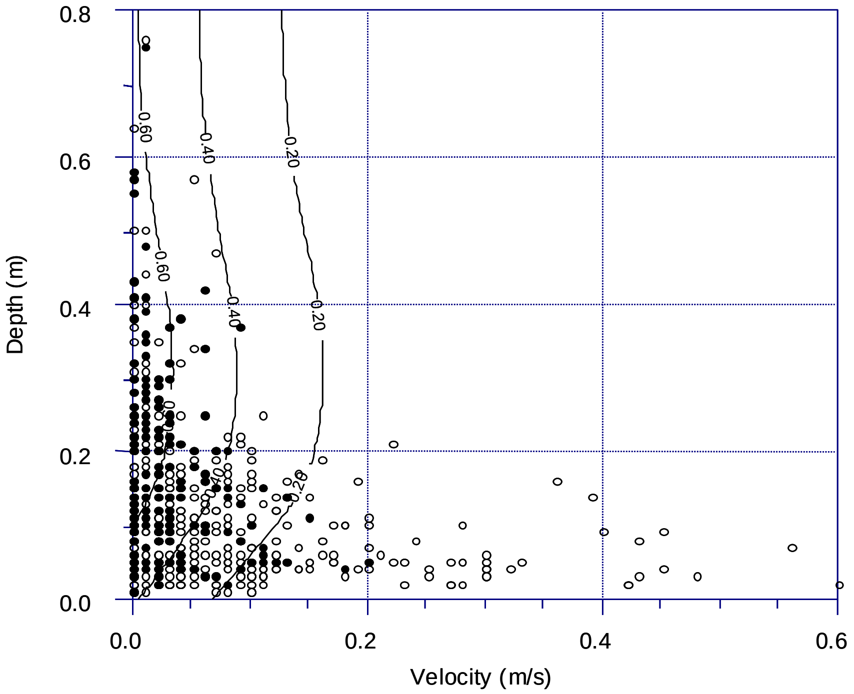


**Figure 4.10.9:** Contour plot of GAM of probability of use using depth and velocity for a substrate index of 3 with points filled if adult banded kokopu were present.

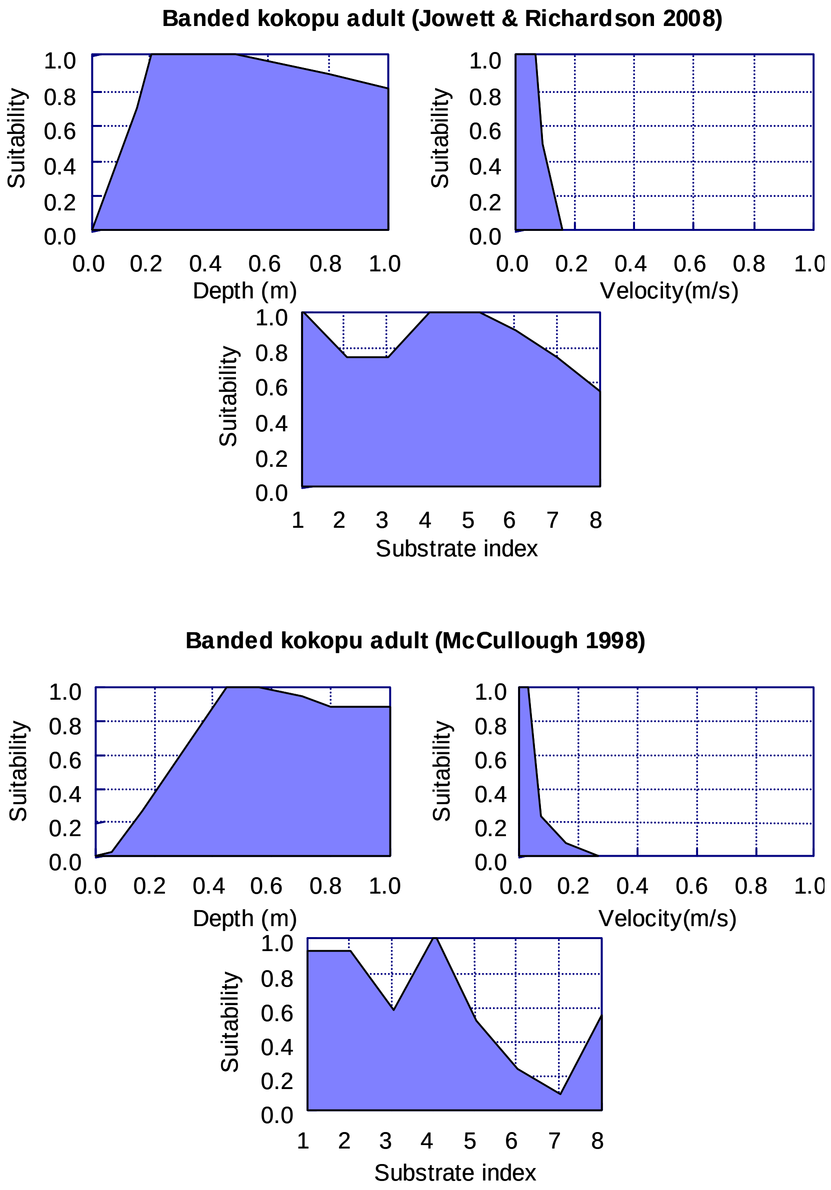


**Figure 4.10.10:** **Habitat suitability curves for adult banded kokopu derived from above analyses (top) compared with curves developed previously (bottom).**

## 4.11 Alpine galaxias

As the name implies, alpine galaxias are found mainly in mountain streams along the eastern side of the Southern Alps from Southland to Marlborough. The fish are usually found in moderately deep riffles and rapids with gravel to boulder substrates (McDowall 1978).

Alpine galaxias are usually about 80-85 mm long and have a similar non-diadromous life cycle to upland longjaw galaxias, and they inhabit many of the same streams at mid to high altitudes along the east coast of the South Island. However, alpine galaxias generally live in deeper, swifter water than longjaw galaxias, and their distribution extends further south into Southland and further north into Marlborough.

**Table 4.11.1: Habitat statistics for 29 alpine galaxias present at 14 out of 192 locations in 2 rivers.**

| | Velocity (m/s) | Depth (m) | Substrate index | Substrate size (mm) |
|---|---|---|---|---|
| Minimum | 0.23 | 0.05 | 2.0 | 37 |
| Maximum | 0.73 | 0.22 | 8.0 | 119 |
| Average (SD) | 0.51 (0.18) | 0.12 (0.05) | 5.6 (0.3) | 64 (22) |

Alpine galaxias preferred swift water with velocities of 0.4–0.6 m/s in depths of 0.15 m or less and coarse substrates (Fig. 4.11.1). Although the sample size of 29 fish is small, the habitat preferences were reasonably clear and matched the descriptions given by McDowall (1978). The velocity at which 64 mm substrate (critical velocity) just begins to move at a depth of 0.12 m is 1.42 m/s.

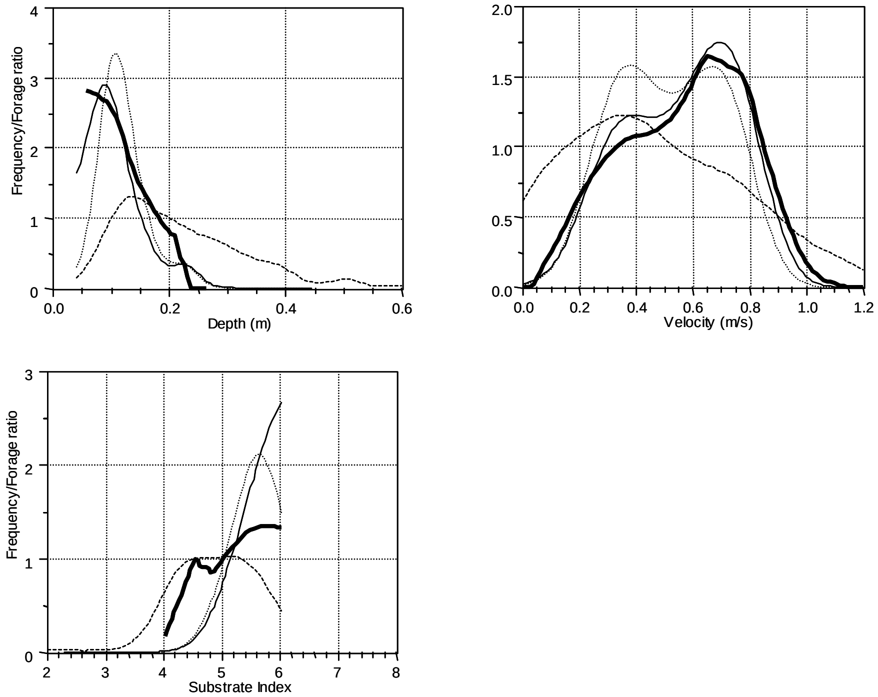


**Figure 4.11.1: Kernel smoothed frequency of habitat availability (dashed line), use (dotted line), and the preference curves derived from all data (solid thin line) and by averaging preference relationships in each river (solid thick line) for alpine galaxias.**

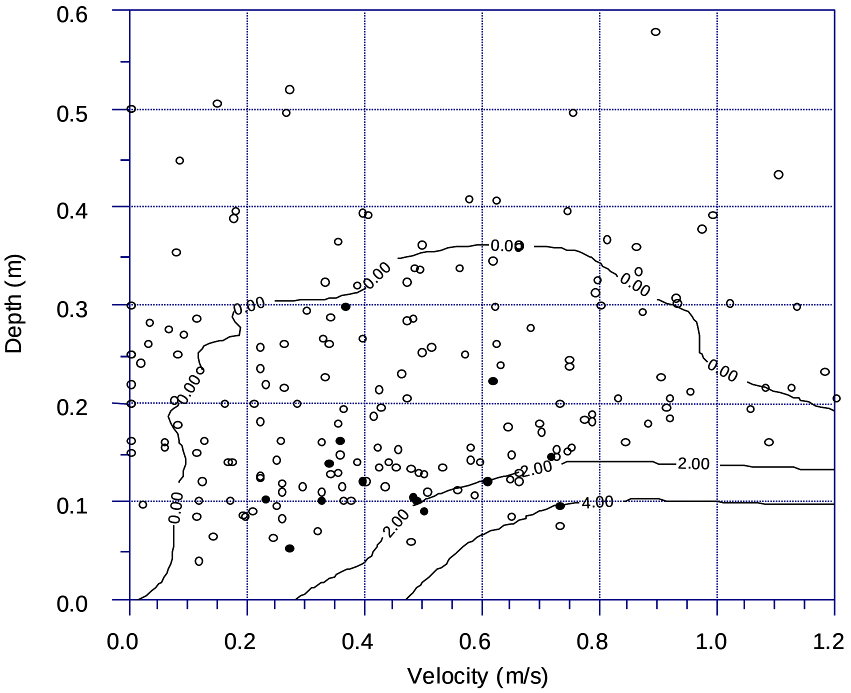


**Figure 4.11.2:** **LOESS contours fitted to alpine galaxias densities and depth and velocity at all sampling locations. Locations containing alpine galaxias are shown shaded.**

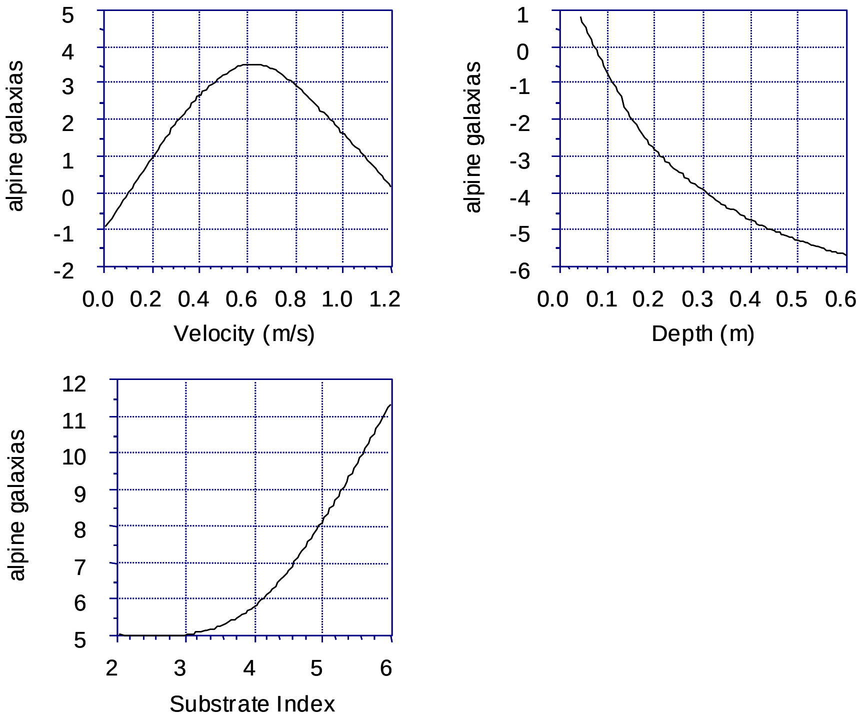


**Figure 4.11.3:** **Generalised additive logistic model of alpine galaxias probability of use using depth, velocity and substrate index to give 90% correct prediction at a cut level of 0.4.**

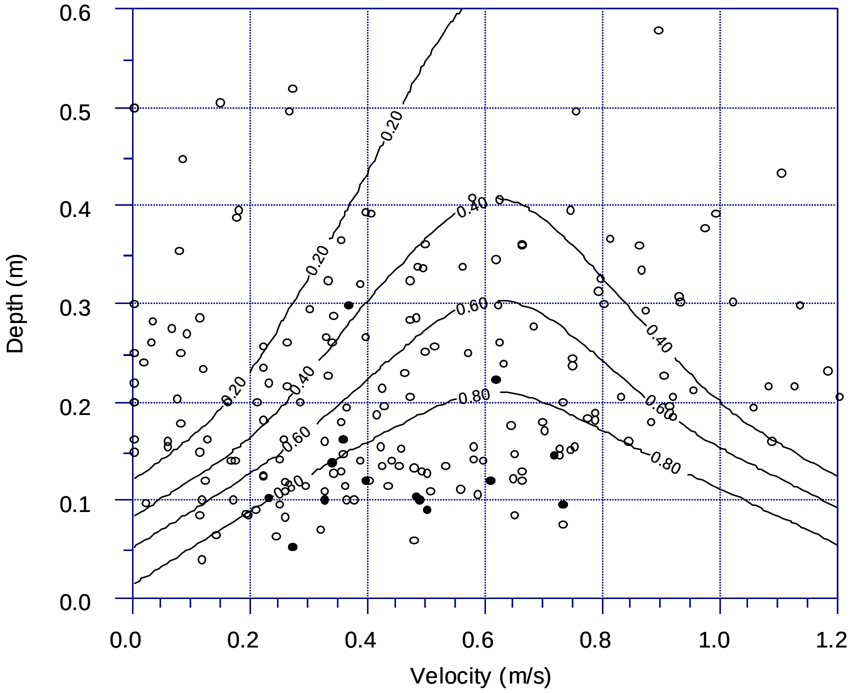


**Figure 4.11.4:** Contour plot of GAM of probability of use using depth and velocity for a substrate index of 6 with points filled if alpine galaxias were present.

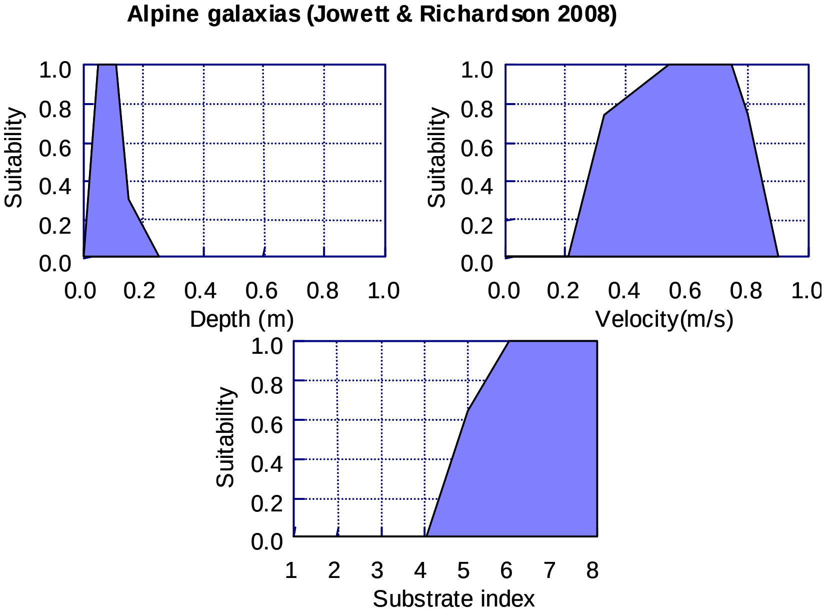


**Figure 4.11.5:** Habitat suitability curves for alpine galaxias derived from above analyses

## 4.12 Shortjaw kokopu

The surveys carried out for habitat suitability analyses used in this report recorded a total of 4 shortjaw kokopu in 2 rivers. Habitat suitability curves have not been developed here, due to the sparse data. These kokopu were found amongst large substrate at an average depth and water velocity of 0.27 m and 0.18 m/s, respectively. McDowall et al. (1996) collected daytime habitat information for shortjaw kokopu mainly in Jones Creek, a tributary of the Totara River on the west coast of the South Island, but noted that they utilised small pools for foraging at night. They developed habitat suitability curves from these data (Figure 4.12.1). The data cannot be found for re-analysis, but it appears that the curves are based on less than 10 fish. The shortjaw kokopu preferred relatively deep water (0.3-0.4 m), although they were most commonly found at depths of about 0.2 m. They preferred boulder cobble substrate and water velocities less than 0.3 m/s. Cover was a very specific requirement for shortjaw kokopu and McDowall et al. (1996) considered that shortjaw locations could be readily identified from the characteristics of the cover. This was large boulders or several smaller boulders piled together, usually at the side of the stream and often near a small pool or eddy.

**Table 4.12.1: Habitat statistics for 4 shortjaw kokopu present at 4 out of 34 locations in 2 rivers.**

| | Velocity (m/s) | Depth (m) | Substrate index | Substrate size (mm) |
|---|---|---|---|---|
| Minimum | 0.00 | 0.12 | 4.0 | 9 |
| Maximum | 0.56 | 0.39 | 7.0 | 288 |
| Average (SD) | 0.18 (0.26) | 0.27 (0.14) | 5.9 (1.3) | 152 (114) |

The velocity at which 152 mm substrate (critical velocity) just begins to move at a depth of 0.27 m is 1.75 m/s.

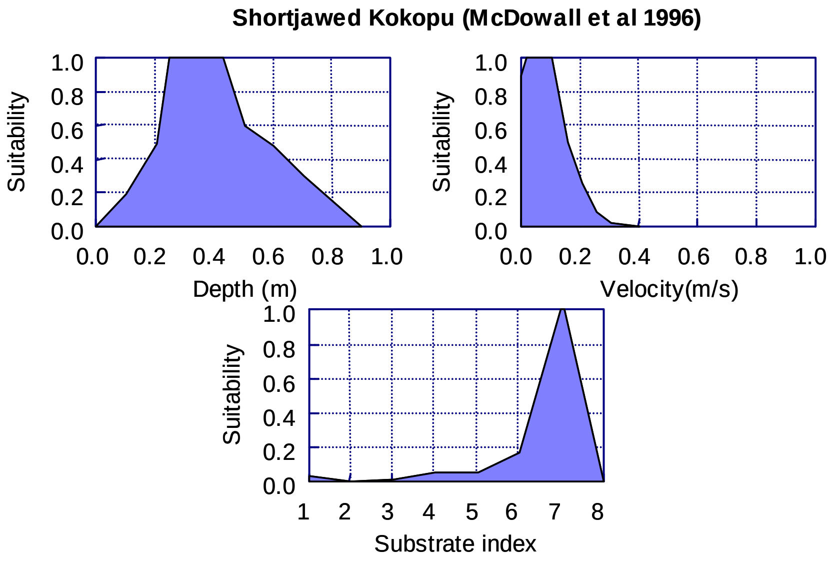


**Figure 4.12.1: Habitat suitability curves for shortjaw kokopu from McDowall et al. (1996).**

## 4.13 Upland longjaw galaxias

The upland longjaw galaxias is found in upland and alpine streams of the South Island, east of the main divide. McDowall (1978) describes its habitat as shallow turbulent water in alpine, gravel-boulder streams. It is often found in the same streams as the alpine galaxias and has the same non-diadromous life cycle. Only eight upland longjaw galaxias were found in the surveys carried out for habitat suitability analyses used in this report. Habitat suitability curves were developed based on these data. These curves should be applied with caution, given the sparse data on which they are based.

**Table 4.13.1: Habitat statistics for 8 upland longjaw galaxias present at 8 out of 154 locations in 3 rivers.**

| | Velocity (m/s) | Depth (m) | Substrate index | Substrate size (mm) |
|---|---|---|---|---|
| Minimum | 0.10 | 0.09 | 5.0 | 22 |
| Maximum | 1.07 | 0.22 | 5.25 | 45 |
| Average (SD) | 0.51 (0.31) | 0.14 (0.05) | 5.2 (0.1) | 38 (8) |

The water depths and velocities occupied by upland longjaw galaxias were practically the same as those occupied by alpine galaxias, although the upland longjaw galaxias was associated with slightly finer substrate, possibly because of its smaller size (c.f. Table 4.11.1). The velocity at which 38 mm substrate (critical velocity) just begins to move at a depth of 0.14 m is 1.29 m/s and 1.3 m/s was taken as the upper velocity limit.

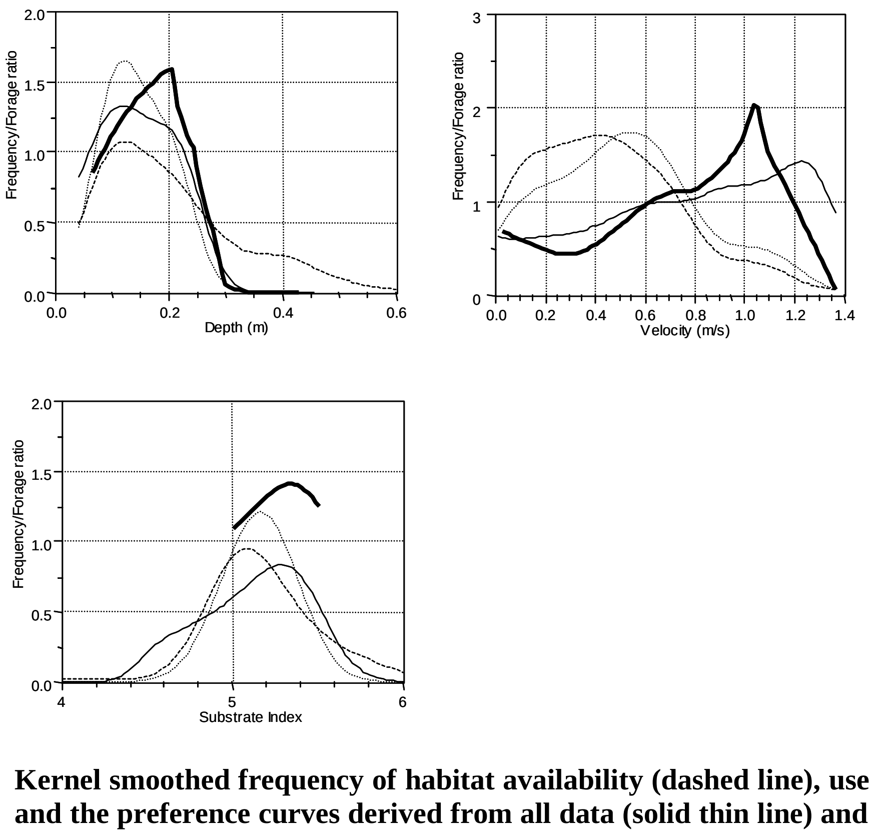


**Figure 4.13.1: Kernel smoothed frequency of habitat availability (dashed line), use (dotted line), and the preference curves derived from all data (solid thin line) and by averaging preference relationships in each river (solid thick line) for upland longjaw galaxias.**

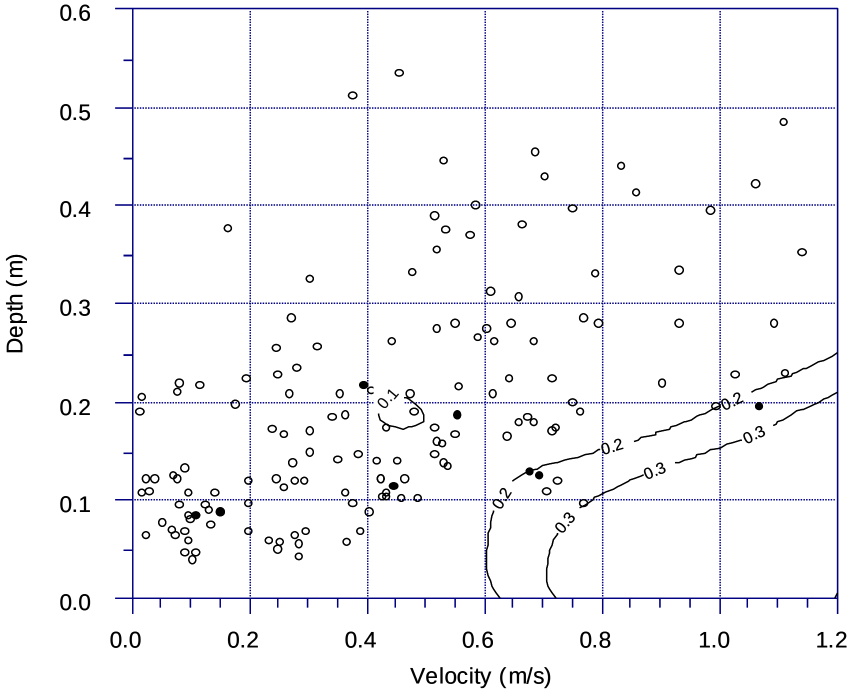


**Figure 4.13.2:** **LOESS contours fitted to upland longjaw galaxias densities and depth and velocity at all sampling locations. Locations containing upland longjaw galaxias are shown shaded.**

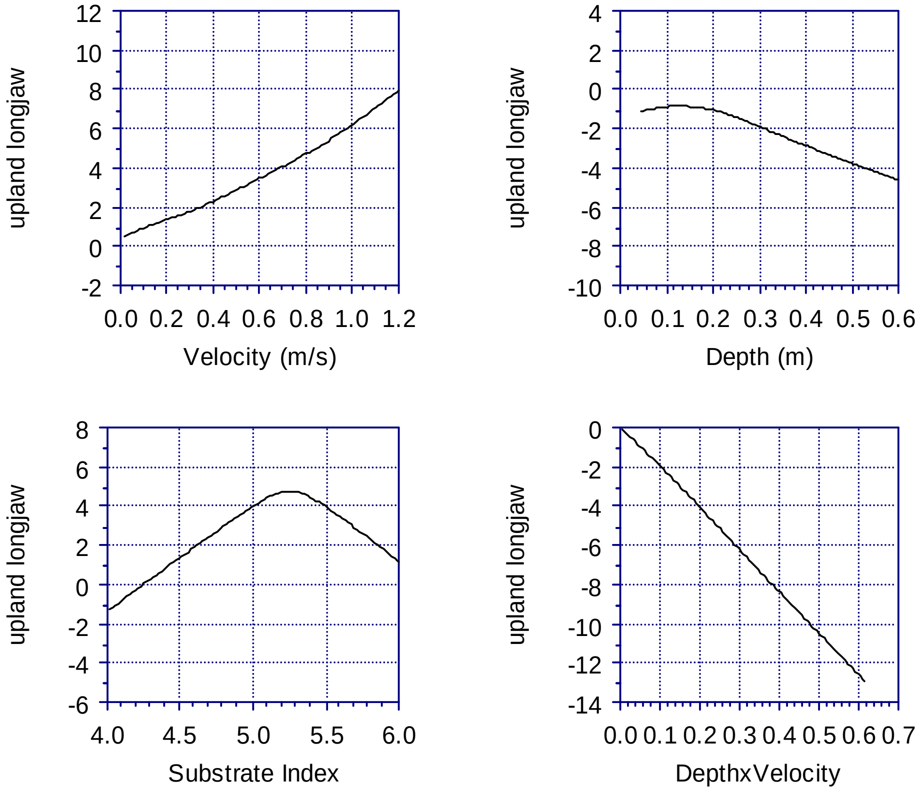


**Figure 4.13.3:** **Generalised additive logistic model of upland longjaw galaxias probability of use using depth, velocity, substrate index and depth/velocity interaction to give 87% correct prediction at a cut level of 0.3. Depth/velocity interaction significant at *P* < 0.001.**

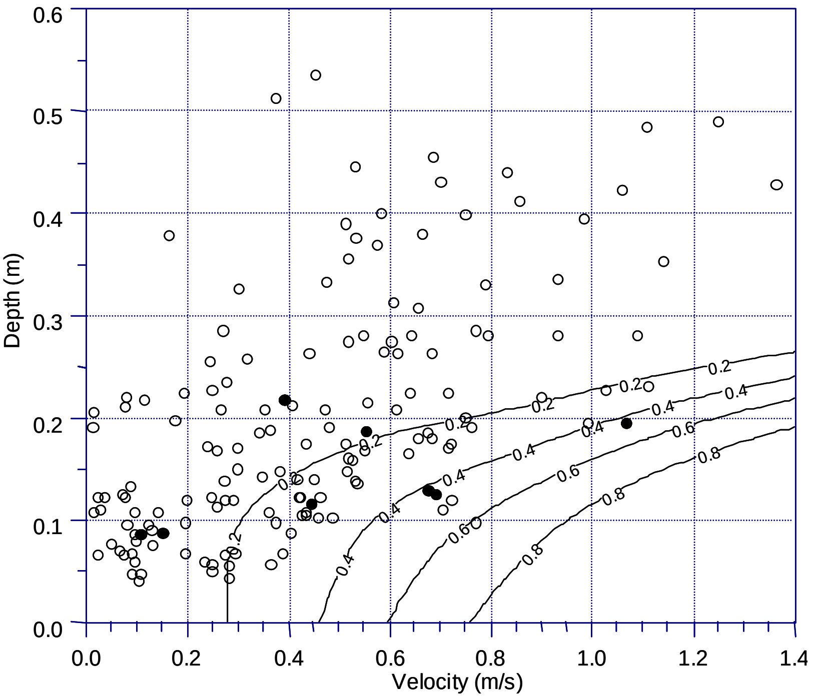


**Figure 4.13.4:** **Contour plot of GAM of probability of use using depth and velocity for a substrate index of 5 with points filled if upland longjaw galaxias were present.**

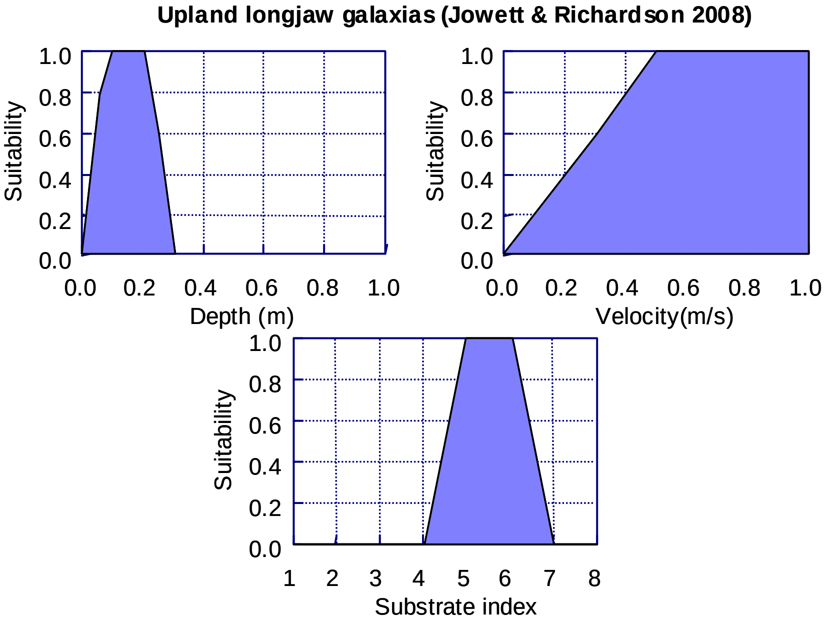


**Figure 4.13.5:** **Habitat suitability curves for upland longjaw galaxias derived from above analyses.**

## 4.14 Canterbury galaxias

The Canterbury galaxias (previously the common river galaxias) is the Canterbury equivalent of the Otago/Southland galaxiids – a non-diadromous galaxiid that inhabits rivers and streams over a broad altitudinal range. Previously, the Canterbury galaxias and the Otago/Southland galaxiids were thought to be the same species, but DNA analysis revealed that the Canterbury galaxias is different to the others. The Otago/Southland group has now split into eight species, although three of these await formal recognition. Detailed study of the Canterbury galaxias shows that more than one species occurs in this region as well. The new and as yet undescribed species is thought to occur in the northern part of the range – from the Clarence River north. As its name implies, the Canterbury galaxias occurs mainly in Canterbury, along the South Island's east coast from just north of Kaikoura to the Shag River south of Oamaru. Data for development of the habitat suitability curves came mainly from the Waipara River and rivers in the Waitaki catchment.

Canterbury galaxias occupied water over a wide velocity range, but preferred water less than 0.4 m deep. Coarse gravel to small cobble was the chosen substrate.

**Table 4.14.1 Habitat statistics for 575 Canterbury galaxias present at 116 of 534 locations in 13 rivers.**

| | Velocity (m/s) | Depth (m) | Substrate index | Substrate size (mm) |
|---|---|---|---|---|
| Minimum | 0.00 | 0.04 | 4.2 | 14 |
| Maximum | 1.20 | 0.67 | 6.0 | 197 |
| Average (SD) | 0.37 (0.24) | 0.17 (0.10) | 5.5 (0.4) | 65 (25) |

The velocity at which 65 mm substrate (critical velocity) just begins to move at a depth of 0.17 m is 1.51 m/s.

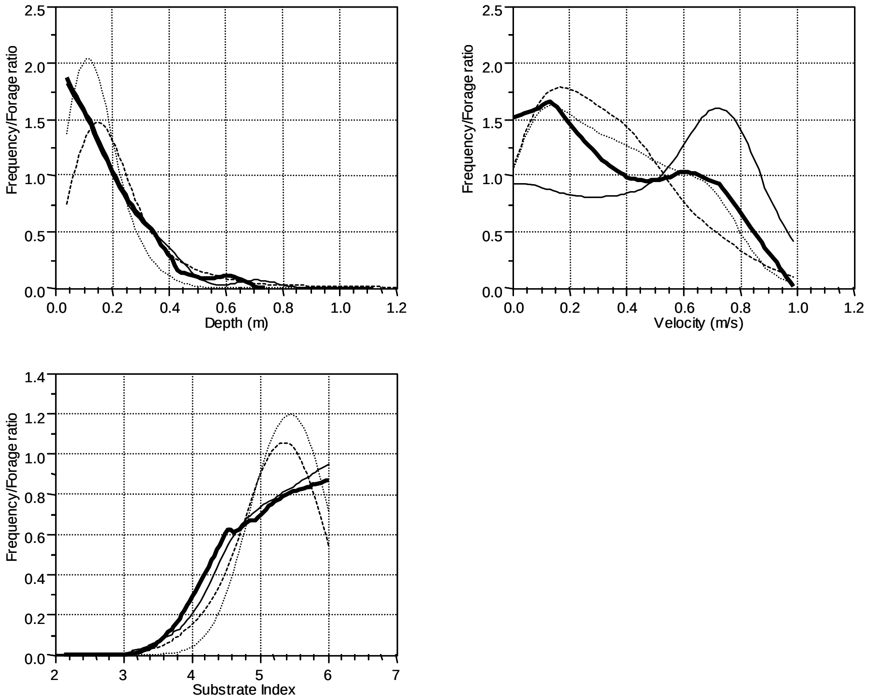


**Figure 4.14.1: Kernel smoothed frequency of habitat availability (dashed line), use (dotted line), and the preference curves derived from all data (solid thin line) and by averaging preference relationships in each river (solid thick line) for Canterbury galaxias.**

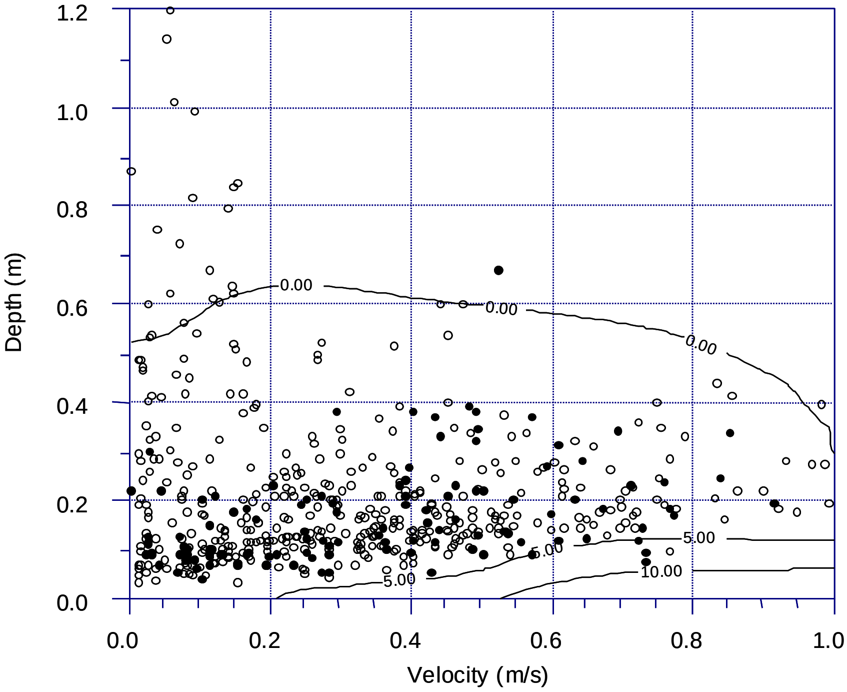


**Figure 4.14.2:** **LOESS contours fitted to Canterbury galaxias densities and depth and velocity at all sampling locations. Locations containing Canterbury galaxias are shown shaded.**

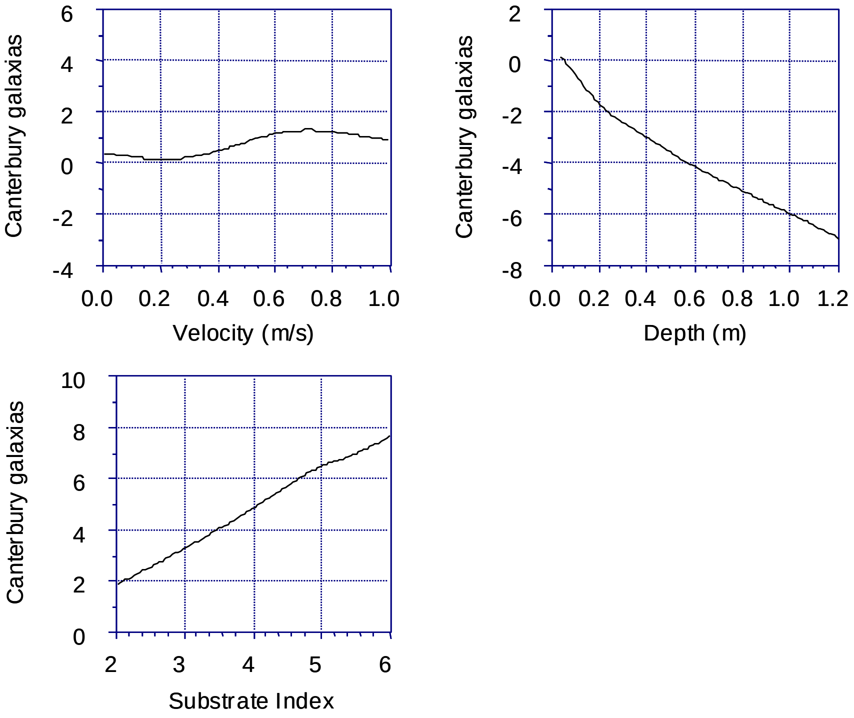


**Figure 4.14.3:** **Generalised additive logistic model of Canterbury galaxias probability of use using depth, velocity and substrate index to give 77% correct prediction at a cut level of 0.5.**

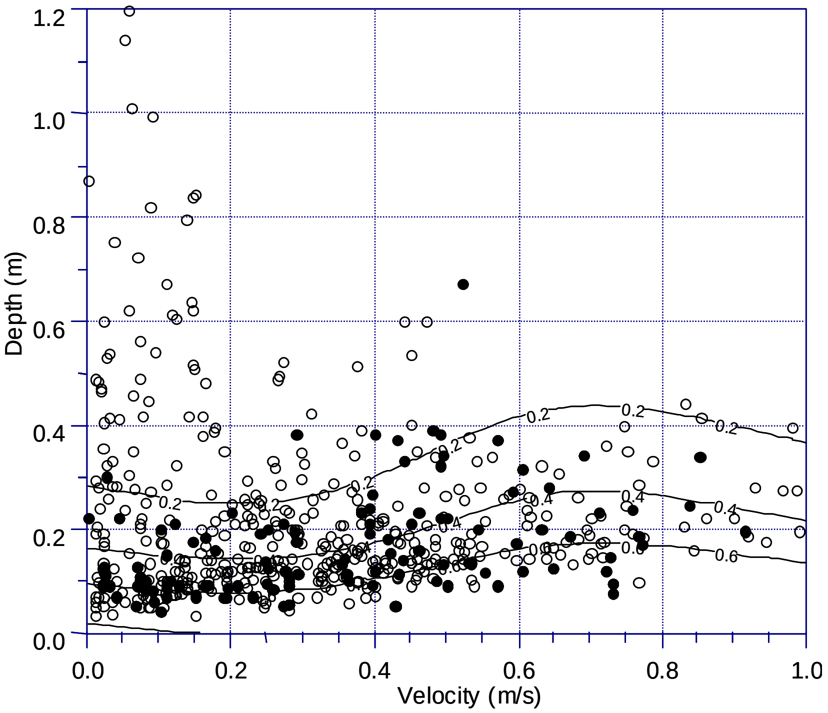
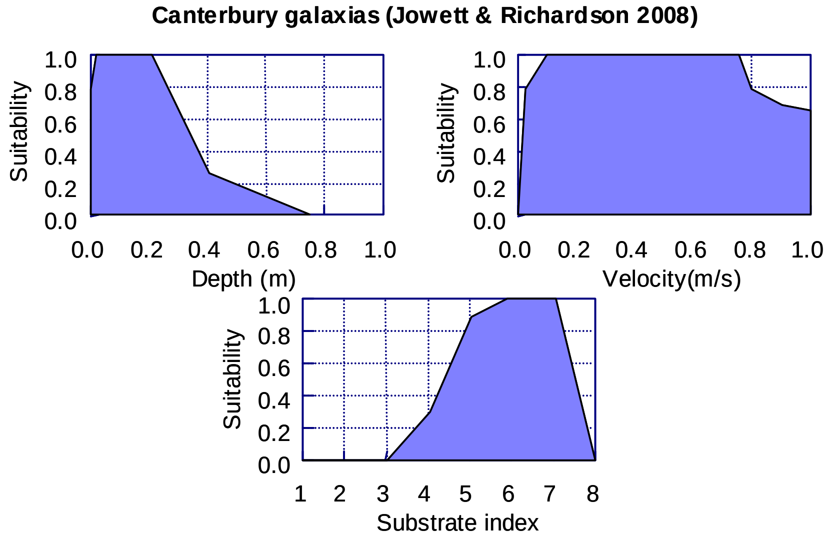
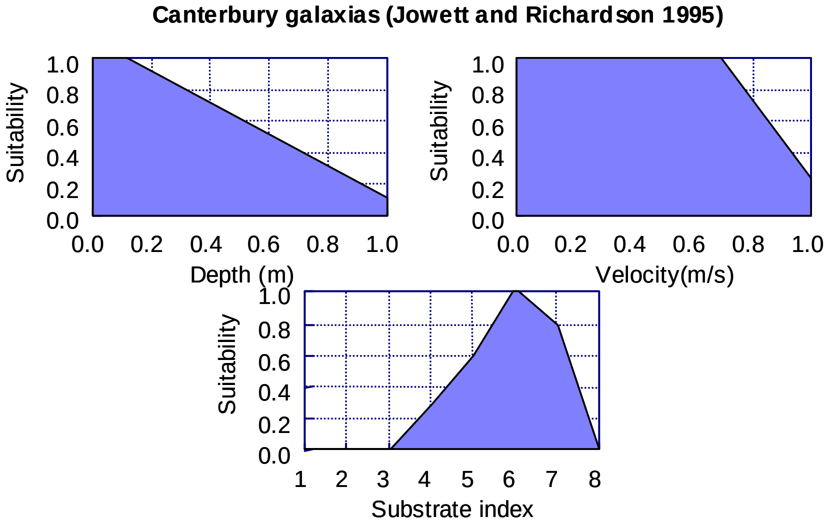


**Figure 4.14.4:** **Contour plot of GAM of probability of use using depth and velocity for a substrate index of 5 with points filled if Canterbury galaxias were present.**



Canterbury galaxias (Jowett & Richardson 2008)



Canterbury galaxias (Jowett and Richardson 1995)

**Figure 4.14.5:** **Habitat suitability curves for Canterbury galaxias (previously called common river galaxias) derived from above analyses (top) compared with curves based on data from Jowett & Richardson (1995) (bottom).**

## 4.15 Giant kokopu

Giant kokopu are the largest of the galaxiid species, sometimes reaching 400 mm in length. Although normally diadromous and forming part of the whitebait run, giant kokopu comprise only a minor percentage of the whitebait catch (McDowall 1984). Landlocked populations also exist in catchments containing large lakes, such as Lake Brunner. No giant kokopu were caught during the electric fishing surveys for this study, but habitat suitability data collected by Bonnett et al. (2002) are analysed here. Bonnett et al. (2002) collected data on giant kokopu from waterways in Westland and Southland using electric fishing, fyke nets, and spotlighting at night. Depth, velocity and substrate were measured at places where giant kokopu were found, and at adjacent areas where they were not found. This gave a total of 69 site measurements for 39 observations of giant kokopu.

**Table 4.15.1: Habitat statistics for 39 giant kokopu present at 39 out of 69 locations in 18 rivers*.**

| | Velocity (m/s) | Depth (m) | Substrate index | Substrate size (mm) |
|---|---|---|---|---|
| Minimum | 0.00 | 0.10 | 1.0 | <0.01 |
| Maximum | 0.15 | 1.50 | 6.0 | 109 |
| Average (SD) | 0.05 (0.05) | 0.53 (0.49) | 3.3 (1.8) | 24 (31) |

* Although 18 rivers were sampled, giant kokopu were not always found.

Giant kokopu preferred very low velocity water, but exhibited little preference for depth or substrate. David (2003) observed habitat use by 16 giant kokopu in two small streams and found that they used low velocities (maximum 0.17 m/s) and moderate depths (0.2-0.6 m), which is consistent with Bonnett's data. The unusual group average curves for depth and substrate reflect a paucity of data for individual rivers. Bonnett & Sykes (2002) used discriminant function analysis to determine important features of giant kokopu habitat, and noted that in addition to velocity, instream cover (logs, debris, man-made structures), shade from riparian vegetation, and the distance inland were more important predictors for giant kokopu than depth or substrate.

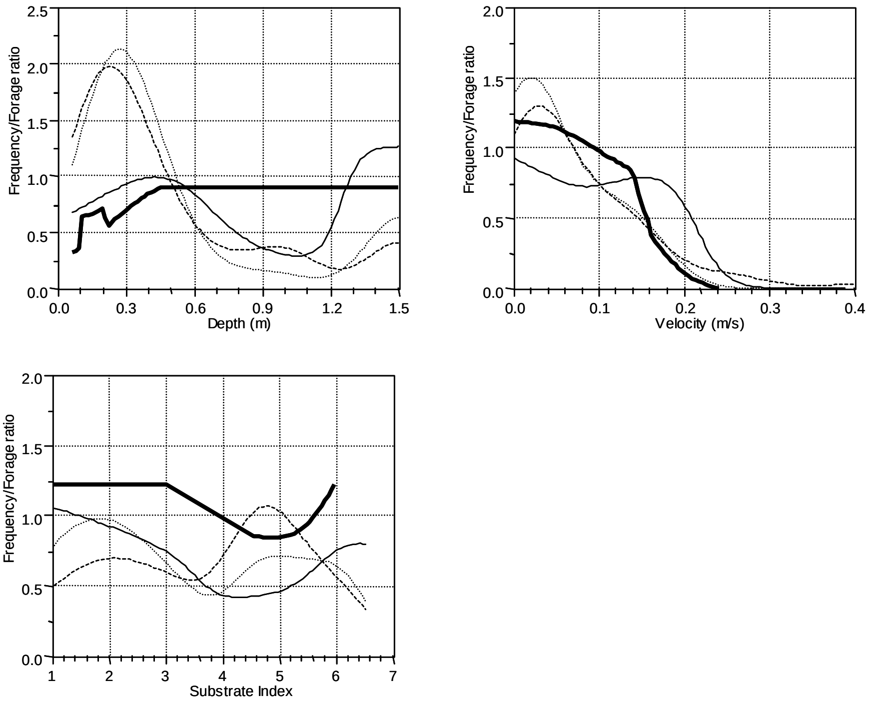


**Figure 4.15.1: Kernel smoothed frequency of habitat availability (dashed line), use (dotted line), and the preference curves derived from all data (solid thin line) and by averaging preference relationships in each river (solid thick line) for giant kokopu.**

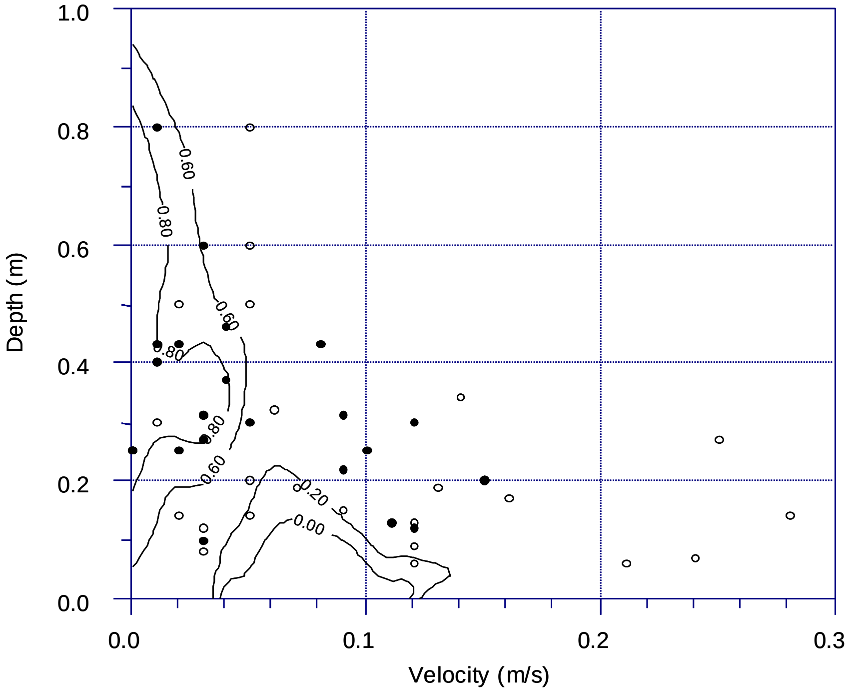


**Figure 4.15.2:** LOESS contours fitted to giant kokopu densities and depth and velocity at all sampling locations. Locations containing giant kokopu are shown shaded.

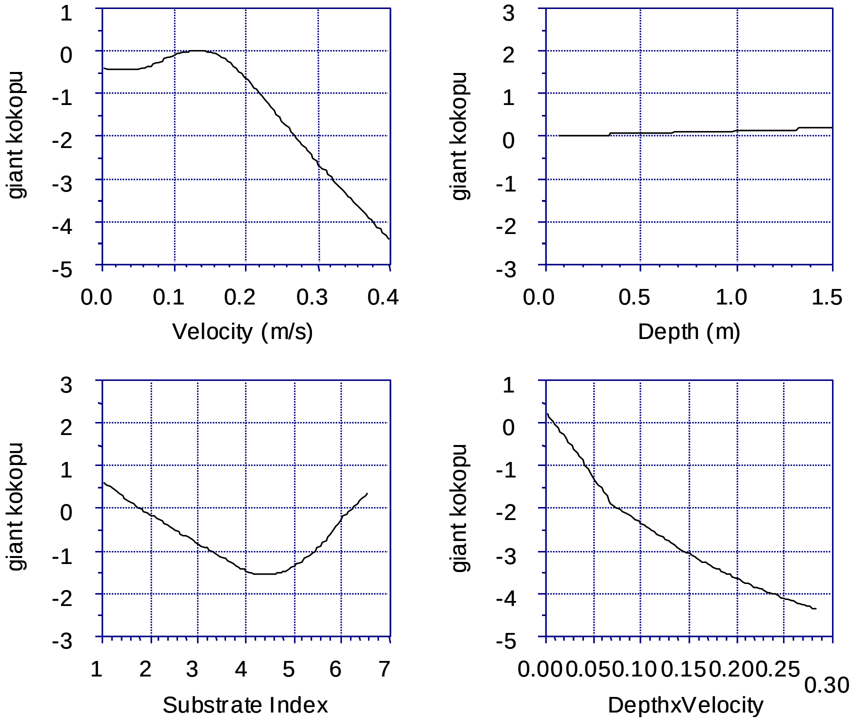


**Figure 4.15.3:** Generalised additive logistic model of giant kokopu probability of use using depth, velocity, substrate index and depth/velocity interaction to give 75% correct prediction at a cut level of 0.5. Depth/velocity interaction significant at ***P*** **= 0.004.**

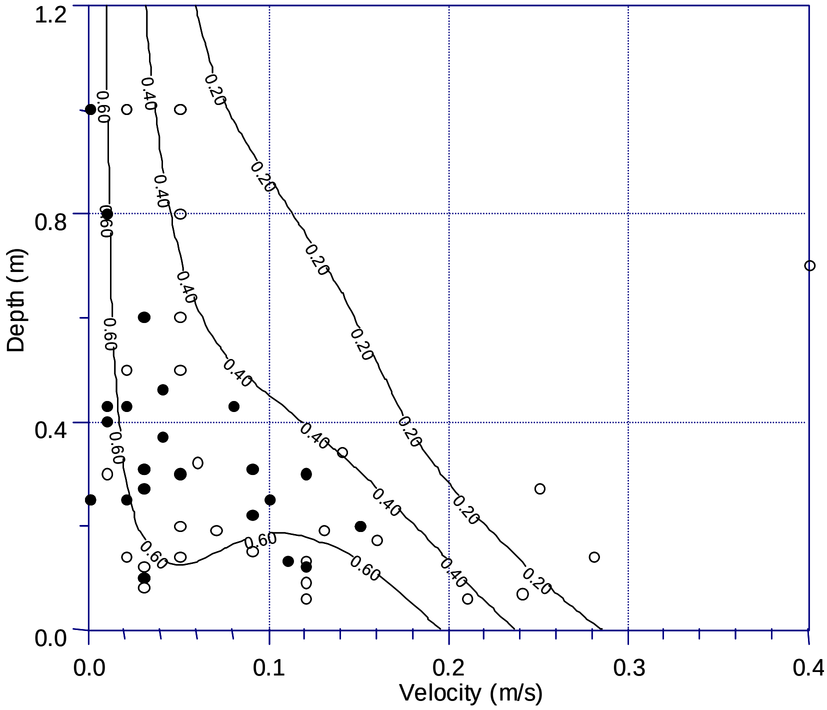


**Figure 4.15.4:** Contour plot of GAM of probability of use using depth and velocity for a substrate index of 3 with points filled if giant kokopu were present.

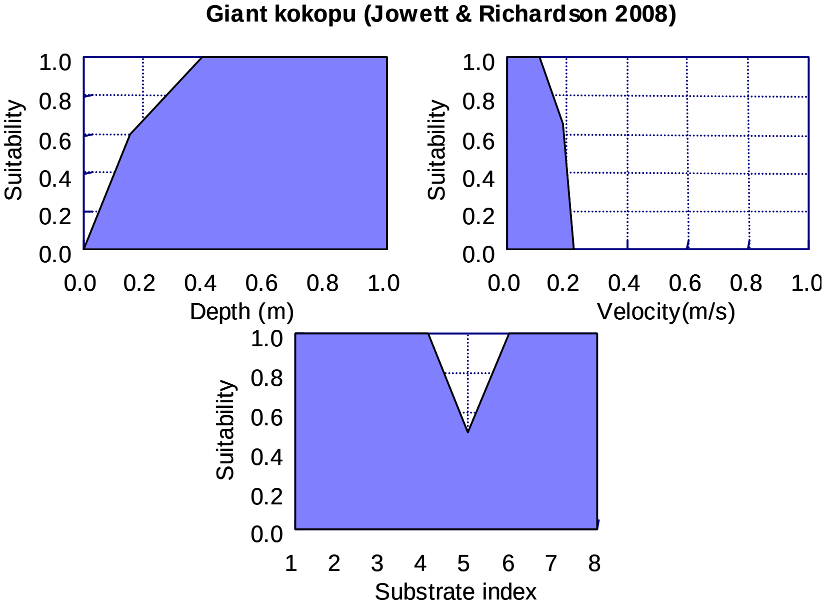


**Figure 4.15.5:** Habitat suitability curves for giant kokopu derived from above analyses.

## 4.16 Inanga

Inanga are the most common species in the whitebait fishery (McDowall 1984), with the juveniles being netted in spring as they enter river mouths from the sea, enroute to adult habitats in fresh water. Like smelt, inanga are a pelagic species that are generally herded into capture locations by electric fishing, possibly giving a false impression of where they prefer to live. Few inanga were captured in the electric fishing surveys used to construct the habitat suitability curves for the other species. Consequently, the suitability curves presented here for inanga feeding habitat were developed from observations of inanga from the banks of three streams in the North Island (Jowett 2002). The locations of fish that appeared to be feeding were mapped, and then a bank observer directed a second person to the fish's position to measure the depth and velocity. Substrate was not assessed but the predominant substrates in the three streams covered a wide range of substrate types (macrophytes, boulders and fine gravel). This gave measures for 595 inanga at 129 feeding locations. Jowett (2002) compared habitat use with available habitat data obtained from cross-section surveys of two of the three streams and this analysis is not repeated here. In this study, we analysed the data on fish density, which is not entirely satisfactory because these data contain no information on the habitat that was not used. However, the results of this analysis were compared to the habitat suitability curves derived by Jowett (2002), to show the problems associated with targeted surveys where no information on habitat availability is collected.

**Table 4.16.1: Habitat statistics for 595 inanga present at 129 locations in 3 rivers.**

| | Velocity (m/s) | Depth (m) |
|---|---|---|
| Minimum | 0.00 | 0.08 |
| Maximum | 0.18 | 2.0 |
| Average (SD) | 0.05 (0.03) | 0.30 (0.24) |

Using just the data on fish density, the habitat use and availability curves were very similar and it was difficult to determine clear preferences. Figure 4.16.1 shows that inanga had no depth preferences above about 0.2 m and were found in shallow water in the 2 shallow streams and in deep water in the one deep stream and this is consistent with Jowett (2002). However, velocity preferences appeared to be constant over the range of velocities 0–0.14 m/s and Jowett (2002) found that when velocities used by the inanga were compared to velocities available in the streams, they preferred the most frequently used velocity of 0.06 m/s. It was not possible to produce a reasonable contour plot of inanga density from the feeding location densities.

Drift-feeding locations were related to current patterns and water velocity, with inanga feeding at locations where the current concentrated food and where water velocities were sufficiently low to allow the fish to hold position. The mean feeding velocity did not vary significantly between streams, although the range of velocities used did. Optimum feeding velocities were 0.03–0.07 m/ s. Depth use was very different between streams and this was attributed to the variation in available habitat. Depths greater than 0.3 m were optimum, with some use of depths between 0.1 and 0.3 m.

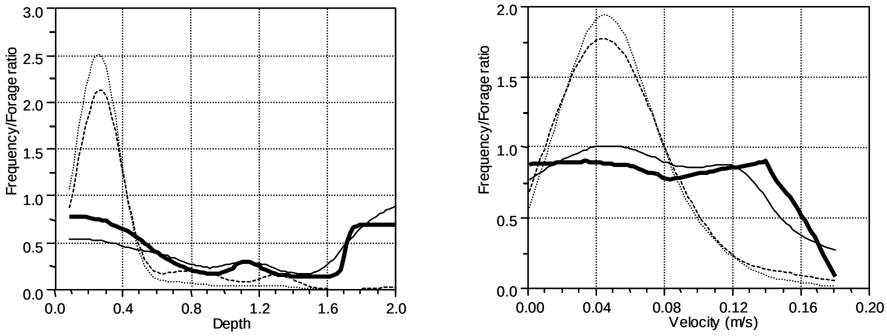


**Figure 4.16.1:** **Kernel smoothed frequency of habitat availability (dashed line), use (dotted line), and the preference curves derived from all data (solid thin line) and by averaging preference relationships in each river (solid thick line) for inanga density.**

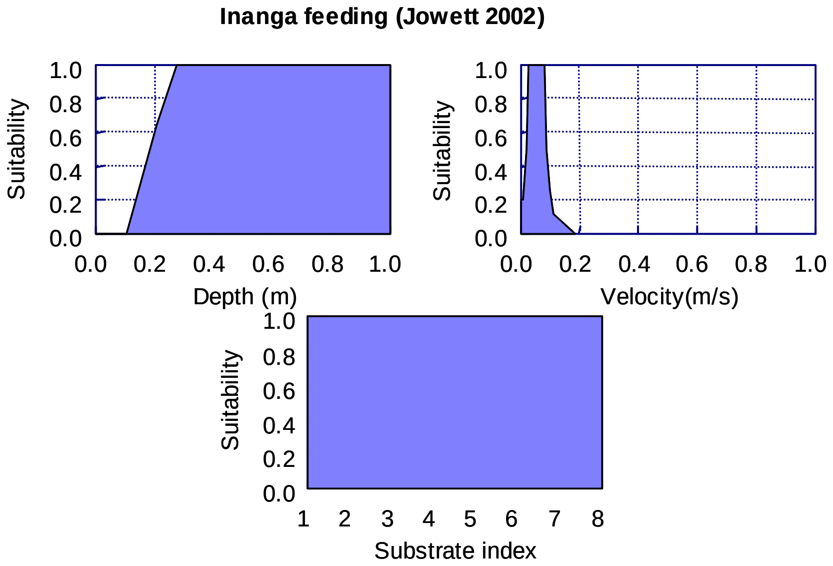


**Figure 4.16.2:** **Habitat suitability curves for inanga derived from Jowett (2002).**

## 4.17 Lamprey

Four anadromous lamprey species are found in the Southern Hemisphere, but only one species is found in New Zealand. The duration of the parasitic marine phase is thought to last two years (Potter et al. 1979), after which the adults return to freshwater to eventually spawn and die more than a year later. After hatching, the juveniles (ammocoetes) live in burrows along stream margins for three or more years, before metamorphosing into the macrophthalmia stage and migrating to sea (Todd & Kelso 1993). Their size also tends to increase with distance downstream, indicative of growth and movement from headwater spawning areas.

We used data from a 2001 survey of the Mataura River that targeted lamprey habitat (Jellyman & Glova 2002). Jellyman & Glova (2202) electric fished small sites (0.25 m$^2$) for at least 3 minutes or until no more juvenile lamprey emerged from the substrate. The fish were then counted, measured and returned. Average depth and velocity were calculated from 3 measures within each site, while the average substrate size was determined from 10 cm long core samples taken at each site that were dried, sieved and weighed in the laboratory (in comparison to the other surveys discussed in this paper, all the lamprey substrates were effectively mud, sand or fine gravel). We did not use the data for 24 juvenile lamprey recorded in the other electric fishing data used for this study (Table 4.1.2), because these data were collected from larger areas and the velocities were not necessarily representative of lamprey locations.

**Table 4.17.1: Habitat statistics for 422 juvenile lamprey present at 63 of 80 sites in the Mataura River catchment.**

| | Velocity (m/s) | Depth (m) | Substrate size (mm) |
|---|---|---|---|
| Minimum | 0.00 | 0.07 | 0.1 |
| Maximum | 0.24 | 0.57 | 8 |
| Average (SD) | 0.06 (0.07) | 0.26 (0.14) | 1 (2) |

Juvenile lamprey showed preferences for very low velocity water over a range of depths (Fig. 4.17.1); essentially muddy margins and backwaters of streams, as is often described in the literature (Maskell 1929; McDowall 1990; Kelso & Todd 1993). Because the juveniles burrow into the substrate, fine substrate is essential. Lamprey were only found in water up to 0.6 m deep, although depths of up to 0.8 m were sampled (Fig. 4.17.2).

The average depth in the Mataura dataset (0.26 m, Table 4.17.1) was similar to the average depth of 0.27 m for the 24 lamprey in the main dataset. However, the average velocity in the main dataset was 0.10 m/s compared to 0.06 m/s in the Mataura data. The difference is because the larger sampling grid (about 3 m$^2$) included more flowing water than the small (0.25 m$^2$) grid of the Mataura dataset. Most lamprey of the main data set were associated with silt substrate.

The velocity at which 1 mm substrate (critical velocity) just begins to move at a depth of 0.26 m is 0.29 m/s.

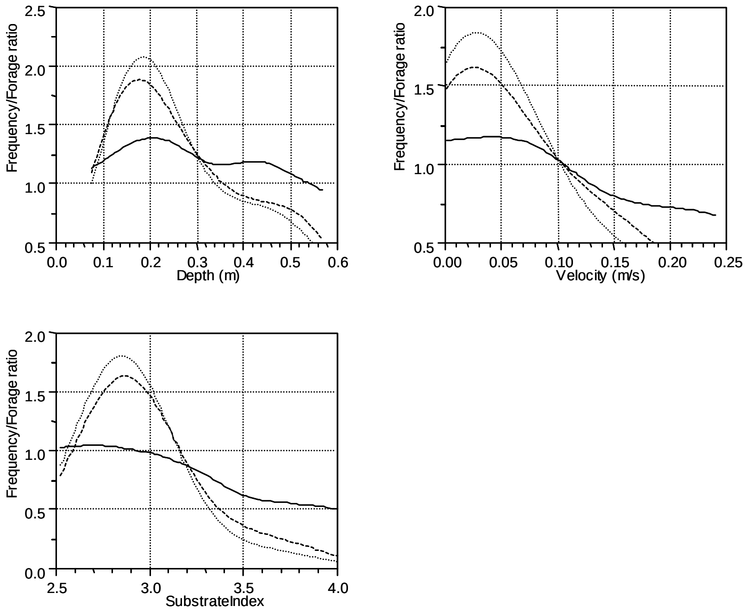


**Figure 4.17.1:** **Kernel smoothed frequency of habitat availability (dashed line), habitat use (dotted line), and the preference curves derived from all data (solid thin line) for juvenile lamprey.**

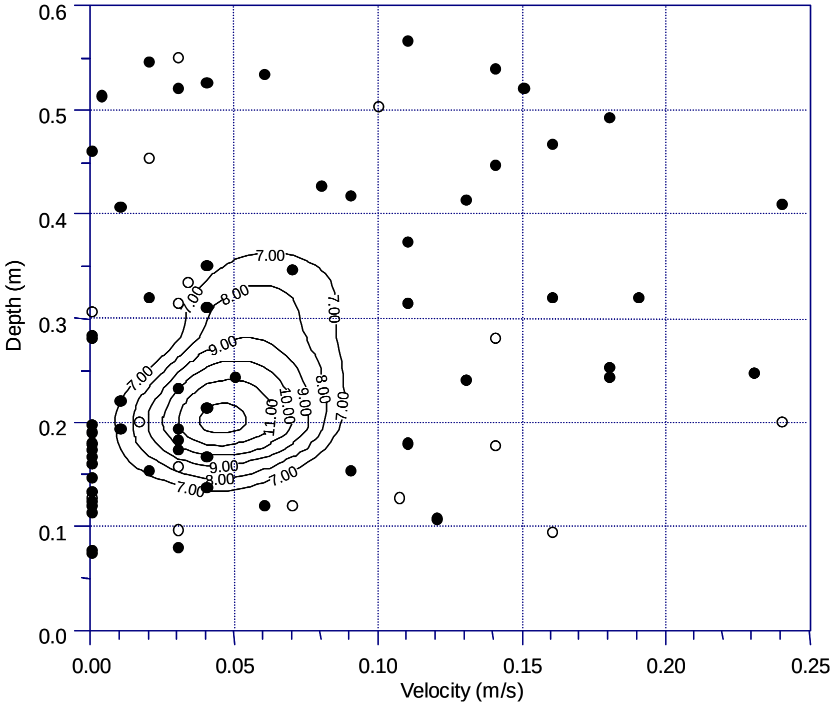


**Figure 4.17.2:** **LOESS contours fitted to juvenile lamprey densities and depth and velocity at all sampling locations. Locations containing juvenile lamprey are shown shaded.**

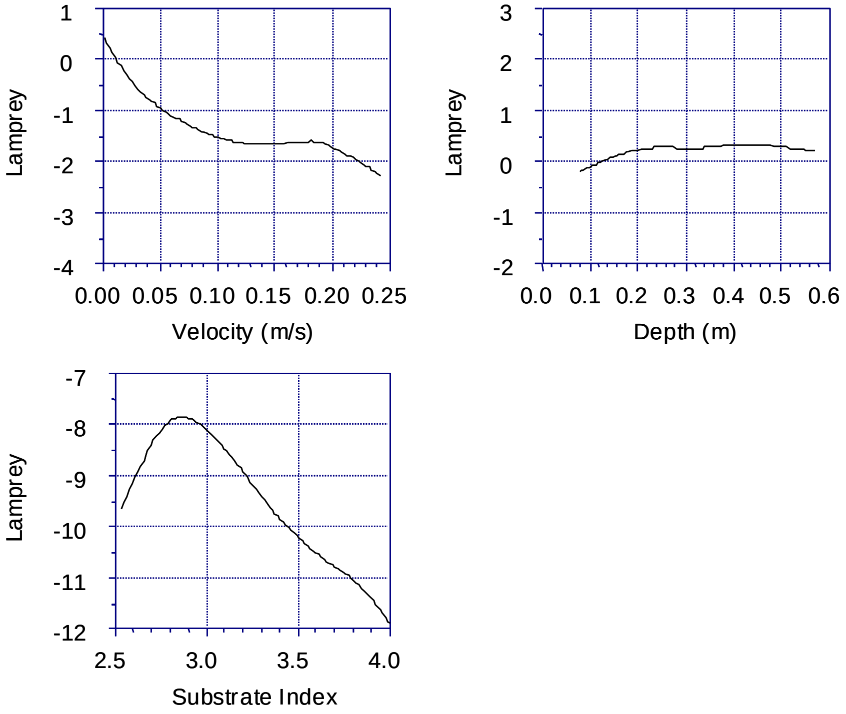


**Figure 4.17.3:** **Generalised additive logistic model of juvenile lamprey probability of use using depth, velocity and substrate index to give 77% correct prediction at a cut level of 0.5.**

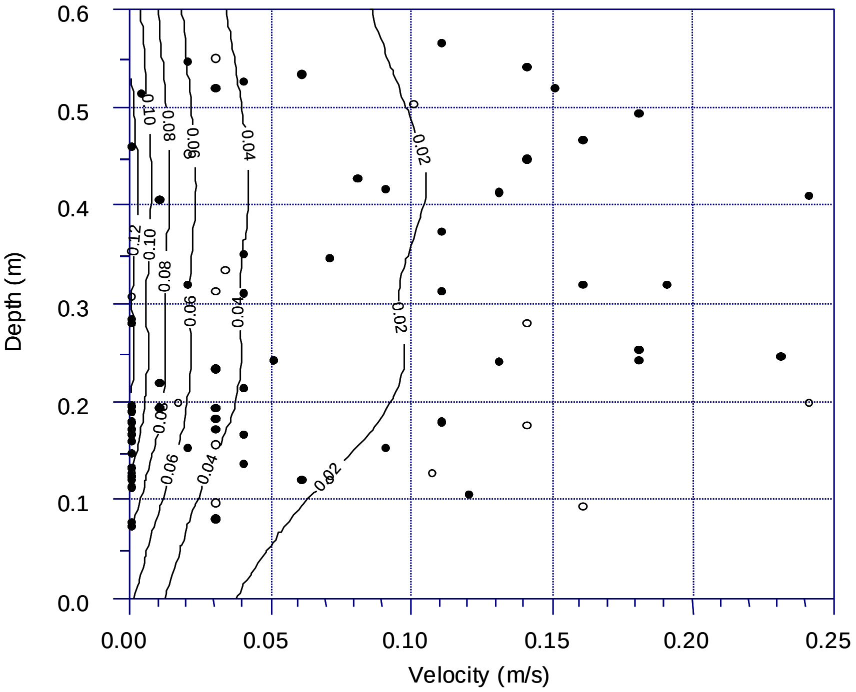


**Figure 4.17.4:** **Contour plot of GAM of probability of use using depth and velocity for a substrate index of 2 with points filled if juvenile lamprey were present.**

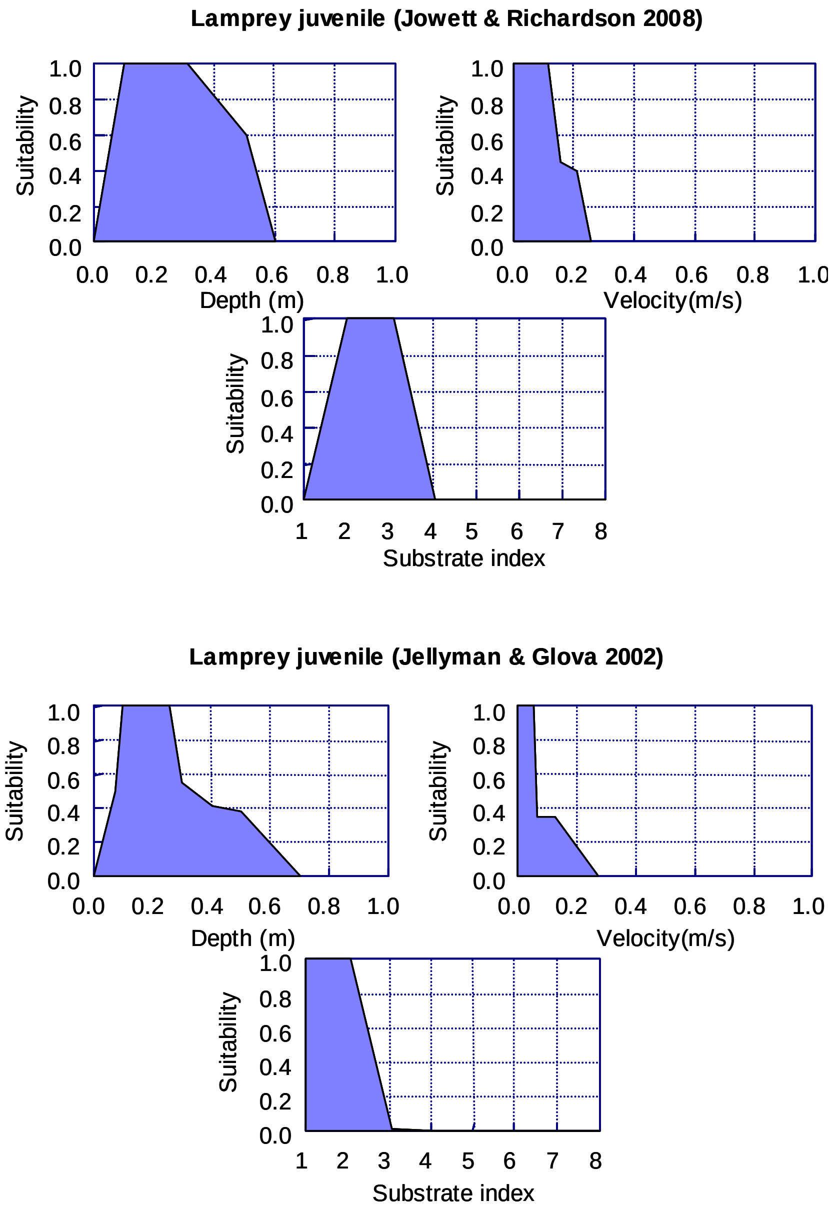


Figure 4.17.5: **Habitat suitability curves for juvenile lamprey derived from above analyses (top) compared with previous curves based on data from Jellyman & Glova (2002) (bottom).**

## 4.18 Crans bully

The non-diadromous Crans bully occurs only in the North Island, but not in the Bay of Plenty or East Cape, where its local extinction is thought to be due to the Taupo eruptions (McDowall 1996). Crans bully occurs well inland in low gradient waterways.

**Table 4.18.1: Habitat statistics for 560 Crans bully present at 133 of 799 locations in 17 rivers.**

| | Velocity (m/s) | Depth (m) | Substrate index | Substrate size (mm) |
|---|---|---|---|---|
| Minimum | 0.00 | 0.03 | 3.5 | 2.0 |
| Maximum | 0.97 | 0.85 | 6.8 | 210 |
| Average (SD) | 0.18 (0.18) | 0.19 (0.12) | 5.1 (0.7) | 49 (39) |

Crans bully preferred shallow water with low velocities, and gravel/cobble sized substrate (Fig. 4.18.1). The velocity at which 49 mm substrate (critical velocity) just begins to move at a depth of 0.18 m is 1.43 m/s.

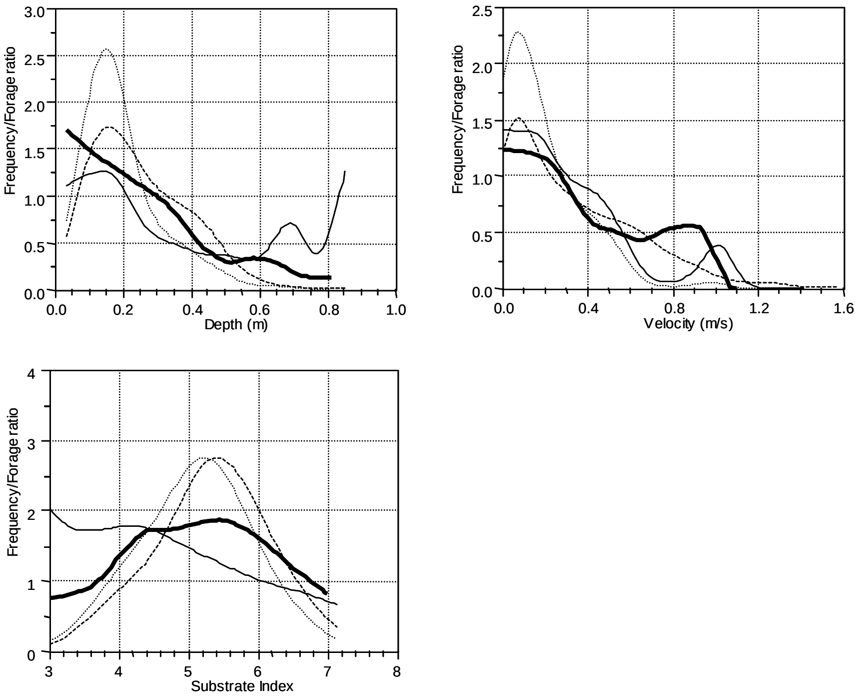


**Figure 4.18.1: Kernel smoothed frequency of habitat availability (dashed line), use (dotted line), and the preference curves derived from all data (solid thin line) and by averaging preference relationships in each river (solid thick line) for Crans bully.**

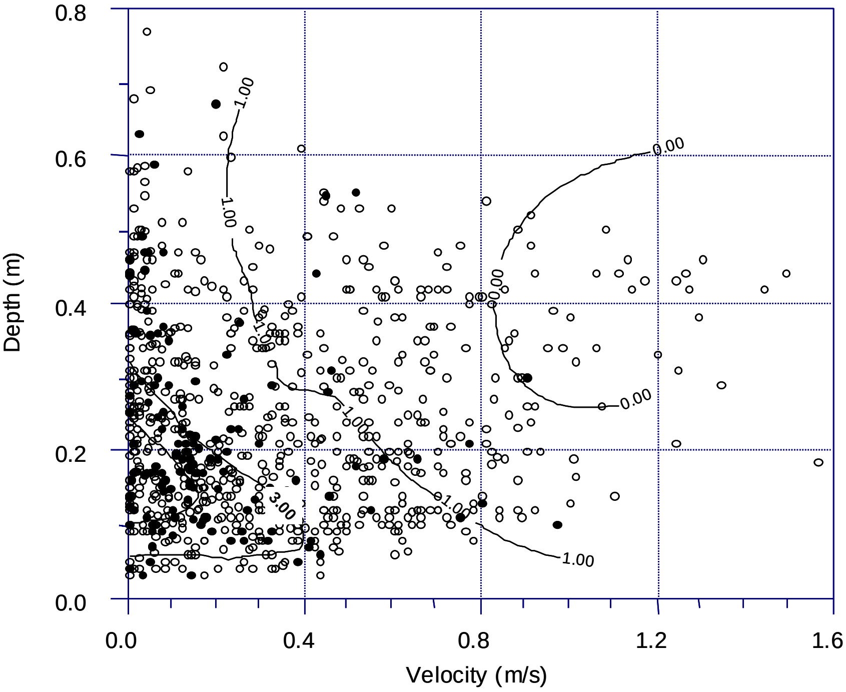


**Figure 4.18.2:** LOESS contours fitted to Crans bully densities and depth and velocity at all sampling locations. Locations containing Crans bully are shown shaded.

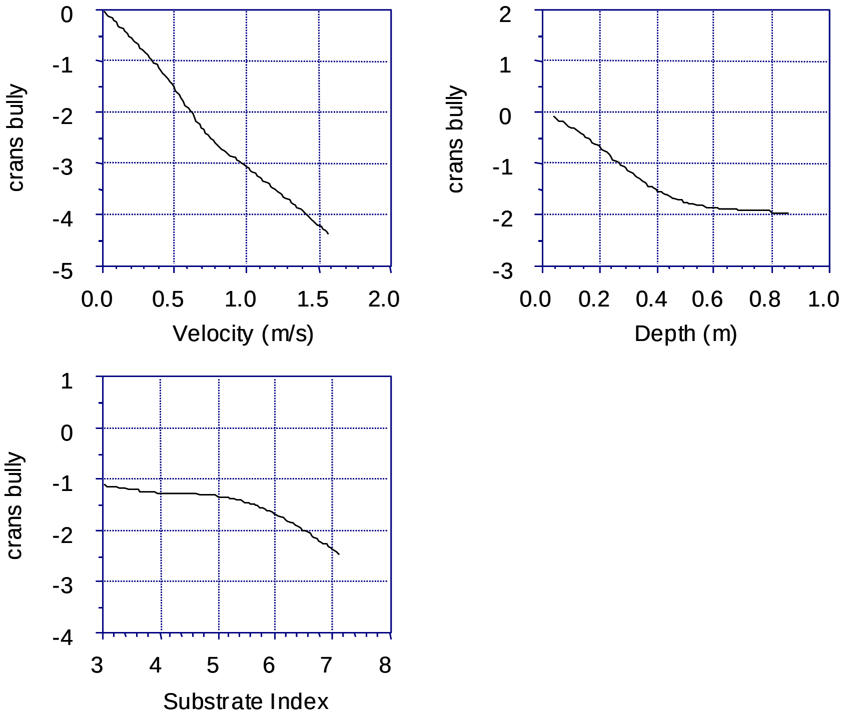


**Figure 4.18.3:** Generalised additive logistic model of Crans bully probability of use using depth, velocity and substrate index to give 75% correct prediction at a cut level of 0.7.

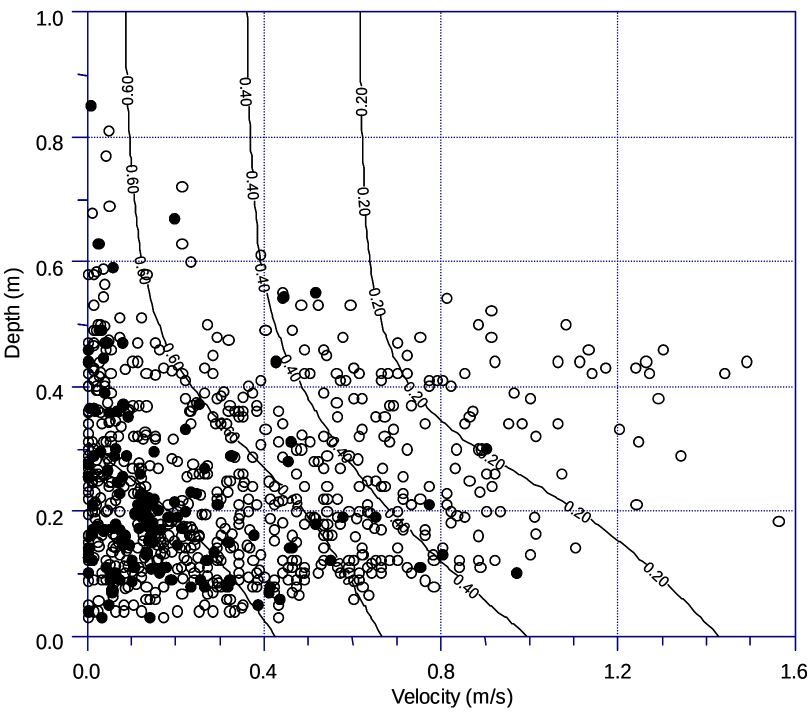


**Figure 4.18.4:** **Contour plot of GAM of probability of use using depth and velocity for a substrate index of 5 with points filled if Crans bully were present.**

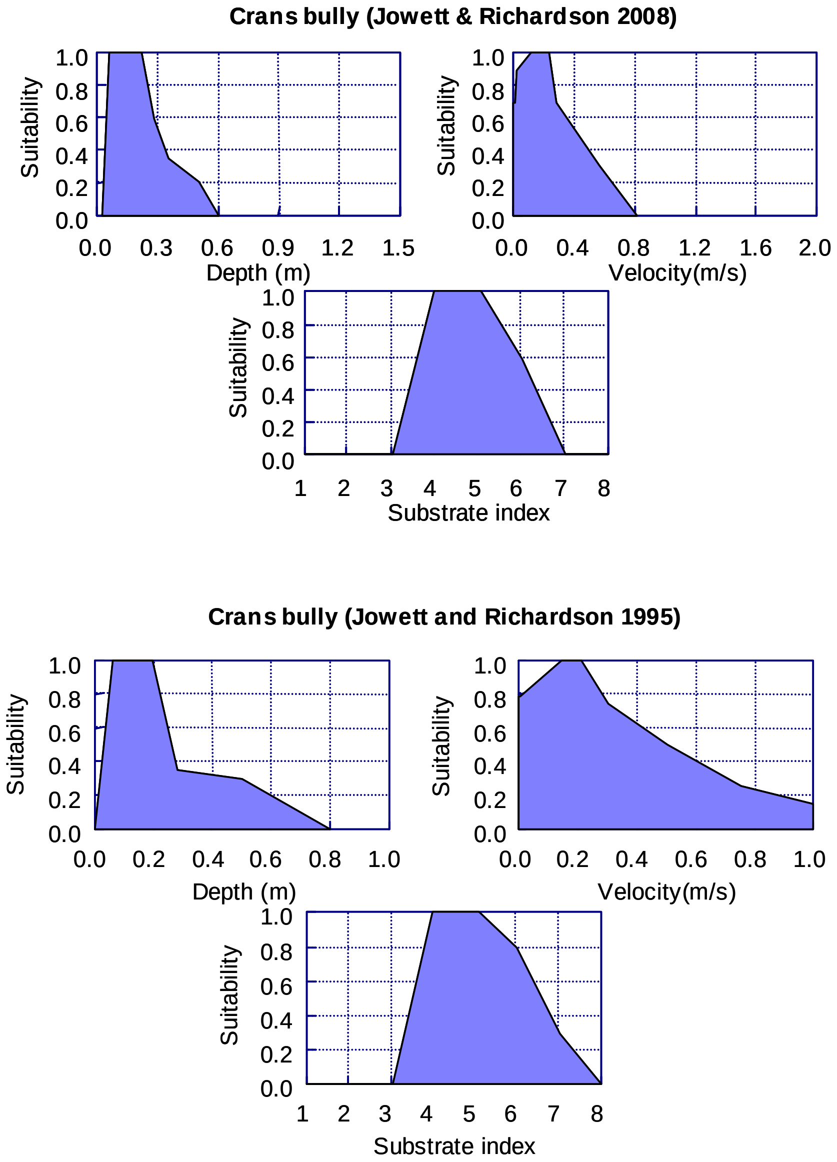


**Figure 4.18.5:** **Habitat suitability curves for Crans bully derived from above analyses (top) compared with curves based on data from Jowett & Richardson (1995) (bottom).**

## 4.19 Upland bully

Although the non-diadromous upland bully is confined to waterways south of Lake Taupo and was not a targeted species of any of the surveys, it was the most abundant species encountered, with over 3500 individuals being caught. Upland bully occurred in just under 40% of the rivers surveyed.

**Table 4.19.1: Habitat statistics for 3688 upland bully caught at 523 out of 1078 locations in 36 rivers.**

| | Velocity (m/s) | Depth (m) | Substrate index | Substrate size (mm) |
|---|---|---|---|---|
| Minimum | 0.00 | 0.03 | 2 | 0.01 |
| Maximum | 1.09 | 0.69 | 8 | 300 |
| Average (SD) | 0.40 (0.25) | 0.19 (0.11) | 5.0 (0.6) | 51 (29) |

Jowett & Richardson (1995) described upland bullies as edge-dwellers, preferring shallow depths and low velocities that are found along the margins of large to medium-sized rivers. Fine gravel to small cobble was their preferred substrate size, which upland bully use for cover and as a spawning substrate. The velocity at which 51 mm substrate (critical velocity) just begins to move at a depth of 0.20 m is 1.47 m/s. Upland bully are very tolerant of drought conditions (Jowett et al. 2005) and breed several times a year (McDowall & Eldon 1997), giving their populations the ability to recover quickly from adverse circumstances.

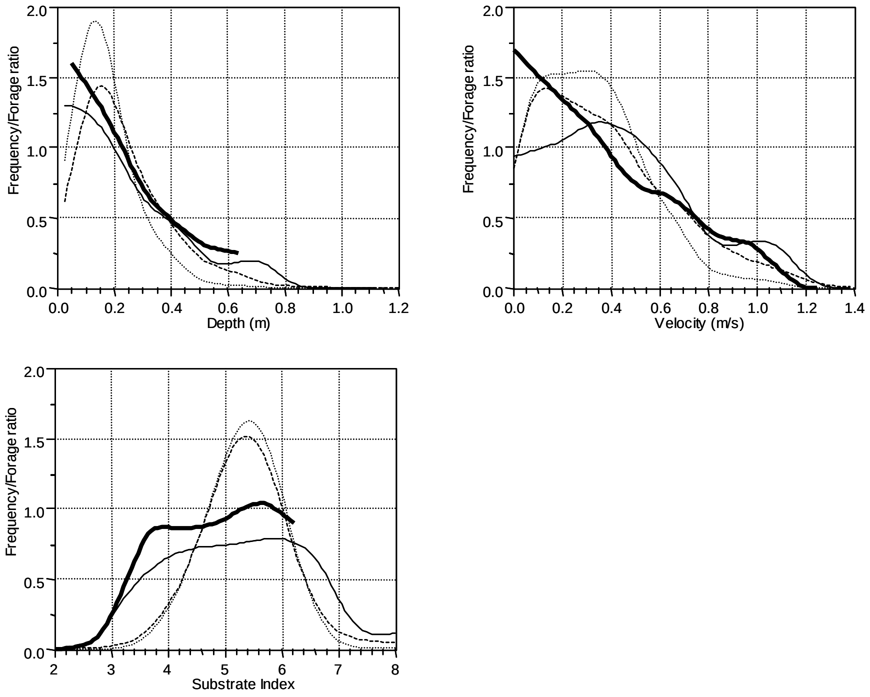


**Figure 4.19.1: Kernel smoothed frequency of habitat availability (dashed line), use (dotted line), and the preference curves derived from all data (solid thin line) and by averaging preference relationships in each river (solid thick line) for upland bully.**

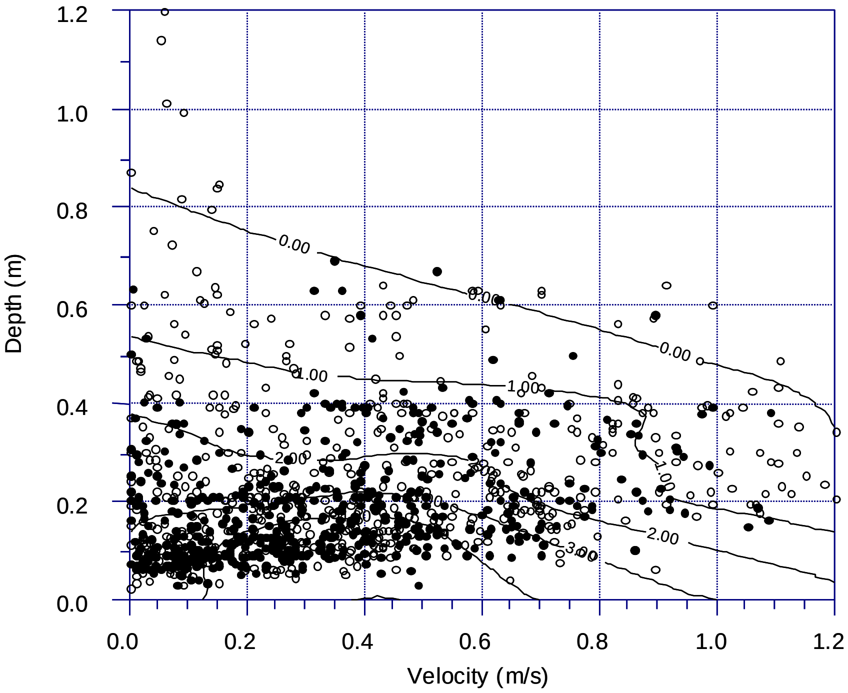


**Figure 4.19.2:** LOESS contours fitted to upland bully densities and depth and velocity at all sampling locations. Locations containing upland bully are shown shaded.

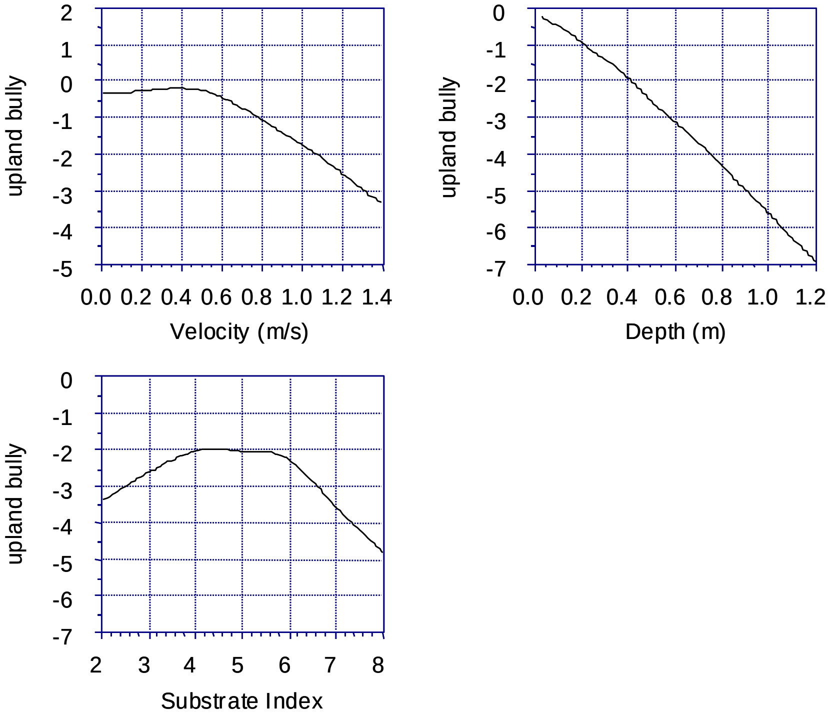


**Figure 4.19.3:** Generalised additive logistic model of upland bully probability of use using depth, velocity and substrate index to give 85% correct prediction at a cut level of 0.7.

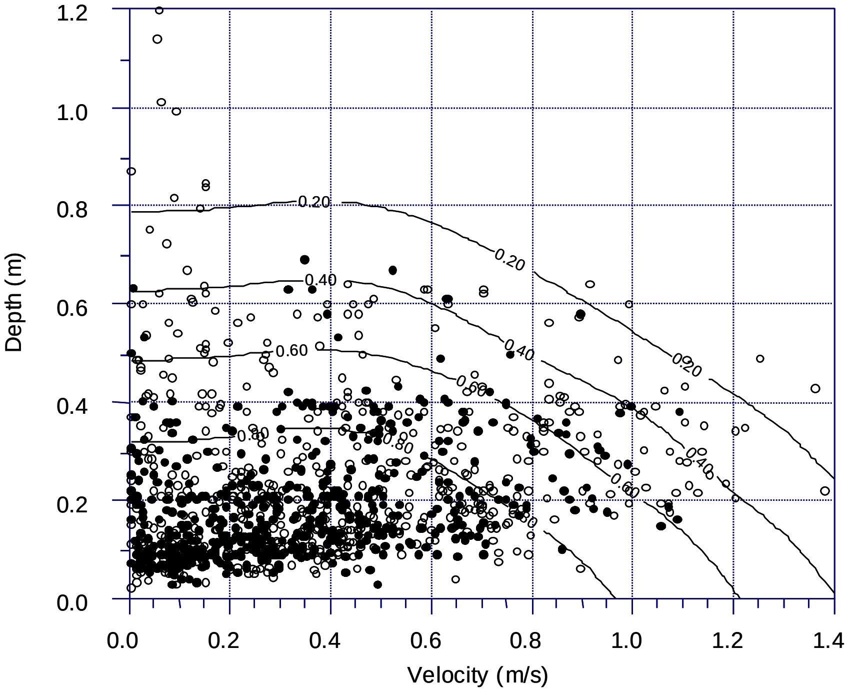


**Figure 4.19.4:** **Contour plot of GAM of probability of use using depth and velocity for a substrate index of 5 with points filled if upland bully were present.**

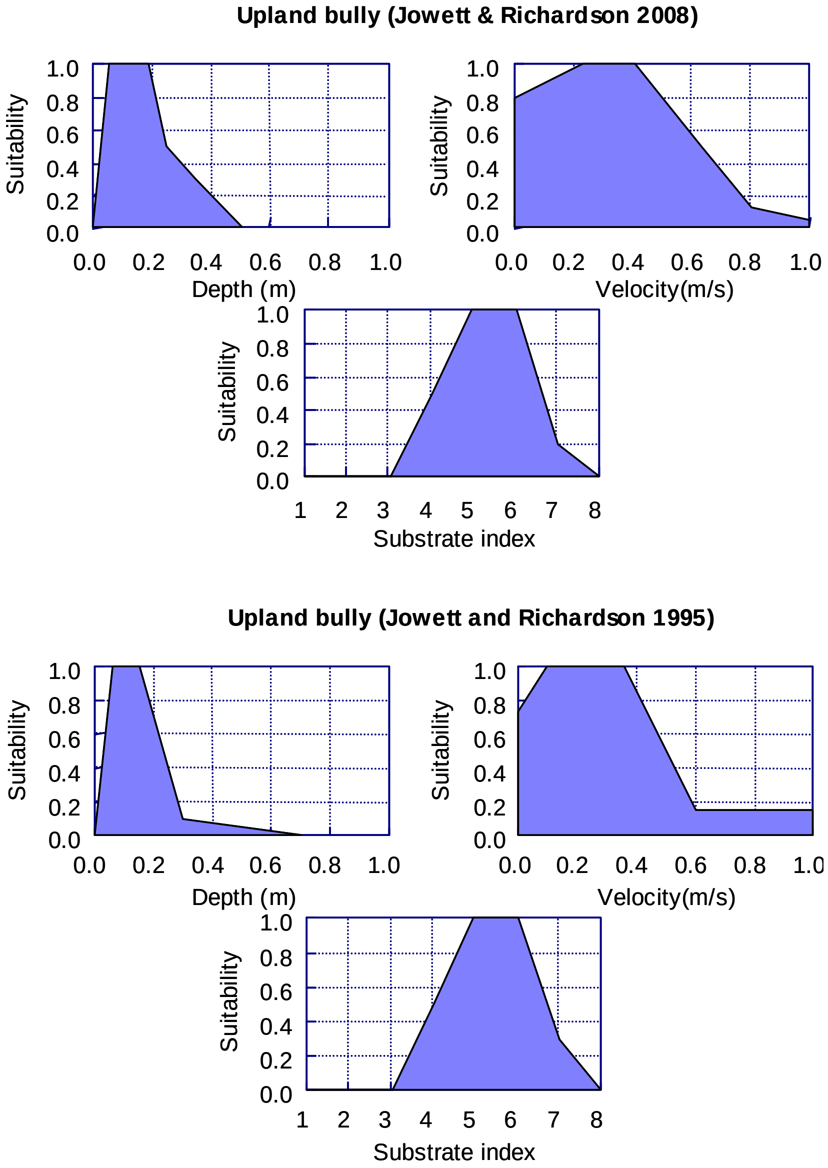


**Figure 4.19.5:** **Habitat suitability curves for upland bully derived from above analyses (top) compared with curves based on data from Jowett & Richardson (1995) (bottom).**

## 4.20 Common bully

Common bully are found throughout New Zealand, although they are rare on offshore islands such as Great Barrier. Truly diadromous populations occur in rivers and streams near the coast, and land-locked populations have become established in many of our lakes.

**Table 4.20.1: Habitat statistics for 1224 common bully present at 226 of 1400 locations in 31 rivers.**

| | Velocity (m/s) | Depth (m) | Substrate index | Substrate size (mm) |
|---|---|---|---|---|
| Minimum | 0.00 | 0.05 | 2.0 | <0.1 |
| Maximum | 1.07 | 0.67 | 7.0 | 360 |
| Average (SD) | 0.35 (0.22) | 0.21 (0.12) | 4.9 (0.7) | 45 (50) |

In this dataset, common bully occupied a wider range of depths than described by Jowett & Richardson (1995) and were mostly found in velocities ranging from 0–0.4 m/s, rather than 0.25-0.5 m/s in the Jowett & Richardson curve (Fig 4.20.5). The average depth of locations occupied by common bully was about 0.2 m, and the average velocity 0.35 m/s (Table 4.20.1). Common bully preferred low velocities and depths less than 0.5 m/s and relatively small substrate, with more than 60% found in fine and coarse gravel sized substrates (Fig. 4.20.1). The mean substrate size of 45 mm was skewed upward by bedrock outcrops occurring in some of the rivers they inhabited. The velocity at which 45 mm substrate (critical velocity) just begins to move at a depth of 0.21 m is 1.44 m/s.

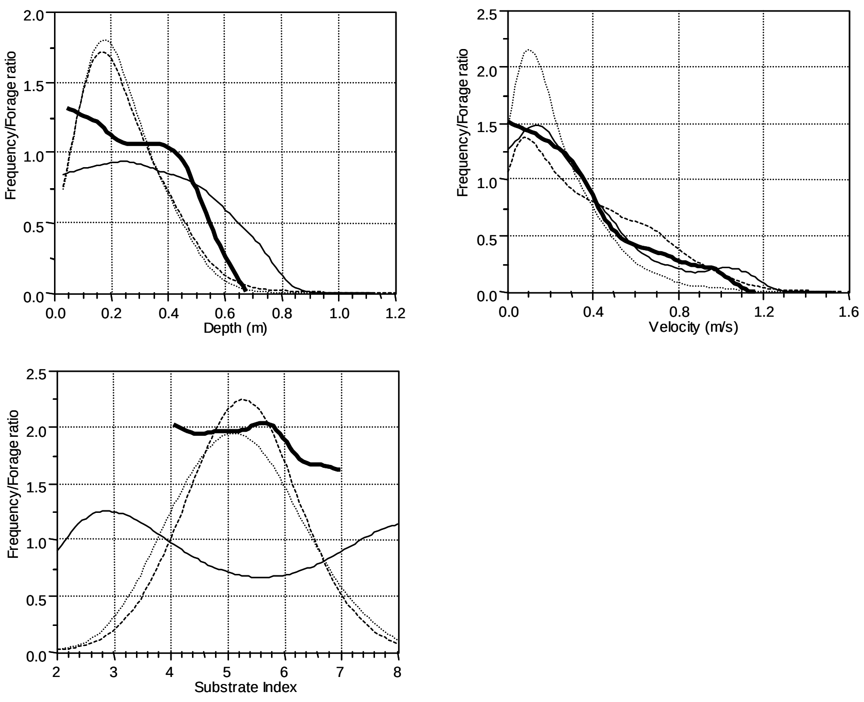


**Figure 4.20.1: Kernel smoothed frequency of habitat availability (dashed line), use (dotted line), and the preference curves derived from all data (solid thin line) and by averaging preference relationships in each river (solid thick line) for common bully.**

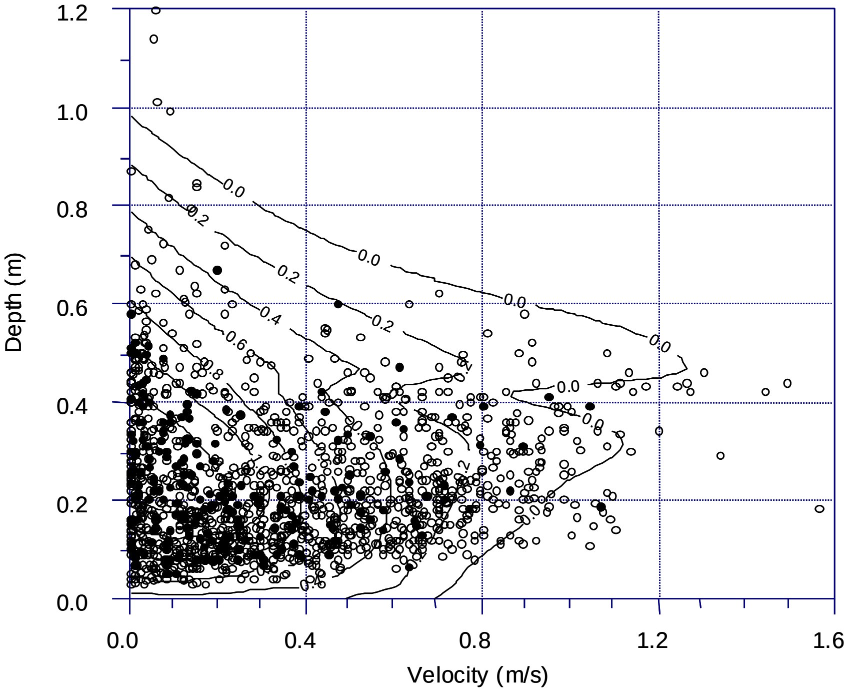


**Figure 4.20.2:** LOESS contours fitted to common bully densities and depth and velocity at all sampling locations. Locations containing common bully are shown shaded.

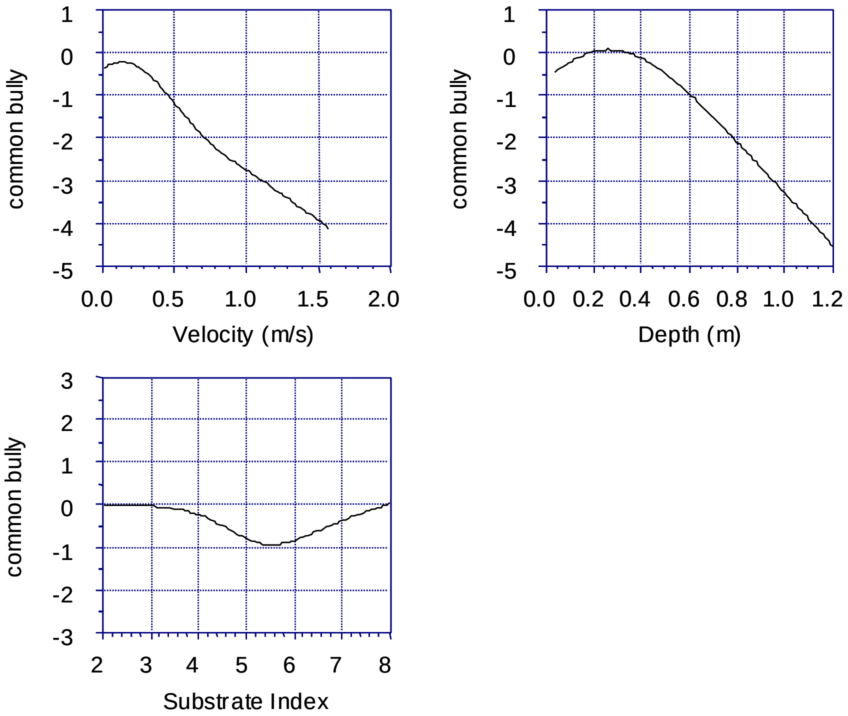


**Figure 4.20.3:** Generalised additive logistic model of common bully probability of use using depth, velocity and substrate index to give 65% correct prediction at a cut level of 0.5.

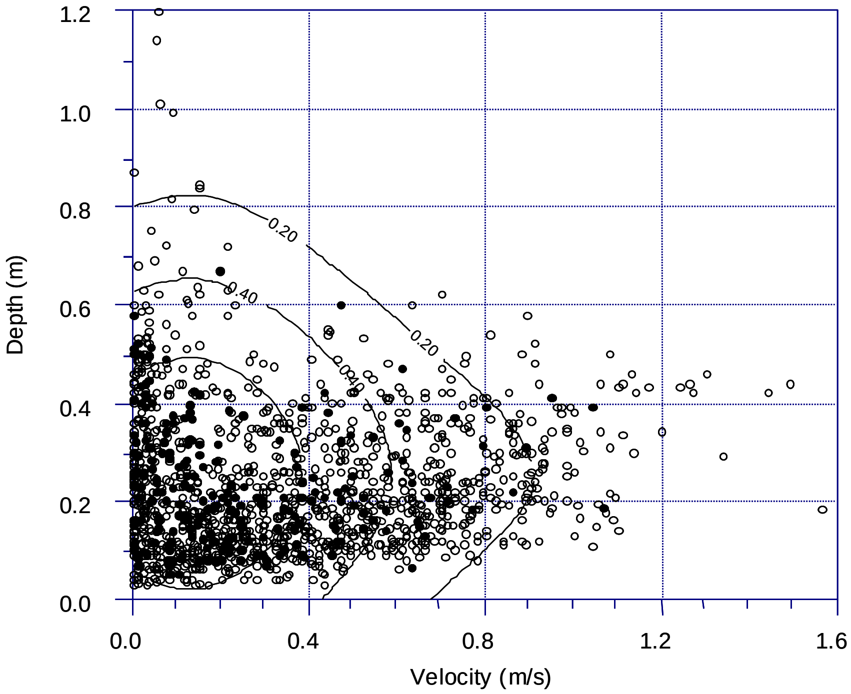
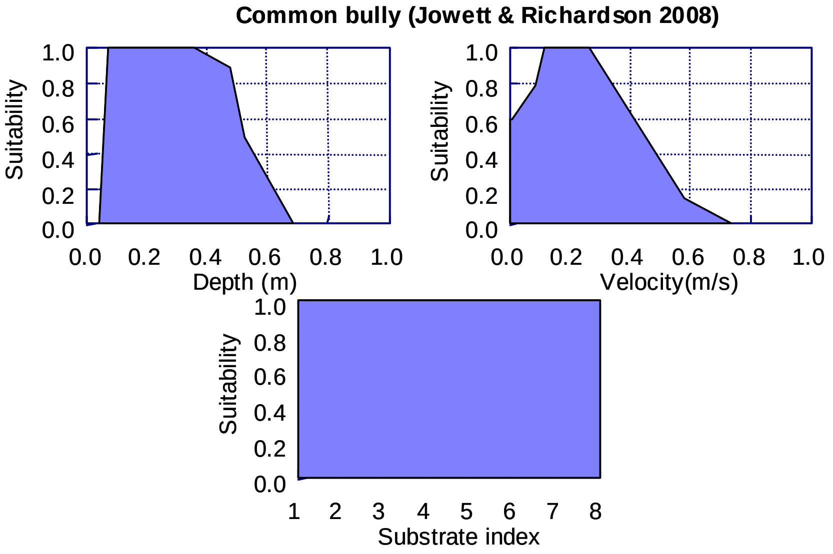


Figure 4.20.4: Contour plot of GAM of probability of use using depth and velocity for a substrate index of 4 with points filled if common bully were present.


Common bully (Jowett & Richardson 2008)

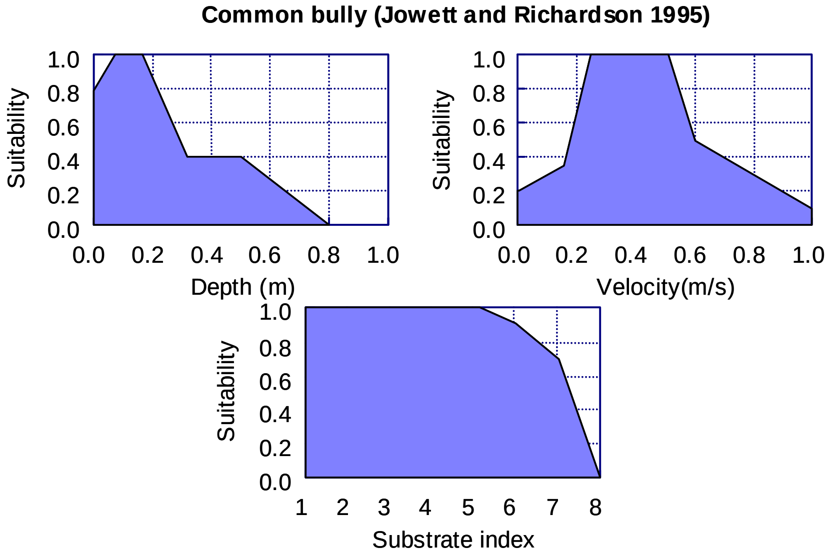

Common bully (Jowett and Richardson 1995)

**Figure 4.20.5:** **Habitat suitability curves for common bully derived from above analyses (top) compared with curves based on data from Jowett & Richardson (1995) (bottom).**

## 4.21 Bluegill bully

Surprisingly, bluegill bully were the second most abundant species encountered in the survey with over 3200 individual fish being caught. Although bluegill bully occur in waterways at moderate to low elevations throughout New Zealand, they were confined to just 15 of the 94 rivers included in the survey. Habitat suitability curves were first defined for bluegill bullies in the Rakaia River by Glova & Duncan (1985) and these curves are very similar to those described below.

Night observations for bluegill bully were available from the Waipara River and analysis of these data showed that bluegill bully use similar habitat at night as they do during the day.

**Table 4.21.1: Habitat statistics for 3253 bluegill bully present at 174 of 764 locations in 15 rivers.**

| | Velocity (m/s) | Depth (m) | Substrate index | Substrate size (mm) |
|---|---|---|---|---|
| Minimum | 0.02 | 0.05 | 4.1 | 11 |
| Maximum | 1.29 | 0.63 | 6.9 | 257 |
| Average (SD) | 0.68 (0.25) | 0.24 (0.09) | 5.1 (0.5) | 51 (28) |

Bluegill bullies occupy swift shallow water, like torrentfish, although they tend to be found in slightly smaller substrate. About 70% of the fish occurred in water between 0.1 and 0.3 m deep, and the mean velocity of 0.68 m/s (Table 4.21.1) was the second highest after torrentfish for the species included in the analysis (Table 4.1.2). Good habitat for bluegill bullies was identified as occurring at velocity greater than 0.45 m/s over a range of depths up to 0.5 m deep (Fig. 4.21.1). Preferred substrate size was between coarse gravel and small cobble, with boulders being generally avoided. The velocity at which 51 mm substrate (critical velocity) just begins to move at a depth of 0.24 m is 1.52 m/s. The maximum velocity was taken as 1.3 m/s, the maximum recorded (Fig. 4.21.2).

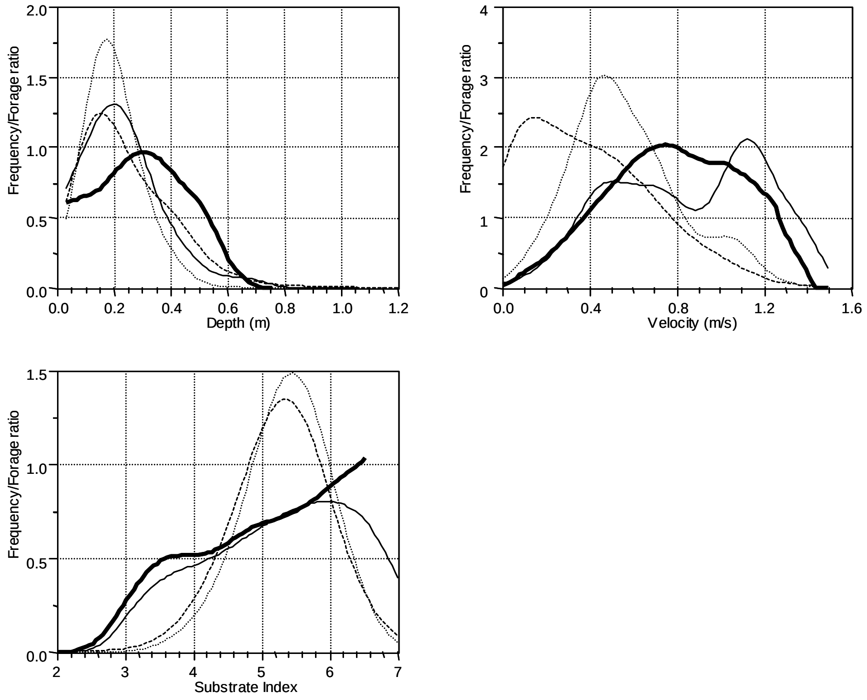


**Figure 4.21.1: Kernel smoothed frequency of habitat availability (dashed line), use (dotted line), and the preference curves derived from all data (solid thin line) and by averaging preference relationships in each river (solid thick line) for bluegill bully.**

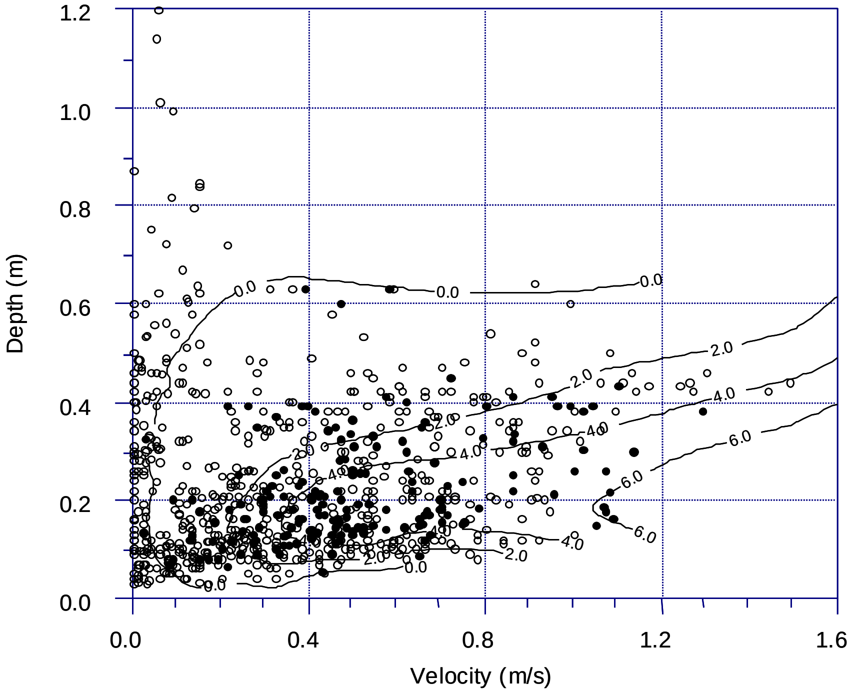


**Figure 4.21.2:** **LOESS contours fitted to bluegill bully densities and depth and velocity at all sampling locations. Locations containing bluegill bully are shown shaded.**

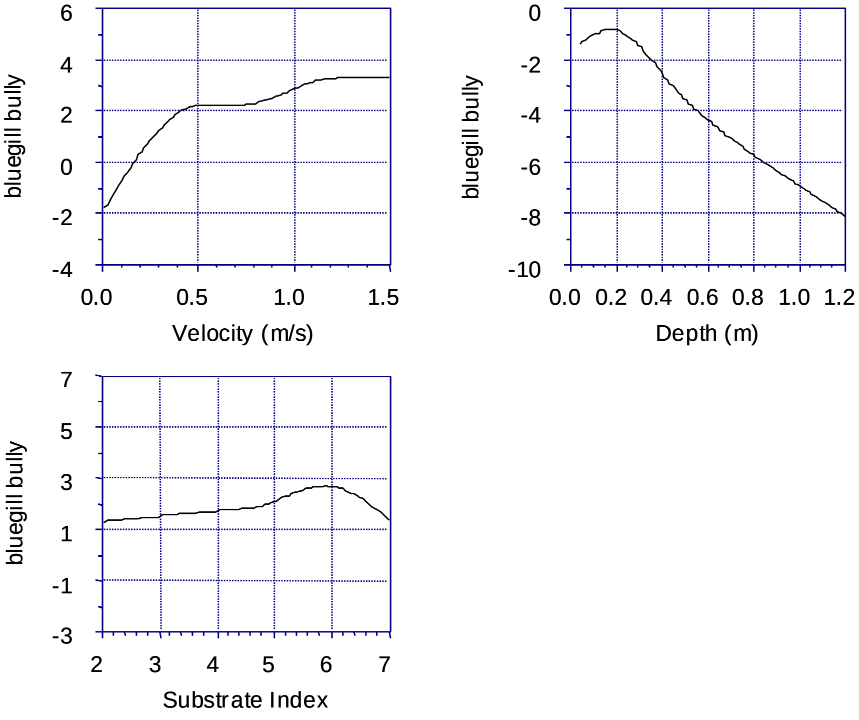


**Figure 4.21.3:** **Generalised additive logistic model of bluegill bully probability of use using depth, velocity and substrate index to give 84% correct prediction at a cut level of 0.6.**

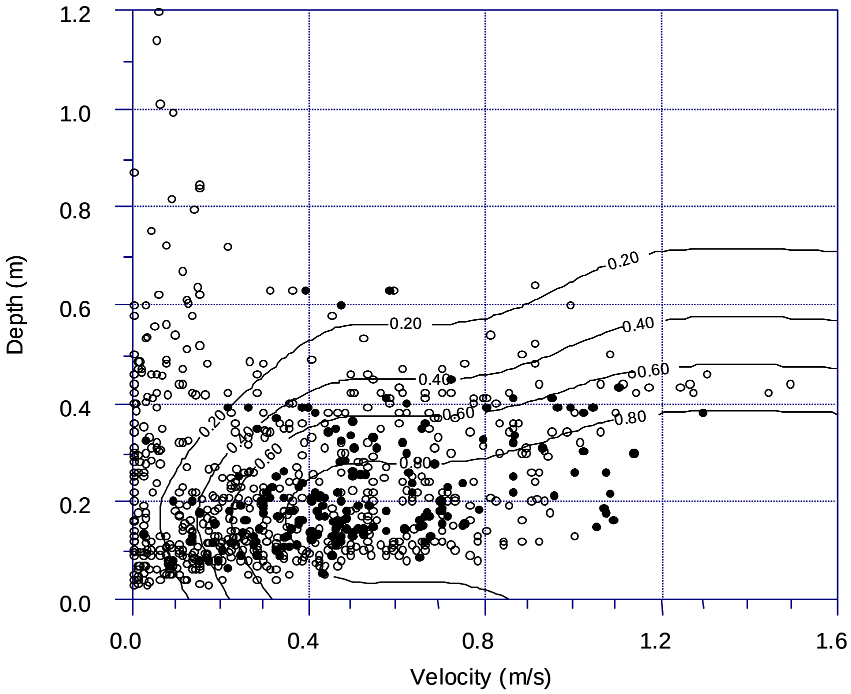


**Figure 4.21.4:** **Contour plot of GAM of probability of use using depth and velocity for a substrate index of 5 with points filled if bluegill bully were present.**

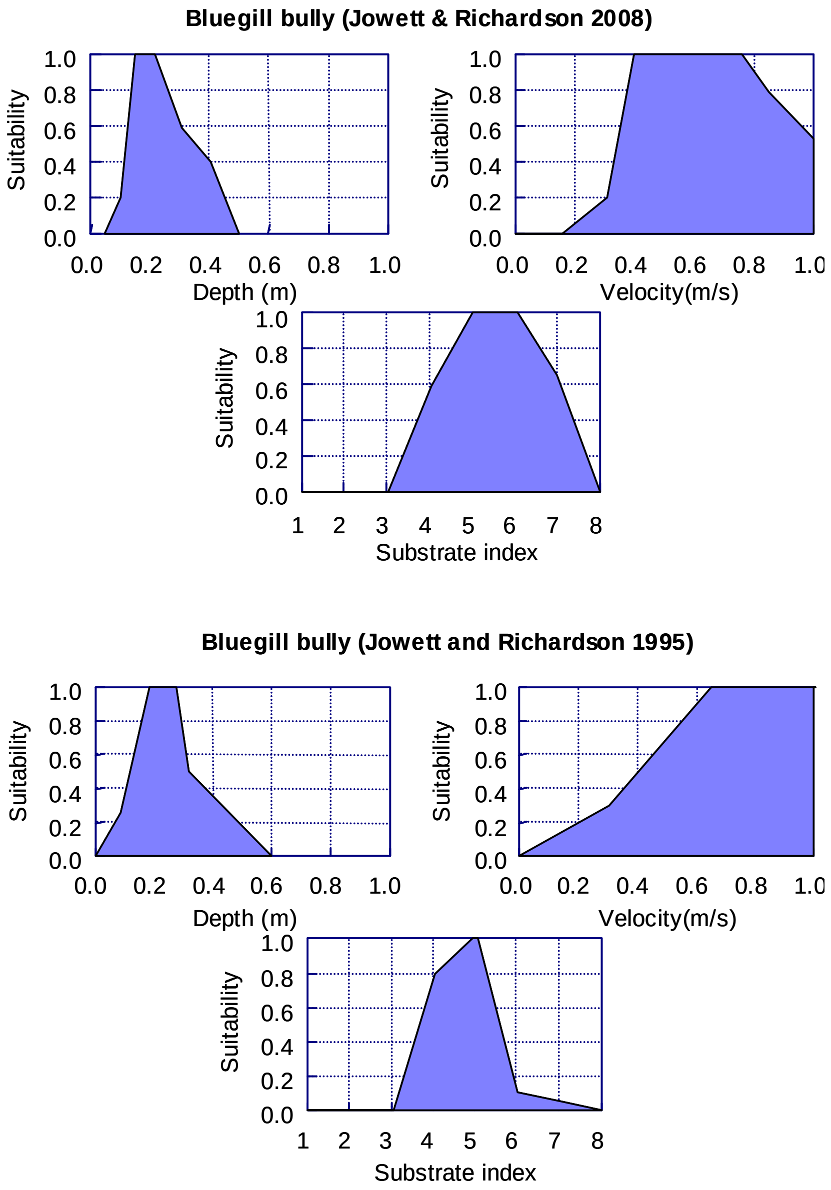


**Figure 4.21.5:** Habitat suitability curves for bluegill bully derived from above analyses (top) compared with curves based on data from Jowett & Richardson (1995) (bottom).

## 4.22 Redfin bully

Redfin bullies are diadromous and undertake obligatory migrations to and from the sea. They occupy transitional zones of rivers, regions where the steep mountainous character is changing to a meandering low gradient stream (McDowall 1964). This region of a stream typically has relatively large substrate, alternating pools and riffles, and little or no floodplain. This means they are rarely recorded in braided river systems, such as on the east coast of the South Island. Despite this, redfins were comparatively widespread, occurring in 28 of the 94 rivers surveyed for all fish species.

**Table 4.22.1: Habitat statistics for 564 redfin bully present at 197 of 920 locations in 28 rivers.**

| | Velocity (m/s) | Depth (m) | Substrate index | Substrate size (mm) |
|---|---|---|---|---|
| Minimum | 0.00 | 0.03 | 3.0 | 2 |
| Maximum | 1.07 | 0.72 | 7.1 | 257 |
| Average (SD) | 0.25 (.20) | 0.21 (0.11) | 5.6 (0.7) | 87 (57) |

Most redfin bullies were recorded in water between 0.1 m and 0.3 m deep, and 40% of those caught occurred in water 0.2–0.4 m/s velocity (Table 4.22.1). The average substrate size was large (87 mm), reflecting their occupation of the transitional zones of rivers, and use of large substrate for cover and spawning. They preferred moderate depths (0.2 m) and velocities (0.3 m/s), with cobble/boulder substrate (Fig. 4.22.1). The velocity at which 87 mm substrate (critical velocity) just begins to move at a depth of 0.21 m is 1.63 m/s.

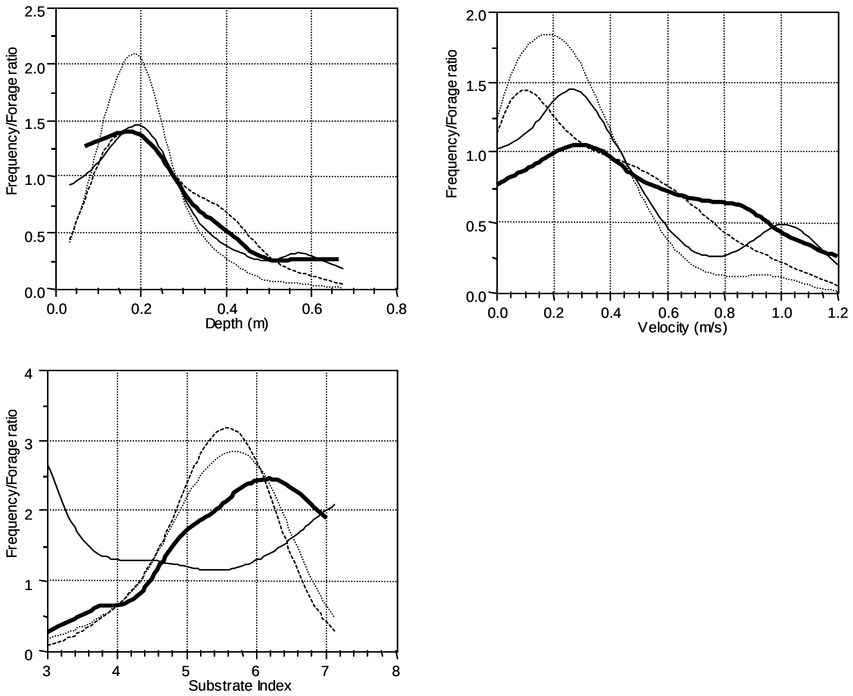


**Figure 4.22.1: Kernel smoothed frequency of habitat availability (dashed line), use (dotted line), and the preference curves derived from all data (solid thin line) and by averaging preference relationships in each river (solid thick line) for redfin bully.**

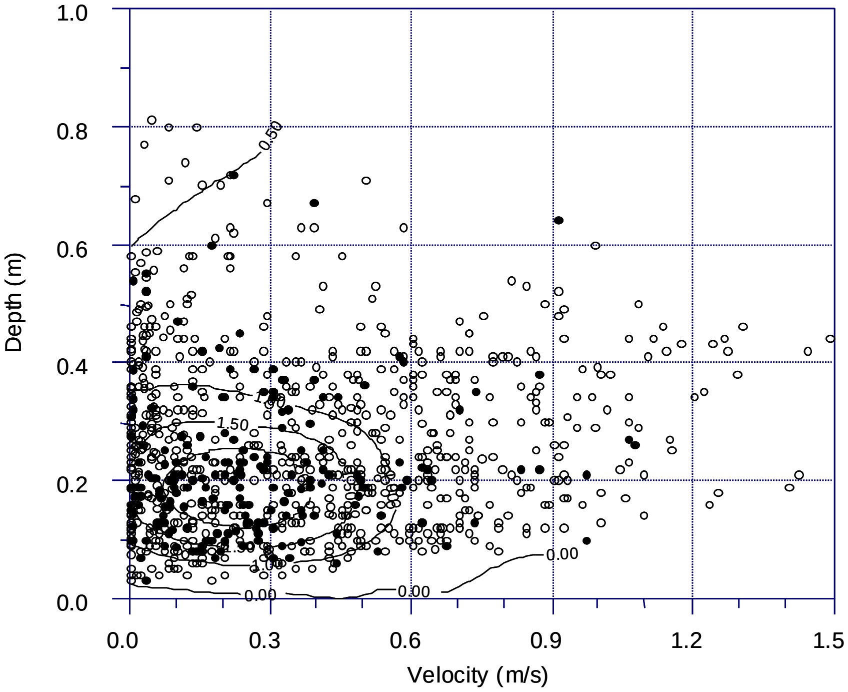


**Figure 4.22.2:** LOESS contours fitted to redfin bully densities and depth and velocity at all sampling locations. Locations containing redfin bully are shown shaded.

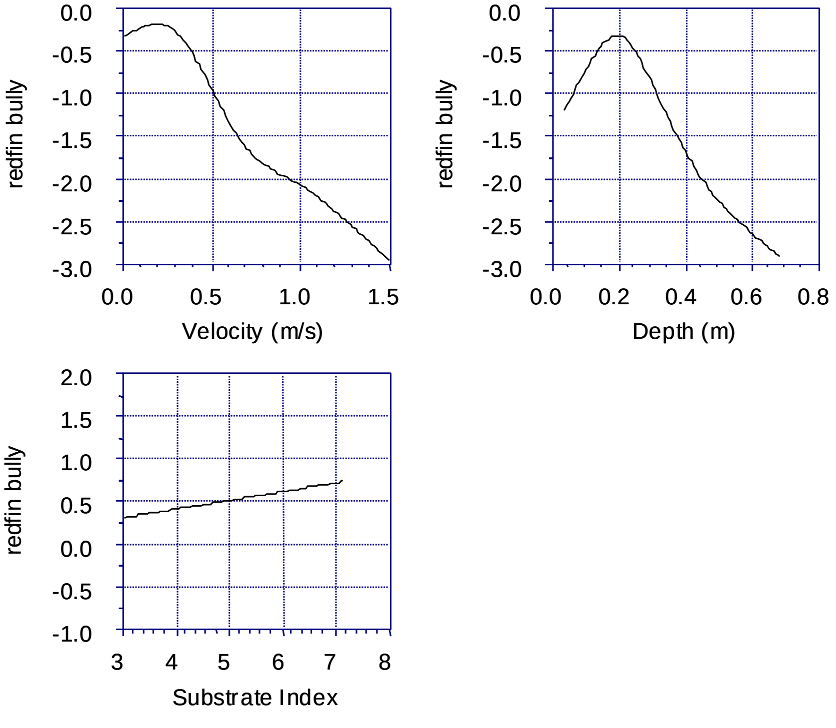


**Figure 4.22.3:** Generalised additive logistic model of redfin bully probability of use using depth, velocity and substrate index to give 70% correct prediction at a cut level of 0.6.

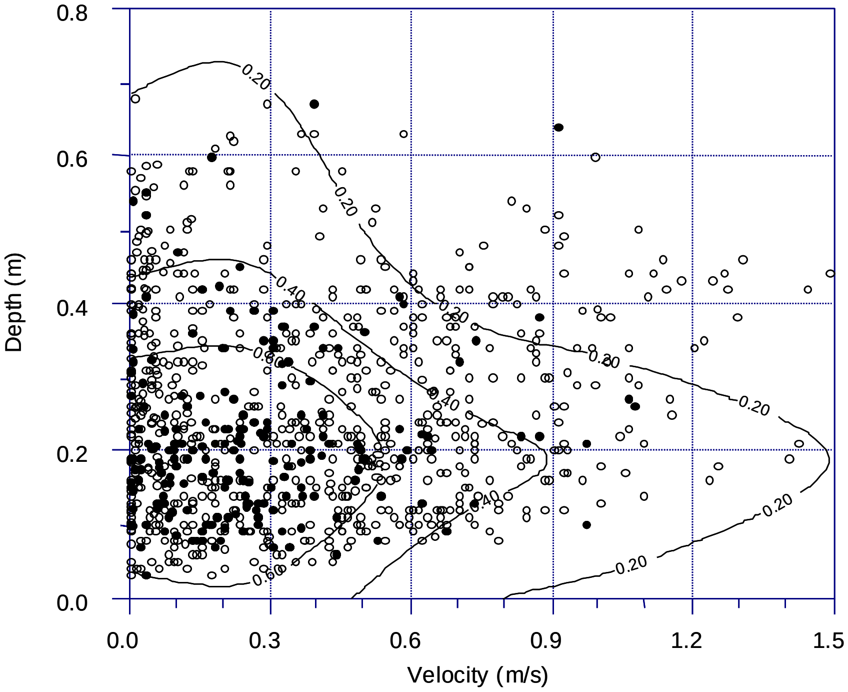


**Figure 4.22.4:** **Contour plot of GAM of probability of use using depth and velocity for a substrate index of 6 with points filled if redfin bully were present.**

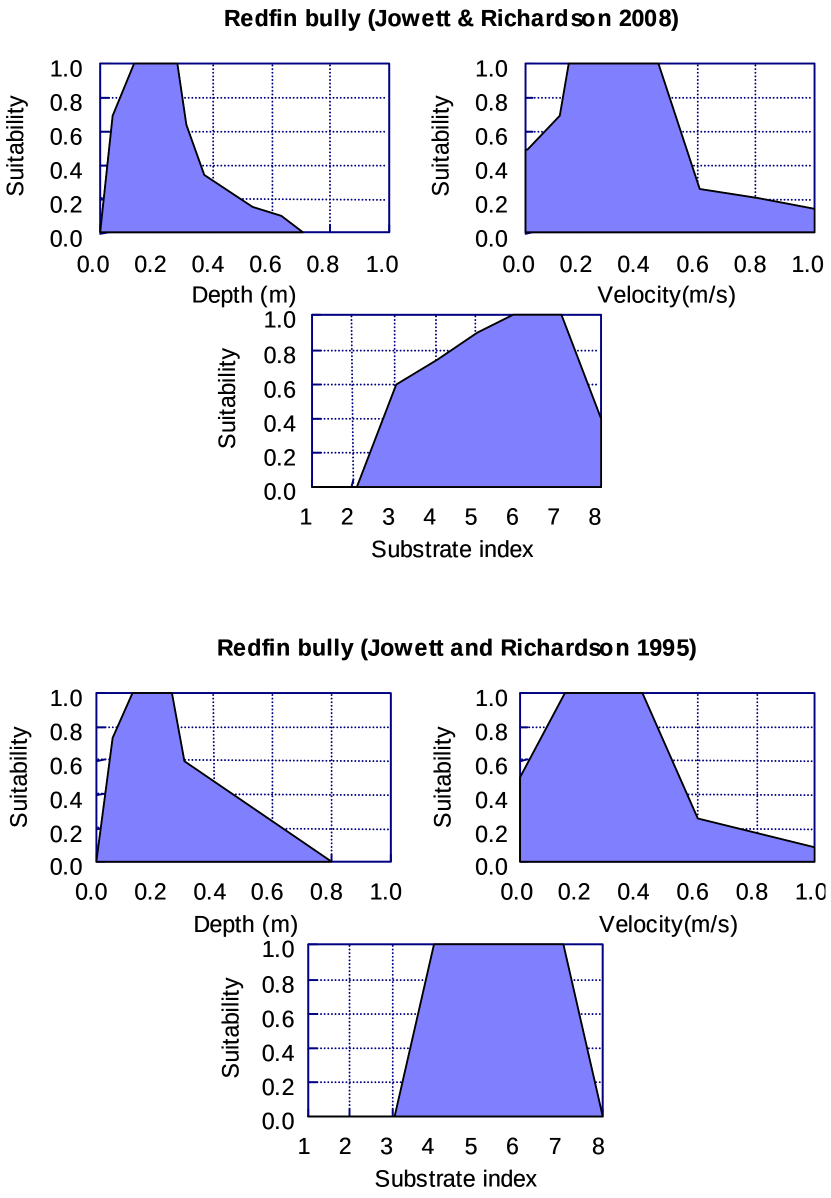


**Figure 4.22.5:** **Habitat suitability curves for redfin bully derived from above analyses (top) compared with curves based on data from Jowett & Richardson (1995) (bottom).**

## 4.23 Smelt

Smelt were the only pelagic species included in our analysis, and the fish may have been herded into the locations where they were caught. They were found in deeper water (average 0.4 m) than any of the other species, in keeping with their mid-water habit, although this finding was influenced by the capture of a small school of smelt at a single deep location in the Waipara River. Observations of smelt in the Waikato River and underwater observations in other rivers indicate that smelt do not avoid deep water, and are found in relatively swift water. Electric fishing disturbs smelt and observations of smelt in deep water and relatively high velocities have been taken into account in the habitat suitability curves. Being a pelagic species, substrate is not as important to smelt as the other species that use it for cover.

**Table 4.23.1: Habitat statistics for 107 smelt present at 35 of 255 locations in 7 rivers.**

| | Velocity (m/s) | Depth (m) | Substrate index | Substrate size (mm) |
|---|---|---|---|---|
| Minimum | 0.03 | 0.09 | 3.0 | 2 |
| Maximum | 0.87 | 0.80 | 6.0 | 118 |
| Average (SD) | 0.25 (0.18) | 0.39 (0.19) | 4.9 (0.8) | 40 (32) |

Only 8% of smelt were found in water velocities over 0.4 m/s, and their preference was for deeper water (> 0.4 m) and a velocity of 0.2 m/s, although they used higher velocities (Fig. 4.23.1), The velocity at which 40 mm substrate (critical velocity) just begins to move at a depth of 0.39 m is 1.55 m/s.

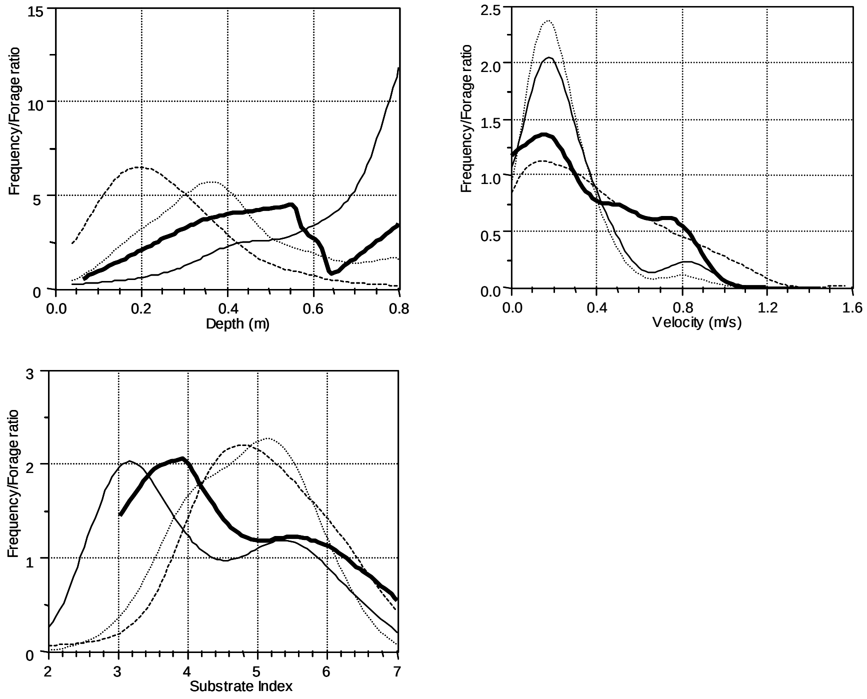


**Figure 4.23.1: Kernel smoothed frequency of habitat availability (dashed line), use (dotted line), and the preference curves derived from all data (solid thin line) and by averaging preference relationships in each river (solid thick line) for smelt.**

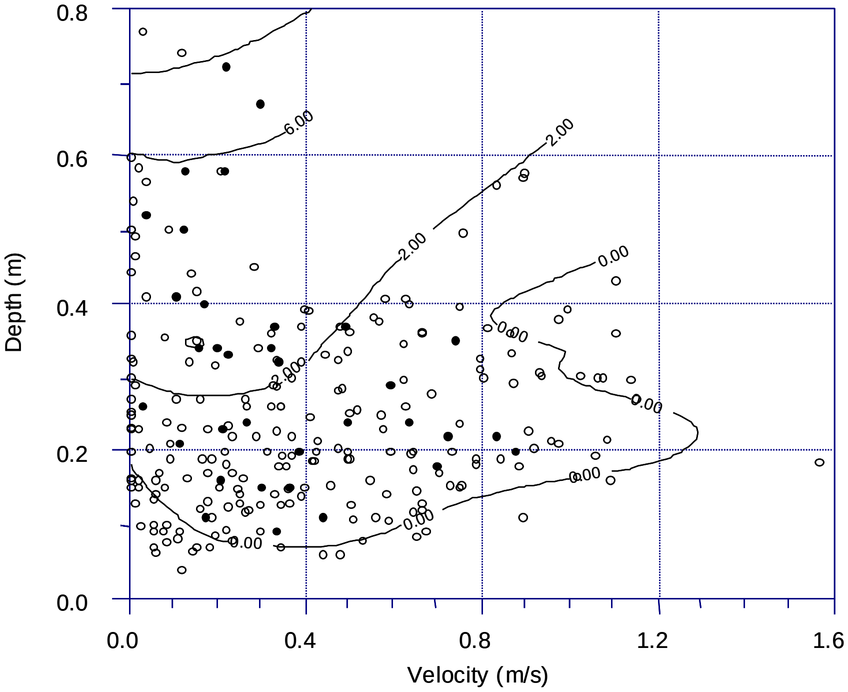


**Figure 4.23.2:** **LOESS contours fitted to smelt densities and depth and velocity at all sampling locations. Locations containing smelt are shown shaded.**

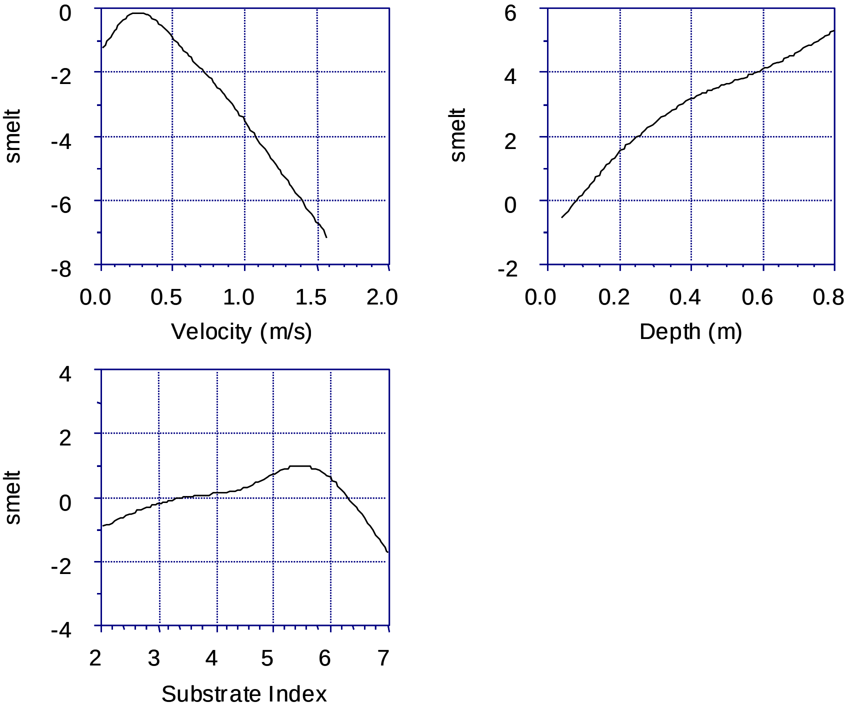


**Figure 4.23.3:** **Generalised additive logistic model of smelt probability of use using depth, velocity and substrate index to give 81% correct prediction at a cut level of 0.7.**

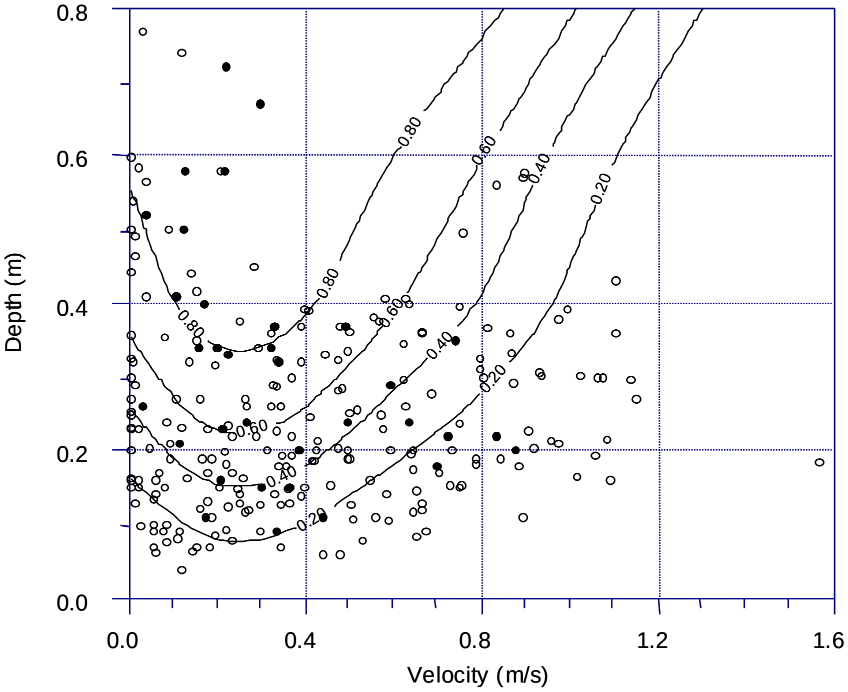


**Figure 4.23.4:** **Contour plot of GAM of probability of use using depth and velocity for a substrate index of 6 with points filled if smelt were present.**

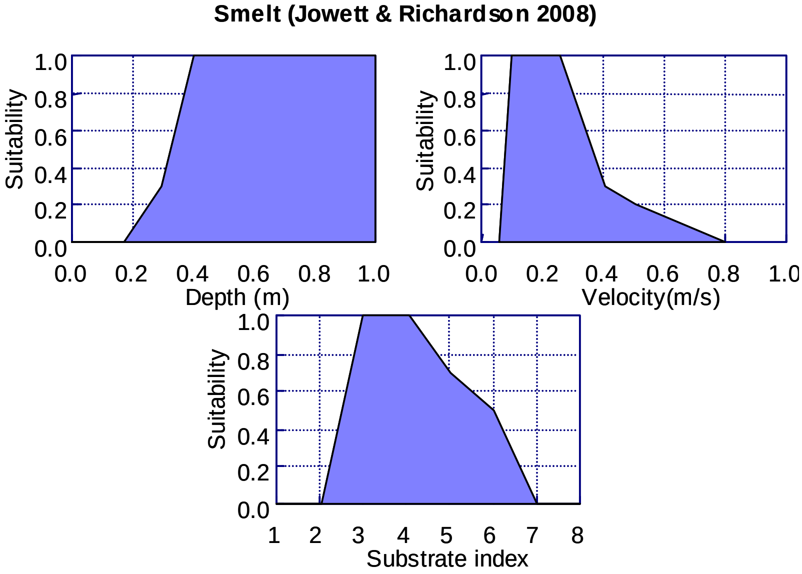


**Figure 4.23.5:** **Habitat suitability curves for smelt derived from above analyses.**

## 4.24 Juvenile rainbow trout (< 100 mm)

Rainbow trout are native to the westward draining rivers of North America and also to the Kamchatka Peninsula on the western side of the Pacific Ocean. The stock introduced into New Zealand was brought from North America as early as 1883. Although they were not as easy to establish as brown trout, self-sustaining populations of rainbow trout are now widespread in New Zealand and form the popular and highly valued fisheries that occur in the lakes and rivers of the central North Island. They also support fisheries in many of the lakes along the eastern flanks of the Southern Alps in the South Island.

Most rainbow trout migrate to their spawning grounds, with both lake and river dwelling fish moving upstream to suitable locations, often in small tributaries. Here they may congregate in large schools just prior to spawning, although generally adult rainbow trout are found in deep locations (Jowett et al. 1996; Jowett & Davey 2007).

The suitability curves presented here are for rainbow trout < 100 mm that were present in the wadeable rivers of our study. Small trout observed by drift-diving (Teirney and Jowett 1990) were usually seen in shallow boulder/cobble runs or riffles. Trout < 100 mm were usually on the edges of riffles in water less than 0.3 m deep. The trout locations used for the derivation of habitat suitability here were sampled by electric-fishing, so the fish were probably in cover near their feeding locations.

**Table 4.24.1: Habitat statistics for 252 rainbow trout (< 100 mm) present at 82 of 679 locations in 9 rivers.**

| | Velocity (m/s) | Depth (m) | Substrate index | Substrate size (mm) |
|---|---|---|---|---|
| Minimum | 0.00 | 0.04 | 3.0 | 2 |
| Maximum | 1.09 | 0.45 | 6.1 | 143 |
| Average (SD) | 0.53 (0.28) | 0.21 (0.09) | 4.9 (0.6) | 53 (35) |

Juvenile rainbow trout preferred shallow water, coarse substrate and a wide range of velocities (Fig. 4.24.1). The velocity at which 53 mm substrate (critical velocity) just begins to move at a depth of 0.21 m is 1.50 m/s. Disturbance during sampling may have affected habitat preferences for juvenile trout with electric fishing causing them to flee into coarse substrates in shallow water. However, observations in the Tongariro (Table 4.24.2) indicate that preferred water depths and velocities of juvenile rainbow trout increase with size and the data analysed here are consistent with juvenile trout of about 50-60 mm from the Tongariro River.

**Table 4.24.2: Rainbow trout habitat measurements from the Tongariro River (Jowett et al. 1996 and unpublished underwater observations in 2002)**

| | Fry (1996) (N=469, mean size 34mm) | Juvenile (1996) (N=265, mean size 60 mm) | Feeding 30-80 mm (2002) (N=74, mean 50 mm) | Feeding 100-200 mm (2002) (N=67, mean 150 mm) | Adult lies N=147, 1996 |
|---|---|---|---|---|---|
| Depth (m) | 0.17 | 0.26 | 0.23 | 0.72 | 1.32 |
| Velocity (m/s) | 0.11 | 0.16 | 0.17 | 0.59 | 0.68 |

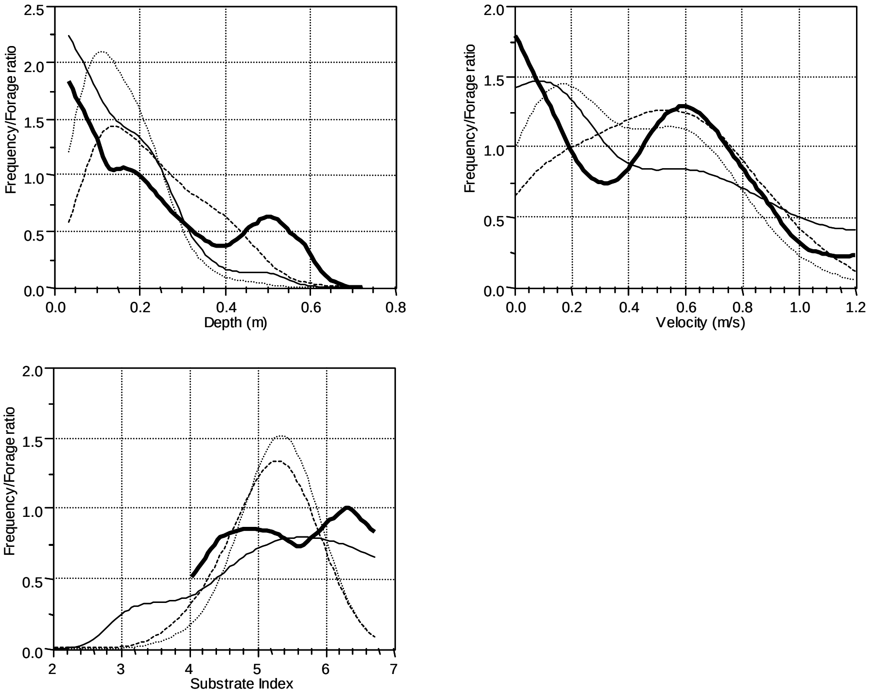


**Figure 4.24.1:** Kernel smoothed frequency of habitat availability (dashed line), use (dotted line), and the preference curves derived from all data (solid thin line) and by averaging preference relationships in each river (solid thick line) for rainbow trout (< 100 mm).

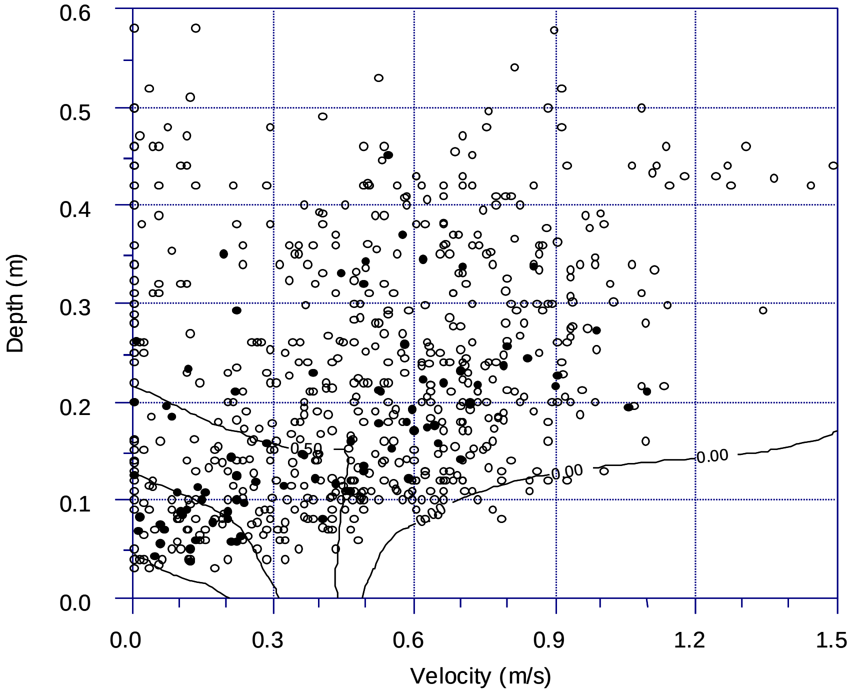


**Figure 4.24.2:** LOESS contours fitted to rainbow trout (< 100 mm) densities and depth and velocity at all sampling locations. Locations containing rainbow trout are shown shaded.

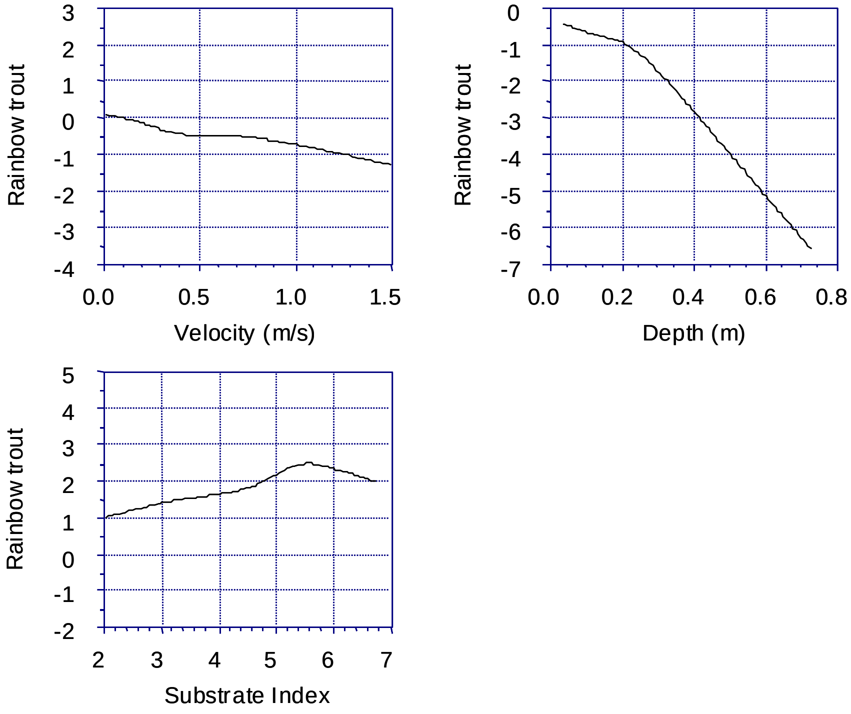


**Figure 4.24.3:** **Generalised additive logistic model of rainbow trout (< 100 mm) probability of use using depth, velocity and substrate index to give 74% correct prediction at a cut level of 0.5.**

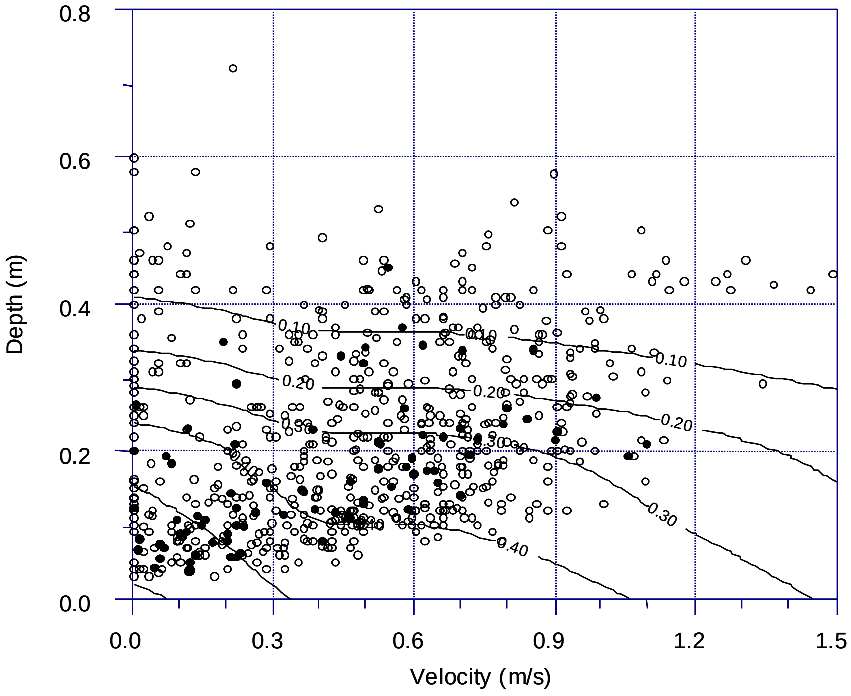
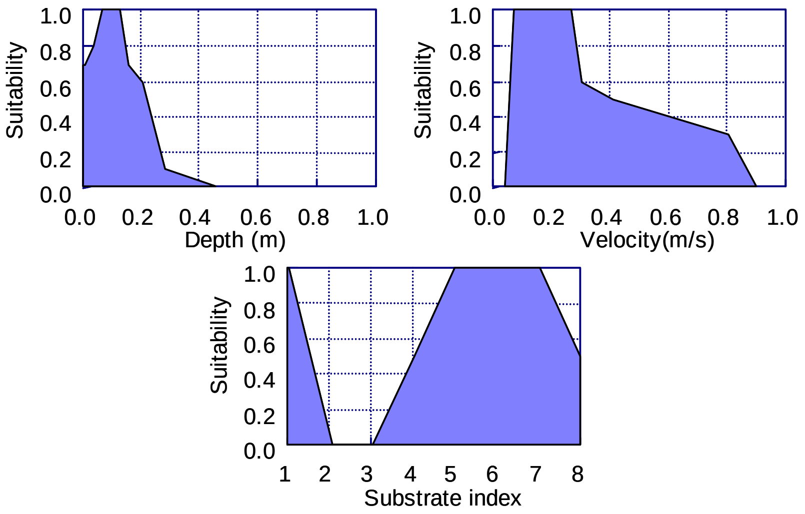
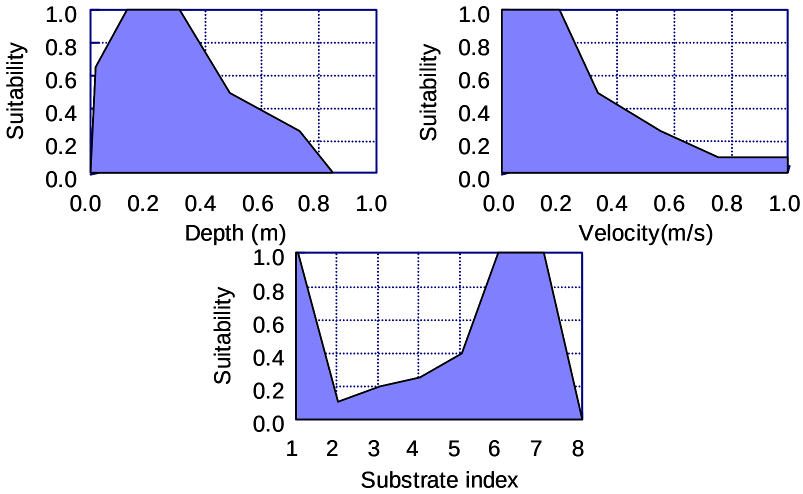


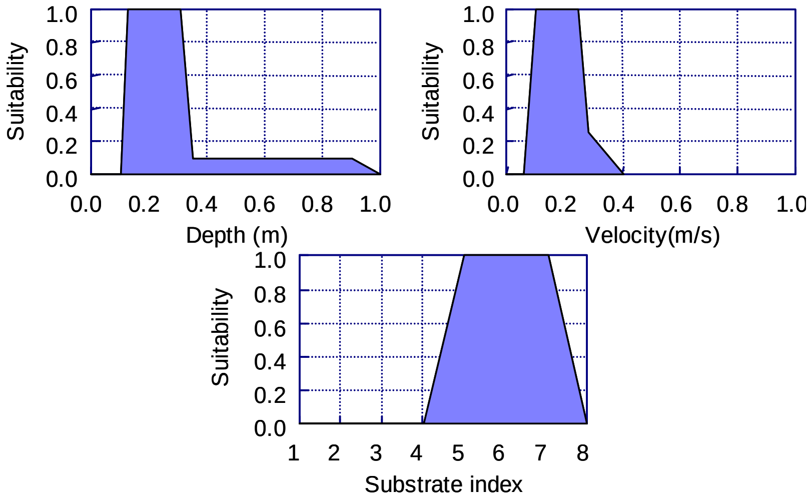
**Figure 4.24.4:** **Contour plot of GAM of probability of use using depth and velocity for a substrate index of 5 with points filled if juvenile rainbow trout were present.**



Rainbow trout (< 100 mm) (Jowett & Richardson 2008)



Rainbow trout fingerlings (Jowett et al. 1996)



Rainbow trout 3-8 cm feeding (Jowett et al. 1996)

**Figure 4.24.5:** **Habitat suitability curves for juvenile rainbow trout derived from above analyses (top) compared with curves based on data Jowett et al. (1996) (middle and bottom).**

## 4.25 Juvenile Chinook salmon

Chinook salmon are native to the northwest coast of North American and northeast Asia, and are also known as Quinnat or king salmon. Chinook salmon in New Zealand have a life cycle that is typical of salmon in the North Pacific. The adults grow to maturity in the sea and migrate upstream to spawn, usually when they are three years old. All of the adults die after spawning, which occurs in autumn. Juveniles hatch in spring, and typically spend three months in fresh water before migrating downstream to enter the ocean in summer. In some populations, a second downstream migration, consisting of individuals that have spent a year in fresh water, occurs the following spring.

Chinook salmon occur mainly on the east coast of the South Island from the Waiau River in the north to the Clutha River in the south. The main runs occur in the large braided rivers – the Waimakariri, Rakaia, Rangitata and Waitaki. There are also small runs in the Paringa, Taramakau, and Hokitika River on the west coast, but other records of Chinook salmon on the west coast are probably stray fish. A few land-locked stocks are also known from lakes along both the east and west coasts. Although juvenile fish have been caught in some North Island rivers, indicating successful spawning had occurred, there are no consistent runs of Chinook salmon in the North Island. The data used in this analysis are for juvenile Chinook salmon (< 100 mm) caught from wadeable sites in the Rakaia, Rangitata and Waitaki catchments.

**Table 4.25.1: Habitat statistics for 97 juvenile Chinook salmon present at 45 of 404 locations in 7 rivers.**

| | Velocity (m/s) | Depth (m) | Substrate index | Substrate size (mm) |
|---|---|---|---|---|
| Minimum | 0.00 | 0.04 | 4.0 | 8 |
| Maximum | 1.10 | 0.48 | 6.6 | 197 |
| Average (SD) | 0.48 (34) | 0.21 (10) | 5.1 (0.5) | 48 (28) |

The velocity at which 48 mm substrate (critical velocity) just begins to move at a depth of 0.21 m is 1.46 m/s.

Moderate velocity water (0.10–35 m/s) in the depth range of 0.15–0.25 m was the most commonly used habitat for juvenile Chinook salmon. However, they did not exhibit strong depth preferences and preferred velocities less than about 0.4 m/s (Fig. 4.25.1). Coarse substrates were the preferred substrate and most of the rivers sampled were gravel/cobble bedded.

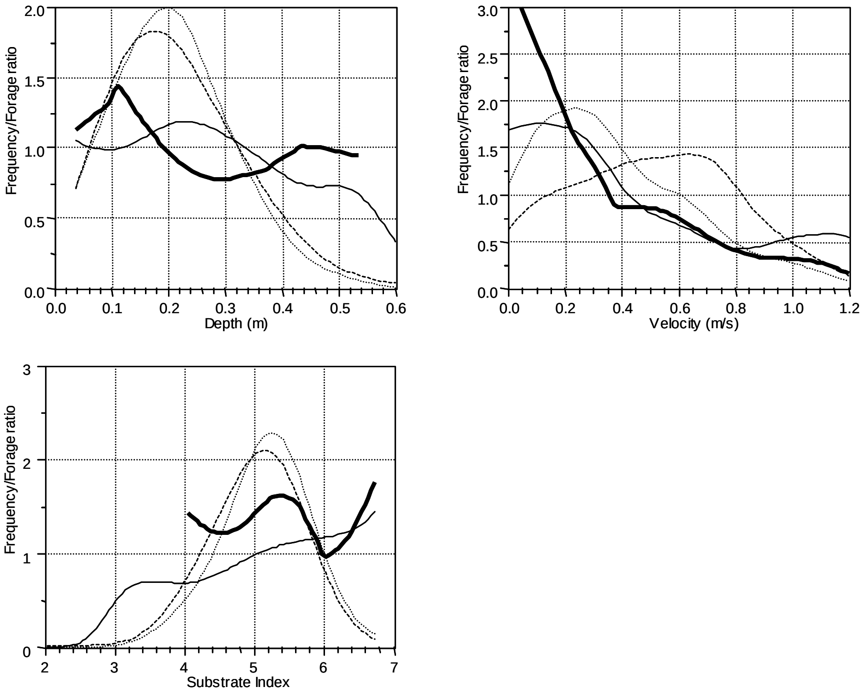


**Figure 4.25.1:** Kernel smoothed frequency of habitat availability (dashed line), use (dotted line), and the preference curves derived from all data (solid thin line) and by averaging preference relationships in each river (solid thick line) for juvenile Chinook salmon.

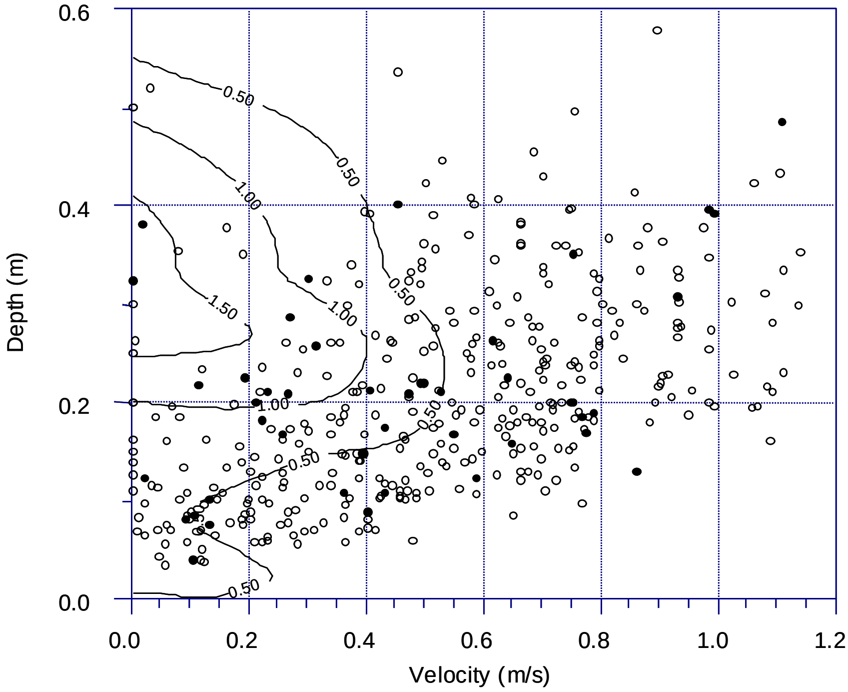


**Figure 4.25.2:** LOESS contours fitted to juvenile Chinook salmon densities and depth and velocity at all sampling locations. Locations containing juvenile Chinook salmon are shown shaded.

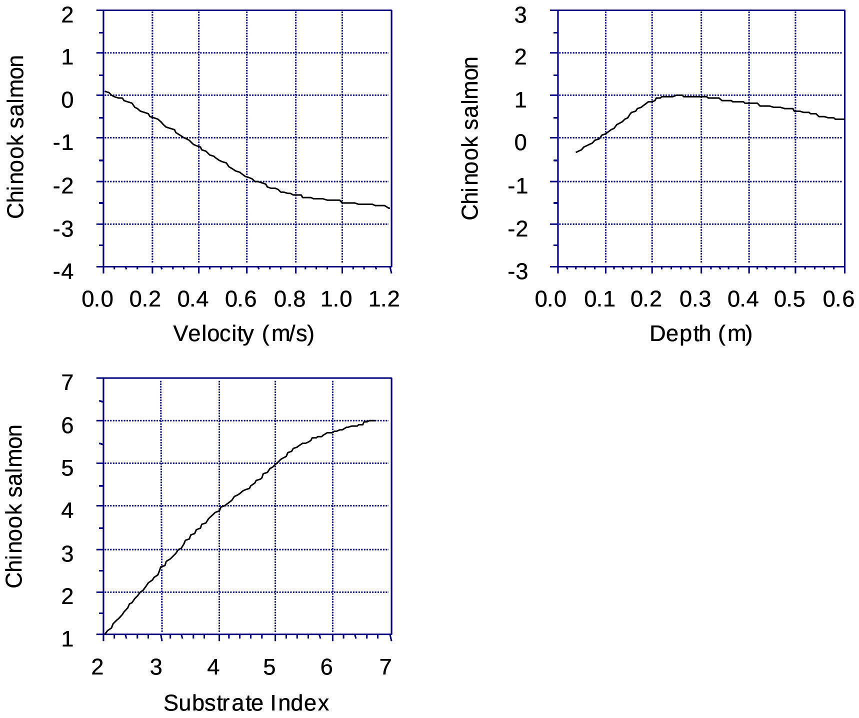


**Figure 4.25.3:** **Generalised additive logistic model of juvenile Chinook salmon probability of use using depth, velocity and substrate index to give 73% correct prediction at a cut level of 0.4.**

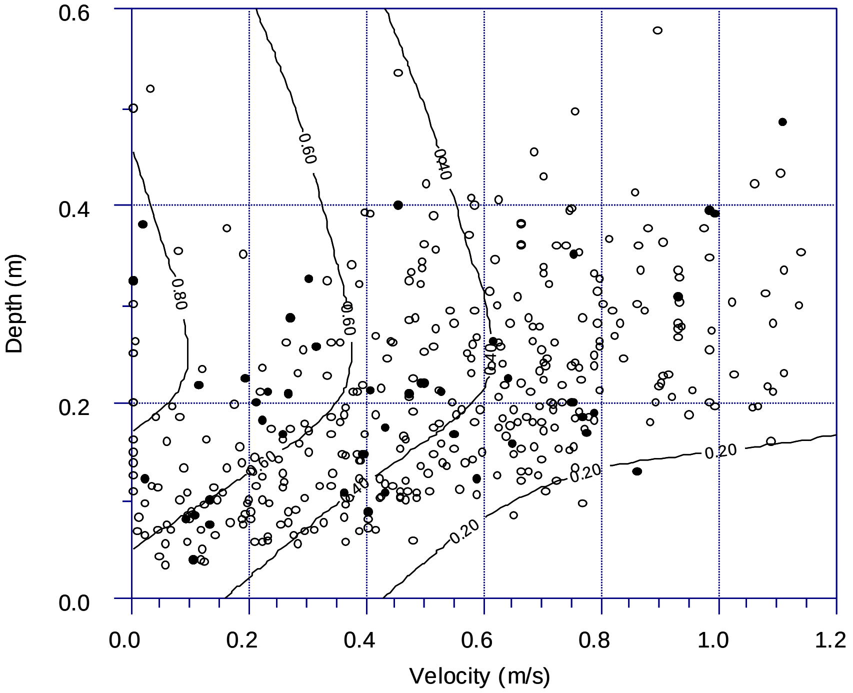
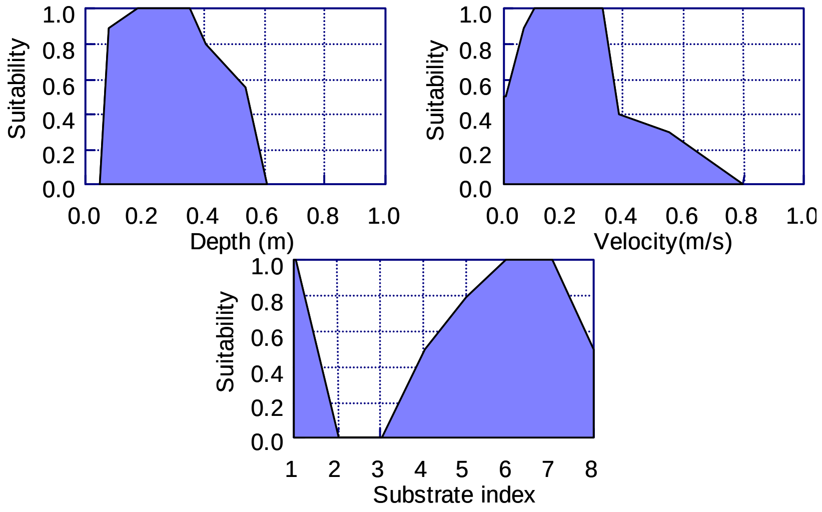


**Figure 4.25.4:** **Contour plot of GAM of probability of use using depth and velocity for a substrate index of 6 with points filled if juvenile Chinook salmon were present.**

Chinook salmon juvenile (Jowett & Richardson 2008)



Chinook salmon fry < 55 mm (Glova and Duncan 1985)

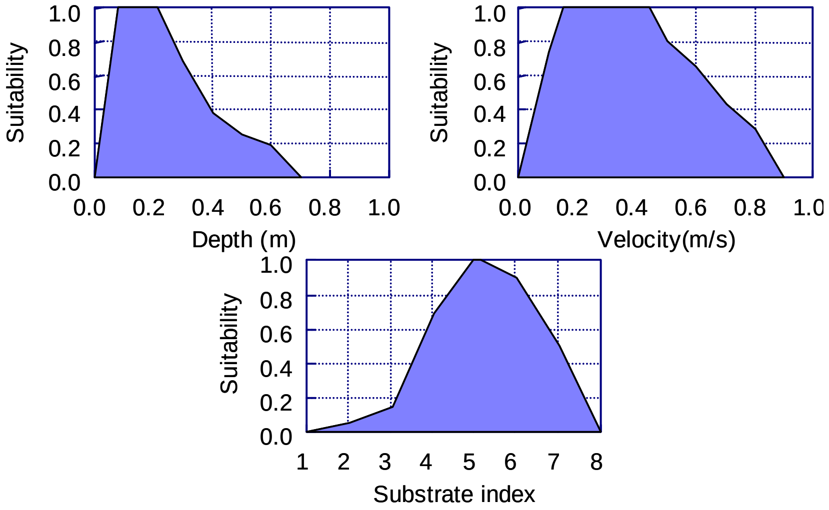


**Figure 4.25.5: Habitat suitability curves for juvenile Chinook salmon derived from above analyses (top) compared with curves based on data from Glova & Duncan (1985) (bottom).**

## 4.26 Juvenile brown trout (< 100 mm)

Brown trout are native to Europe and were first introduced into New Zealand in the late 1860s from British stock that was first established in Tasmania. Many subsequent introductions have occurred, and brown trout now occur virtually everywhere in New Zealand south of the Auckland region. Populations in the northern North Island are limited because winter water temperatures are probably too warm for successful egg development. Although brown trout were not a target species of the surveys, as one of the most widespread and common introduced fish in New Zealand waters, they were present in 45 of the sampled rivers and were the fourth most abundant species.

Our surveys occurred in wadeable waters, and therefore only juvenile (0+ <100 mm) brown trout were caught. Large brown trout occupy deeper water, but similar velocities (Hayes & Jowett 1994), and suitability curves for adult trout have been developed from data collected by bank observation (Hayes & Jowett 1994). To date, flow assessments in New Zealand for juvenile brown trout have relied on suitability curves developed overseas.

**Table 4.26.1: Habitat statistics for 1769 brown trout (< 100 mm) present at 446 of 1248 locations in 45 rivers.**

| | Velocity (m/s) | Depth (m) | Substrate index | Substrate size (mm) |
|---|---|---|---|---|
| Minimum | 0.00 | 0.03 | 1.0 | 2 |
| Maximum | 1.34 | 0.69 | 8.0 | 300 |
| Average (SD) | 0.48 (0.27) | 0.20 (0.09) | 5.0 (0.8) | 68 (64) |

The most commonly used habitat for juvenile brown trout (< 100 mm) was at depths of 0.1–0.3 m and velocities of 0.15–0.48 m/s. These are similar to the results of Campbell & Scott (1984) who measured juvenile (0+) brown trout densities in a tributary of the Taieri River and found that their preferred habitat was runs with an average velocity of 0.3 m/s and average depth of 0.2 m, and considered that their behaviour changed to shoaling in pools at lower velocities. In our study, brown trout preferred velocities between 0.3 and 0.9 m/s, with a small proportion of brown trout found in velocities greater than 1.2 m/s (Fig. 4.26.2) .Velocities greater than 1.2 m/s were excluded from the GAM analysis. The velocity at which 68 mm substrate (critical velocity) just begins to move at a depth of 0.20 m is 1.56 m/s. A maximum velocity of 1.4 m/s was assumed for the velocity suitability curve (Fig. 4.26.5).

The substrate component of the generalised additive model (Fig. 4.26.3) did not appear to be realistic in that it showed a strong preference for silt and sand and avoidance of coarser substrate, which is contrary to field observations. The water depths used by juvenile brown trout in New Zealand appear to be slightly less than those in North America, but velocities were similar and there does not seem to be a particular preference for substrate, although gravel/cobble substrates were the most commonly used.

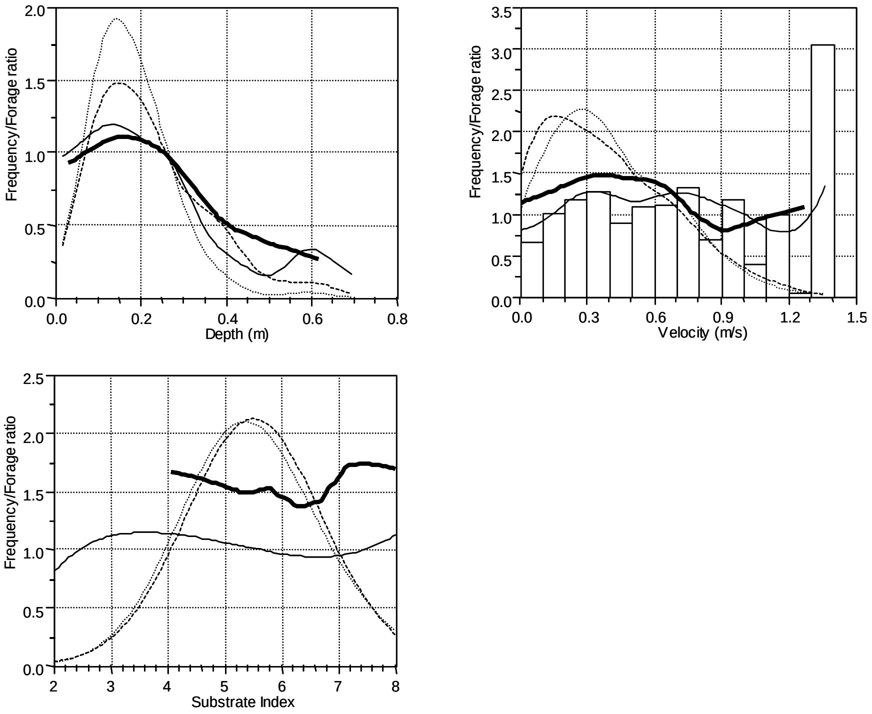


**Figure 4.26.1:** Kernel smoothed frequency of habitat availability (dashed line), use (dotted line), and the preference curves derived from all data (solid thin line) and by averaging preference relationships in each river (solid thick line) for juvenile brown trout (< 100 mm). The velocity preference histograms are shown to illustrate the effect of including measurements at velocities greater than 1.2 m/s.

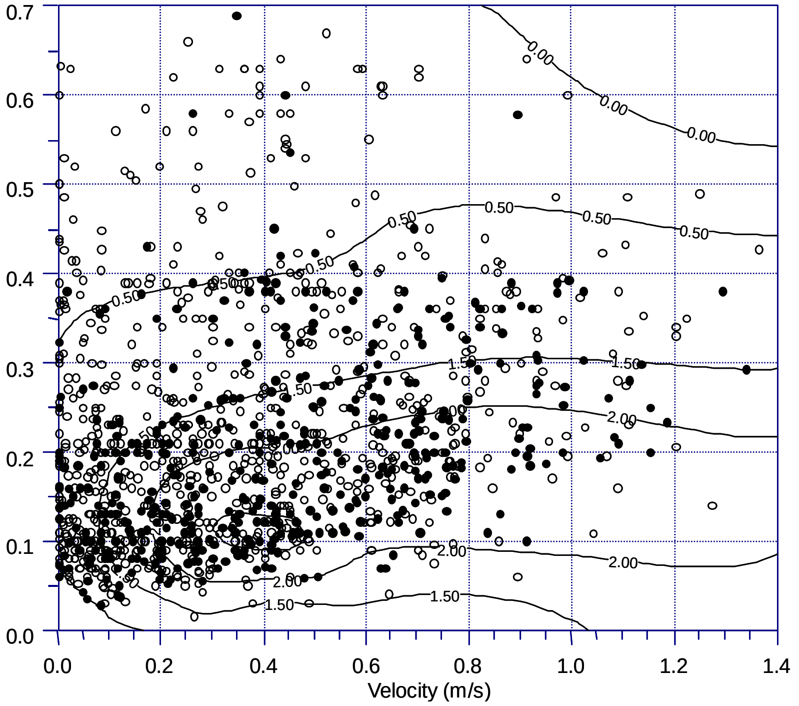


**Figure 4.26.2:** LOESS contours fitted to juvenile brown trout densities and depth and velocity at all sampling locations. Locations containing juvenile brown trout are shown shaded.

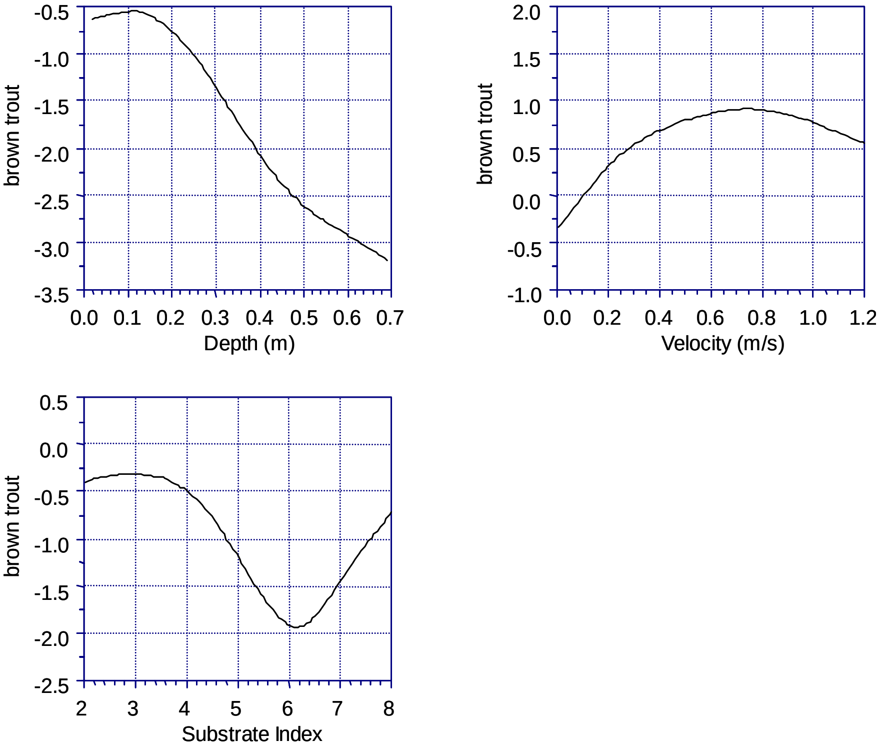


**Figure 4.26.3:** **Generalised additive logistic model of juvenile brown trout probability of use using depth, velocity and substrate index to give 73% correct prediction at a cut level of 0.7.**

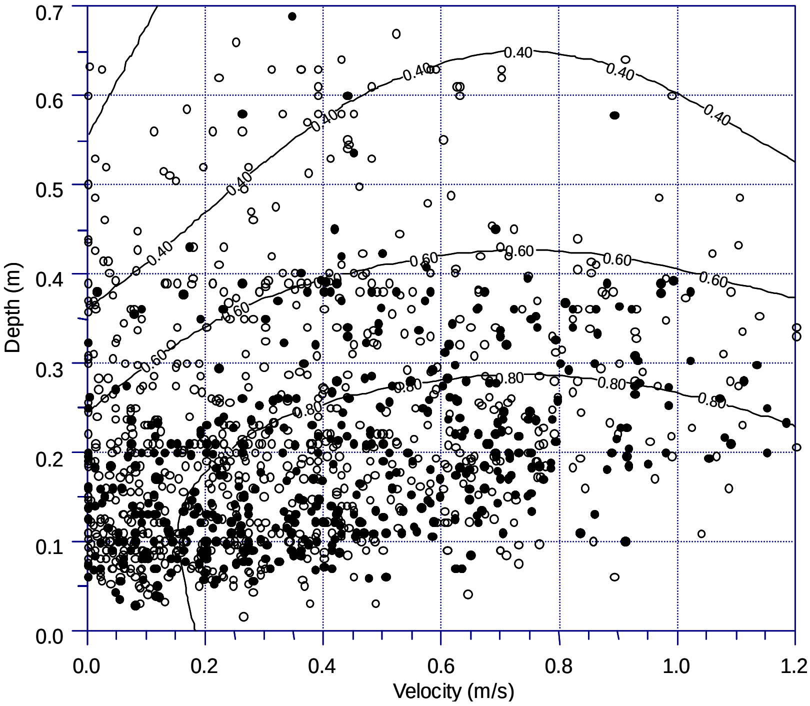
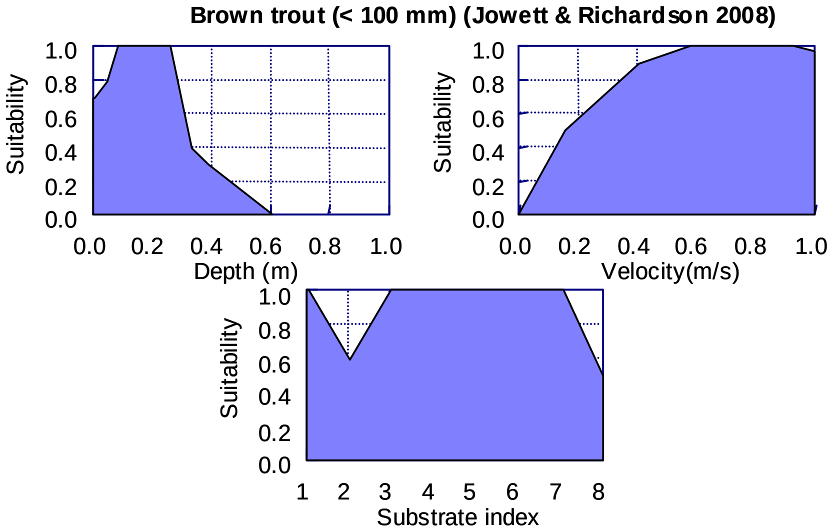
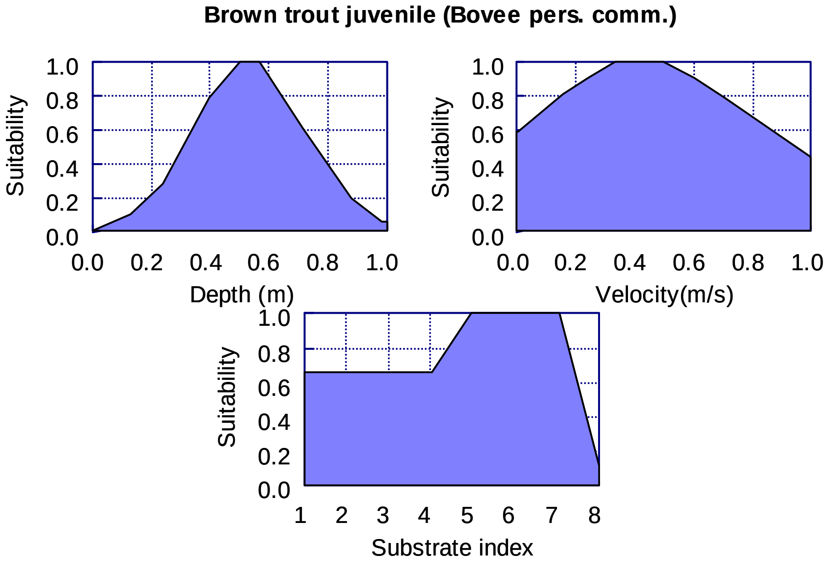


**Figure 4.26.4:** **Contour plot of GAM of probability of use using depth and velocity for a substrate index of 5 with points filled if juvenile brown trout were present.**



Brown trout (< 100 mm) (Jowett & Richardson 2008)



Brown trout juvenile (Bovee pers. comm.)

**Figure 4.26.5:** **Habitat suitability curves for juvenile brown trout (< 100 mm) derived from above analyses (top) compared with curves based on data from Bovee (pers. comm.) (bottom).**

# 5. Interpretation of habitat analyses

The methods used for the derivation of habitat suitability indices were described in Section 3.3. The suitability index is based on the forage ratio ($w$), which measures the strength of selection for a particular habitat category (a value of $w = 1$ indicates neutral selection; habitats with $w < 1$ are used less commonly than expected by chance and habitats with $w > 1$ are used more commonly than expected by chance).

In conventional habitat analysis, the forage ratios are then divided by the highest ratio so that they take a value between 0 and 1. This conversion from forage ratio to an index is not a necessary step in habitat analysis. If an instream habitat analysis were carried out using forage ratios instead of suitability indices, the shape of the relationship with flow would be the same, although the resulting values would be different. The reason for the conversion to a value of between 0 and 1 is not clear, but the terminology, weighted usable area, suggests that it was to create an index similar to the older binary concept of usable area, where area with a value of 1 is classed as usable and area with a value of 0 is unusable.

In assessing the overall suitability of a fish location for depth, velocity, and substrate, the individual suitability values are multiplied together, as would be appropriate for probabilities, assuming they are independent, to form a combined suitability index (*csi*). The performance of habitat suitability curves in predicting fish probability of use or abundance can be examined by calculating the *csi* from each curve and comparing this to the observed presence/absence or abundance of the relevant species. This was carried out using the study measurements of depth, velocity, substrate (to calculate *csi*) and comparing this with species density using the regression coefficient, $r^2$, as a measure of correlation between the *csi* and fish abundance at each sampling location (Table 5.1). A similar comparison was made using the area under the receiver operating characteristics (ROC) curve (AUC) as a measure of the ability of *csi* to predict fish presence (Fawcett 2006). The *csi* can be regarded as an index of probability of use taking a value of between 0 and 1. A fish is considered to be present if the *csi* exceeds a cut-off value. As the cut-off value decreases the number of correct positive predictions increases, but so does the number of false positive predictions. If the cut-off is zero, all positive occurrences will be predicted correctly, but all negative occurrences would be false positives. Similarly, if the cut-off is 1, all negative occurrences will be correct but there will be no correct positive predictions. The ROC graph displays the trade-off between the number of correct positive predictions and the number of false positive predictions as the cut-off value changes. The area under this graph is a measure of classification performance. The larger the area, the better the performance. If the area is 1.0, you have an ideal model. If the area is 0.5, then you have a model which has effectively 50% true positives and 50% false positives. This is no better than flipping a coin. The closer the area is to 1.0, the better the performance, and the closer the area is to 0.5, the worse the performance.

This review of habitat suitability curves has developed curves for 10 new species or life stages and has revised existing curves for 19 species or life stages. Where curves have been revised, the new curves are usually similar to the old curves, sometimes surprisingly so. For example, the old curves for dwarf galaxias were based on observations of nine fish, yet those curves are similar to the new curves based on 159 fish. When the performance of the curves was examined (Table 5.1), most of the new curves performed better that the old curves, but many were similar. Neither the values of AUC nor the correlation coefficients were high, and this was because there were many cases where fish were not found in habitat that was apparently suitable. This is because fish species cannot be expected to occupy all available habitat in a river at a given instant (e.g., when the survey was undertaken), otherwise any reduction in the amount of available habitat, such as occur when flows vary over time, would result in habitat limitation and mortality. The correlation between *csi* and fish abundance was significant ($P < 0.01$) for all species.

Although only the forage ratio/habitat relationships averaged over the rivers are shown in this report, we found that the relationships were usually similar from river to river. The only exception was the landlocked koaro population in tributaries of Lake Chalice, where the koaro tended to be in small pools rather than tumbling torrents that are usually described as their habitat.

The area under the ROC curves was greater for GAMs than for the combined habitat suitability indices calculated from conventional habitat curves in all cases except one, juvenile banded kokopu (Table 5.1). However, only about half of the correlation coefficients were higher than the corresponding coefficients for the conventional habitat curves. This analysis used all data to develop GAMs that were the best fit to the data. If part of the data had been used to fit the GAM ('training set'), it is uncertain whether the GAMs would perform any better than *csi* at predicting presence/absence for data not included in the 'training dataset'.

**Table 5.1: Evaluation of relationships between GAMs, combined suitability index calculated from old and new habitat suitability curves and the abundance of fish species (correlation coefficient, $r^2$) and species presence absence (area under ROC curve, AUC) .**

| Suitability curve | Number of locations sampled | GAM | | New curves | | Old curves | |
|---|---|---|---|---|---|---|---|
| | | $r^2$ | AUC | $r^2$ | AUC | $r^2$ | AUC |
| Shortfin eel < 300mm | 2192 | 0.022 | 0.635 | 0.013 | 0.601 | 0.006 | 0.438 |
| Shortfin eel > 300mm | 549 | 0.057 | 0.749 | 0.062 | 0.739 | | |
| Longfin eel < 300mm | 2641 | 0.036 | 0.679 | 0.027 | 0.652 | 0.007 | 0.574 |
| Longfin eel > 300mm | 549 | 0.081 | 0.747 | 0.078 | 0.703 | | |
| Torrentfish | 1217 | 0.108 | 0.858 | 0.078 | 0.796 | 0.065 | 0.810 |
| Koaro | 832 | 0.124 | 0.827 | 0.127 | 0.808 | 0.122 | 0.806 |
| Roundhead galaxias juvenile | 528 | 0.180 | 0.878 | 0.117 | 0.815 | | |
| Roundhead galaxias adult | 528 | 0.029 | 0.815 | 0.031 | 0.773 | 0.035 | 0.779 |
| Lowland longjaw galaxias juvenile | 469 | 0.139 | 0.966 | 0.221 | 0.961 | | |
| Lowland longjaw galaxias adult | 399 | 0.043 | 0.683 | 0.030 | 0.615 | 0.024 | 0.588 |
| Flathead galaxias juvenile | 233 | 0.042 | 0.885 | 0.039 | 0.844 | | |
| Flathead galaxias adult | 233 | 0.085 | 0.731 | 0.030 | 0.635 | 0.001 | 0.467 |
| Dwarf galaxias | 467 | 0.078 | 0.882 | 0.041 | 0.791 | 0.039 | 0.808 |
| Banded kokopu juvenile | 575 | 0.035 | 0.664 | 0.042 | 0.697 | 0.010 | 0.626 |
| Banded kokopu adult | 575 | 0.106 | 0.746 | 0.072 | 0.708 | 0.021 | 0.687 |
| Alpine galaxias | 192 | 0.232 | 0.951 | 0.284 | 0.936 | | |
| Upland longjaw galaxias | 154 | 0.122 | 0.858 | 0.040 | 0.728 | | |
| Canterbury galaxias | 534 | 0.081 | 0.758 | 0.037 | 0.683 | 0.033 | 0.678 |
| Giant kokopu | 69 | 0.280 | 0.809 | 0.109 | 0.630 | | |
| Lamprey | 238 | 0.043 | 0.752 | 0.056 | 0.653 | 0.045 | 0.597 |
| Crans bully | 799 | 0.029 | 0.731 | 0.034 | 0.720 | 0.035 | 0.712 |
| Upland bully | 1078 | 0.022 | 0.716 | 0.083 | 0.704 | 0.069 | 0.696 |
| Common bully | 1400 | 0.037 | 0.706 | 0.032 | 0.668 | 0 | 0.497 |
| Bluegill bully | 764 | 0.097 | 0.857 | 0.131 | 0.820 | 0.056 | 0.748 |
| Redfin bully | 920 | 0.046 | 0.736 | 0.042 | 0.704 | 0.042 | 0.509 |
| Smelt | 255 | 0.113 | 0.882 | 0.293 | 0.841 | | |
| Rainbow trout (< 100 mm) | 679 | 0.044 | 0.718 | 0.046 | 0.703 | 0.017 | 0.650 |
| Chinook salmon juvenile | 404 | 0.048 | 0.716 | 0.023 | 0.655 | 0.008 | 0.603 |
| Brown trout (< 100 mm) | 1248 | 0.041 | 0.710 | 0.026 | 0.640 | | |

Although this study has focussed on defining depth, velocity and substrate preferences for individual species, habitats can be described more broadly as pools, runs and riffles. Jowett (1993) showed that pool, run, riffle habitats can be classified by Froude number $Fr = V/\sqrt{gY}$, where *V* is velocity (m/s), *g* acceleration due to gravity (9.81 m/s$^2$), and *Y* depth (m), with Fr < 0.18 in pools, Fr > 0.41 in riffles, and runs with intermediate values. The average depths and velocities used by the fish species in this study were converted to Froude numbers and displayed in order of Froude number (Fig. 5.1). Adult eels, lamprey, a variety of juvenile galaxiids, and adult kokopu use pool habitat; torrentfish, bluegill bullies, koaro, alpine galaxias, and upland longjaw galaxias use riffle habitat; juvenile eels, trout, and some galaxiid and bully species use run habitat. Although redfin bully, adult roundhead galaxias, Crans bully, and smelt were classified as using pool habitat, these species tend to be found in runs and the division between pool and run habitat should probably be a little lower, say at a Froude number of 0.1, between longfin eel (> 300 mm) and smelt. However, the classifications of pool, run, and riffle habitat do not necessarily mean that those fish are likely to be found entirely in pools, runs or riffles. For example, the margins of riffles often contain slow flowing water that is classified by its Froude number as pool or run habitat. Jowett & Richardson (1995) described many of the fish species that are classed here as using run habitat, as edge-dwellers because they found them along the margins of riffles.

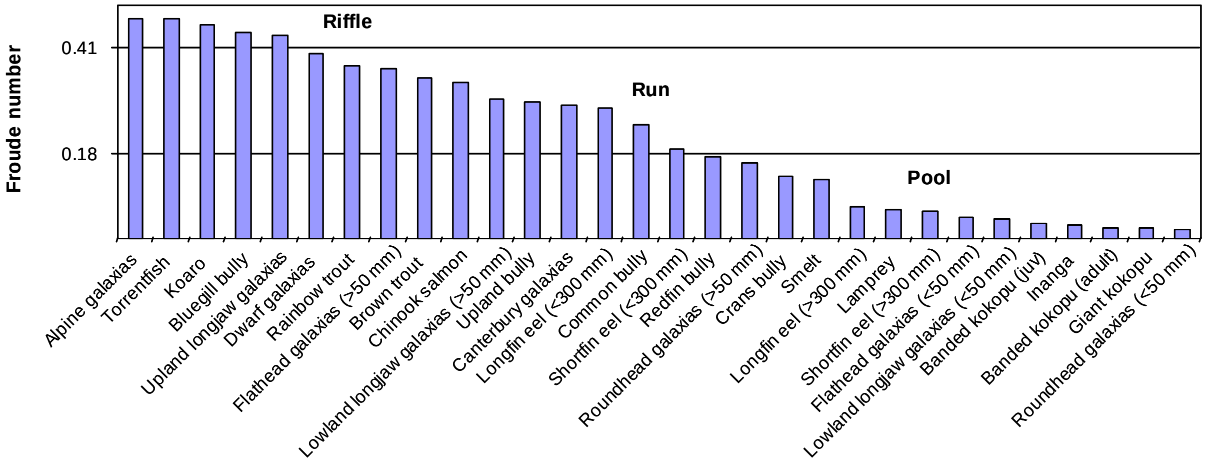


**Figure 5.1 Habitat use by 30 fish species in order of decreasing Froude number, with horizontal lines separating them into pool, run and riffle habitats.**

Some of the habitat suitability curves listed in this report are more useful for flow and habitat assessment than others. For example, as flows reduce in a river, the amount of run and riffle habitat tends to decrease and the amount of pool habitat tends to increase. Thus, an instream flow assessment would indicate a low flow requirement for species that prefer pool habitat. While this may be appropriate for some species, such as banded kokopu where habitat suitability curves describe night feeding habitat, some other species, such as adult eels, may have been utilising cover when the habitat use data were collected, and the suitability criteria should be recognised as applying only to those situations (e.g., flow requirements to maintain night-time feeding habitat for adult eels is usually higher than day cover requirements). Some guidance to the applicability of the curves is given in Section 3.2, Section 4.1 and other sub-sections describing individual species.

The most difficult and uncertain part of an instream habitat analysis is the biological interpretation of the results. The use of appropriate habitat suitability curves is a crucial step. The bottom line is that there must always be some suitable habitat if an aquatic species is to survive.

The often questioned assumption at the heart of habitat-based flow assessments is that there is some relationship between the amount of habitat and the abundance of the aquatic species. Jowett et al. (1991) showed for benthic invertebrates that the combined suitability index formed by multiplying the suitability indices together was the best index of species density that they tested. The conventional habitat suitability curves, as developed in this report, when used with depth, velocity, and substrate predicted by instream habitat analyses, will produce an index of species density. Generalised additive models (GAMs) were fitted to species occurrence data, so that when these are used with a hydraulic model, the resultant index is the area weighted probability of use. The average probability of use is the weighted probability of use divided by the river width. These are the GAM equivalents of weighted usable area (WUA) and average habitat suitability index (HSI).

Species abundance is influenced by factors other than habitat that are not necessarily flow-related, so that it is often difficult to demonstrate relationships between species abundance and habitat. However, it is intuitively reasonable to expect that the amount of habitat available would set a limit to population size, in the absence of other limiting factors (i.e., habitat availability would set the outer envelope of abundance for a given population). This suggests that density dependent mortality or migration will only occur if a high proportion of the available habitat is occupied and a reduction in the amount of available habitat occurs (Orth 1987). The aim of an assessment of flow requirements is to provide sufficient habitat for the maintenance of all life stages of target species and for the other flora and fauna that make up the food chain in the stream ecosystem, and in this way to maintain the life-supporting capacity of the stream.

# 6. Conclusion

The derivation and use of habitat suitability models (habitat suitability curves) are the most important aspects of flow evaluation. Although habitat suitability criteria for many New Zealand fish species are described here, they can be improved by collecting more data, particularly for the rarer species. The method of data collection is important for the derivation of habitat suitability models. The conditions in which fish are sampled should not be extreme (i.e., normal flow and water temperature, usually in summer) and the full range of habitats should be sampled with equal effort, whether they are likely to hold fish or not. This can be difficult, if not impossible, because it requires sampling shallow water over a full velocity range and deep water over a full velocity range.

While many fish undoubtedly make use of habitat on a micro scale, most habitat suitability observations describe mesohabitats – the characteristics of the area in which the organism lives, rather than the microhydraulics of its precise location. In assessing suitability for one species, we are often assessing conditions for a number of species that live in that area. Riffle-dwelling fish are an example, where the habitat suitability curves describe riffle conditions, rather than microhabitat of the location of an individual fish.

The habitat suitability curves derived in this study are very similar to those derived more than 10 years ago with much fewer data. This is reassuring because it suggests that habitat use does not vary significantly between rivers, something that was evident in this study when analysing habitat suitability for individual rivers. Generally, the habitat suitability curves show a slightly wider range of preferences than the earlier curves. However, for some species, high velocity preferences have been reduced by considering the substrate stability under high velocities. Generalised additive models (GAMs) were generally better predictors of presence/absence than the conventional habitat suitability curves. Overall, the hydraulic habitat preferences of the species are consistent with their known use of pool, run, and riffle habitats.

# 7. Acknowledgments

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