Habitat use by non-migratory Otago galaxiids and implications for water management

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Habitat use by non-migratory Otago galaxiids and implications for water management

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ABSTRACT

Ten Otago streams were sampled at 18 sites to determine the characteristics of habitats occupied by three non-migratory galaxiid species, the flathead galaxias (*Galaxias depressiceps*), roundhead galaxias (*G. anomalus*), and lowland longjaw galaxias (*G. cobitinis*). Juveniles of all three species were most common in pools or along the margins of runs, where velocities were low. The average depths and velocities occupied by juveniles did not differ greatly between species, with average depths varying from 0.21 to 0.27 m and average velocities varying from 0.03 to 0.06 m s^{-1}. Adult flathead galaxias were found in pool, run, and riffle habitats, whereas roundhead galaxias tended to be mostly in runs, and lowland longjaw galaxias tended to be mostly in riffles. Adults of the three species were found in higher average water velocities (0.17–0.31 m s^{-1}) and shallower average depths (0.11–0.19 m) than juveniles, consistent with a shift from the pelagic juvenile lifestyle to the benthic adult existence. The depth and velocity preferences of adult flathead galaxias tended to be wider than those of the other two species. A comparison of habitat use by adult flathead galaxias in areas with and without brown trout suggested that the absence of trout might allow flathead galaxias to utilise a greater range of habitats. Application of habitat suitability curves to in-stream habitat data from four small streams (4.5–11 m in wetted width) indicated that flows of 0.1–0.3 m^3 s^{-1} provided near maximum stream habitat for these three species.

Keywords: *Galaxias anomalus*, *Galaxias cobitinis*, *Galaxias depressiceps*, in-stream habitat, habitat suitability, Otago galaxiids, New Zealand

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1. Introduction

Isozyme electrophoresis has revealed a complex of non-migratory galaxiid fish species in the Taieri River (Allibone et al. 1996). These were previously included within the morphologically variable non-migratory galaxiid, the Canterbury galaxias (*Galaxias vulgaris*). This study examines habitat use by three of the non-migratory galaxiid fish species found in Otago: the roundhead galaxias (*G. anomalus*), flathead galaxias (*G. depressiceps*), and lowland longjaw galaxias (*G. cobitinis*).

The roundhead galaxias and flathead galaxias (McDowall & Wallis 1996) have only been recorded in Otago. The lowland longjaw galaxias (McDowall & Waters 2002) is rare, and was first found in a 6 km stretch of the Kauru River in the Kakanui catchment. A single lowland longjaw galaxias was found in the Hakataramea River in Canterbury in 1989, and two other populations are believed to exist in the Waitaki catchment.

These Otago galaxiids are small (< 150 mm long) and usually found in small gravel-bed streams. An adequate stream flow for the supply of food and provision of suitable feeding habitat is a primary requirement for maintaining fish populations in streams. Central and North Otago are known for their dry summers and the habitats of roundhead, flathead and lowland longjaw galaxias could be endangered by low flows, especially where there is water abstraction for irrigation or mining.

In-stream habitat analyses, such as PHABSIM (Milhous et al. 1989) and RHYHABSIM (Jowett 1999), can be used to define suitable flow requirements for fish species if they display clear preferences (i.e. habitat suitability criteria) for specific conditions (e.g. depth, velocity, and substrate). Habitat suitability criteria are important because they have more influence on the relationship between the area of usable habitat and flow than any other part of the in-stream habitat modelling process.

Galaxiid habitat requirements have been examined for the Canterbury galaxias (Jowett & Richardson 1995), inanga (*Galaxias maculatus*) (Sagar 1993; Jowett 2002), koaro (*G. brevipinnis*) (Richardson & Jowett 1995), banded kokopu (*G. fasciatus*) (McCullough 1998), shortjawed kokopu (*G. postvectis*) (McDowall et al. 1996), and giant kokopu (*G. argenteus*) (Bonnett & Sykes 2002). There is no quantitative information on micro-habitat requirements of the non-diadromous Otago galaxiid species, although the characteristics of the streams in which they are found have been described (Allibone & Townsend 1997). Allibone & Townsend (1997) found no significant difference in average depth, maximum depth, and gradient of streams containing roundhead and flathead galaxias, but did find that the ratio of flood channel width to water surface width was greater in roundhead streams than flathead streams. They noted that roundhead streams were generally wide and shallow and dominated by gravel and cobbles.

This study quantified micro-habitat use by three non-migratory Otago galaxiids in a range of streams within the Otago province. These data were used to develop habitat suitability curves for water depth, velocity and substrate. The curves were then used to calculate the variation in available habitat with flow in a range of stream types to illustrate the implications for water management in regions where these non-migratory galaxiids are present.

2. Methods

2.1 STUDY SITES

Four streams (Healy Creek, Three O'clock Stream, Linn Burn, and Akatore Creek Fig. 1, Table 1) were surveyed for flathead galaxias. These streams were accessible by road, and were selected to represent a range of gradients, habitat, and geology.

The five streams containing roundhead galaxias (Deep Creek, Kye Burn, Little Kye Burn, Spec Gully, and German Creek) were in the Kye Burn catchment (Fig. 1; Table 1) and represented a range of stream sizes, with widths ranging from 1 to 10 m.

At the time of the study, the lowland longjaw galaxias had only been found within a 6 km section of the Kauru River and all observations, and measurements were made in this reach of river (Table 1).

TABLE 1. SURVEYED STREAMS WITH LOCATION OF SAMPLING SITES USING THE 1:50 000 MAP SERIES (NZMS 260).

SPECIES	STREAM	MAP REF. OF SAMPLING SITE (NZMS 260)	DATES OF SAMPLING
Flathead galaxias	Healy Creek	I41 994786, I41 993778	Dec. 2000, Jan. 2001 and Mar. 2001
	Three O'clock Strm	I43 112096, I43 111101, I43 111102	Mar. 2000, Dec. 2000, Jan. 2001 and Feb. 2001
	Linn Burn	H42 613307, H42 655322	Feb. 2001
	Akatore Creek	H45 876566	Feb. 2001
Roundhead galaxias	Deep Creek	I41 905756	Jan. 2001
	Kye Burn	I41 951743, I41 960765, I41 935702	Feb. 2000, Feb. 2001, Mar. 2001
	Little Kye Burn	I41 935702	Feb. 2000, Dec. 2000, and Jan. 2001
	Spec Gully	I41 904709	Dec. 2000 and Jan. 2001
	German Creek	I41 995774	Feb. 2000 and Dec. 2000
Lowland longjaw galaxias	Kauru River	J41 362675, J41 342664, J41 366675	Jan. 2001 and Feb. 2001, May 2001, Nov. 2001

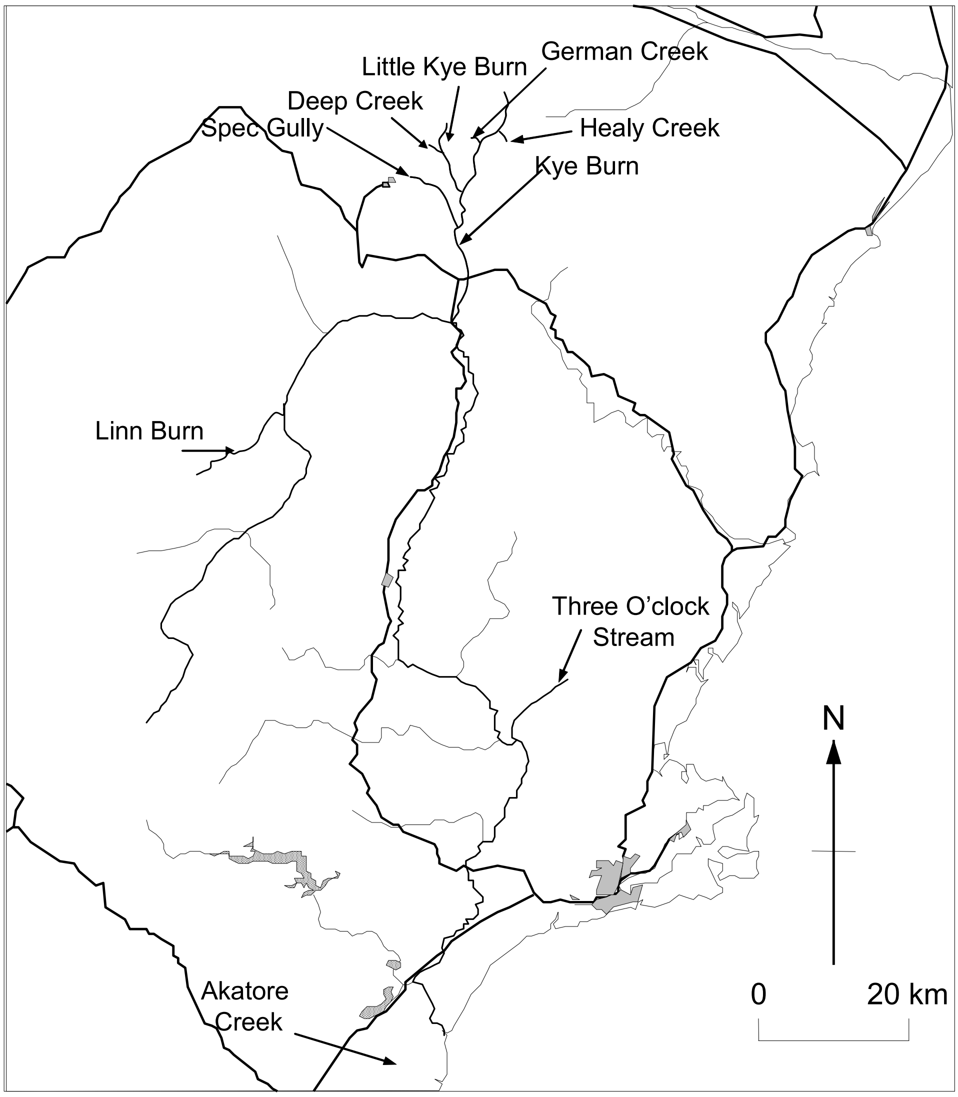


Figure 1. The Taieri River system, showing the location of streams surveyed for roundhead galaxias (*G. anomalus*) and flathead galaxias (*G. depressiceps*).

2.2 FIELD MEASUREMENTS

Field measurements were carried out during the day between November and May under normal flow conditions. Some night observations were also made to ensure that day and night habitats were similar.

Within each stream, up to 3 reaches between 100–300 m in length were surveyed. Our primary survey procedure was to electric fish a range of depths, velocities, and habitat types within the reaches. At each location, we electric-fished about 1 m^2 of stream and recorded the species, numbers and lengths of fish. Spot samples were collected at points across and along each stream, in a systematic manner. Habitat variables were also measured at each location, whether or not fish were found. The habitat variables measured were water depth, mean water column velocity (measured at 0.4 of depth above the bed), substrate composition (estimated visually as the dominant substrate types, e.g. bedrock, boulder > 254 mm, cobble 64–254 mm, gravel 2–64 mm, sand/silt < 2 mm, and vegetation) and habitat type (pool, run, riffle, backwater, and edge).

A secondary technique was bank observation, which was mainly used for locating juvenile fish. Where schools of fish were observed, the number and size range of fish in the school was estimated and measurements of depth, velocity, substrate, and habitat type made at the point where the school was centred.

2.3 DATA ANALYSIS

Both histograms and kernel density plots (Silverman 1986; Hayes & Jowett 1994) were used to display frequency curves of galaxiid habitat use. Frequency histograms were derived for each habitat variable to determine the number of fish that were found in each bar interval. The ordinates of the frequency histogram were then normalised by dividing by the ordinate with the highest frequency (e.g. see Fig. 2 below) to give a relative measure of habitat use. If all bar intervals of a habitat variable are sampled equally, the frequency histogram shows the preference over the range of habitat values, with habitat preference varying between 0 (unsuitable) and 1 (ideal).

For example, assume that the number of fish in water depths of 0–0.1, 0.1–0.2, 0.2–0.3, 0.3–0.4 m was measured at 10 locations in each depth range (Table 2). In this example, the frequency histogram of fish numbers in each depth interval shows the frequency of habitat use and the relative preference of the different depths, with fish most common in depths of 0.2–0.3 m. Depths of less than 0.1 m are unsuitable, and depths of 0.1–0.2 m are about half as suitable as the optimum depth range of 0.2–0.3 m.

TABLE 2. EXAMPLE OF HABITAT PREFERENCE CALCULATION WITH EQUAL SAMPLING EFFORT IN EACH DEPTH RANGE.

	DEPTH RANGE (m)			
	0–0.1	0.1–0.2	0.2–0.3	0.3–0.4
Number of fish	0	3	6	2
Frequency	0	3/10	6/10	2/10
Normalisation	0	0.3/0.6	0.6/0.6	0.2/0.6
Preference	0	0.5	1	0.33

In practice, it is difficult to survey the range of habitats equally, and the manner in which fish abundance varies with the habitat variable can be used as a measure of habitat preference or suitability. Although preference and suitability are often used interchangeably, we use the term preference to mean a value of between 0 and 1, calculated as the normalised ratio of frequency of habitat use divided by the frequency of habitat availability. Habitat suitability values also vary between 0 and 1 but are estimated subjectively in the form of habitat suitability curves, and can take into account data such as swimming ability, sample sizes, habitat use in other locations, as well as preference data (Jowett 2002). The average number of fish per sample (abundance) in each interval range was therefore calculated as the frequency of fish occurrence within each

TABLE 3. EXAMPLE OF HABITAT PREFERENCE CALCULATION WITH UNEQUAL SAMPLING EFFORT IN EACH DEPTH RANGE.

	DEPTH RANGE (m)			
	0–0.1	0.1–0.2	0.2–0.3	0.3–0.4
Number of samples	5	10	8	5
Number of fish	0	3	6	2
Average no. per sample	0	3/10	6/8	2/5
Normalisation	0	0.3/0.75	0.75/0.75	0.4/0.75
Preference	0	0.4	1	0.53

interval divided by the frequency with which that interval was sampled (Table 3), and then normalised to give preference values.

When fish locations were determined by observation, the first method of preference calculation (i.e. Table 2) was the most appropriate, assuming that a wide range of habitat was equally available in different streams. However, because data were also collected by electric-fishing, the second method (abundance) was also used to calculate habitat preference. Calculation of abundance and preference is subject to uncertainty when sample sizes are small, as often occurs when the occurrence of a particular range of habitat is rare. For these reasons, final determinations of habitat suitability were made subjectively from both the observed habitat use and the calculated habitat preference. Raw data for each species are shown in Appendix 1.

Data for each species were divided into juvenile/adult categories depending on fish length. The division was based on observed changes in behaviour and habitat, whereby small, 'juvenile' fish are pelagic and active during the day, and larger, 'adult' fish are benthic. Lowland longjaw, flathead, and roundhead galaxiids were considered to be juveniles if they were less than 30, 40, and 50 mm in length, respectively. Data from streams containing flathead galaxias were also examined to determine whether habitat use was influenced by the presence of brown trout (*Salmo trutta*), which were present in some streams or reaches and not in others. Trout were present at all roundhead and lowland longjaw galaxias sites, and we were unable to make any determination of habitat use without trout present.

The habitat suitability curves were applied to in-stream habitat data collected from four streams, ranging in width from 4.5 to 11 m and containing bedrock, boulder, cobble, and gravel substrate. Three of these streams were in relatively well-confined channels, and were selected because there were considered to be similar to those occupied by flathead galaxias, the other was an alluvial river in Otago that is similar to rivers occupied by roundhead galaxias. The amount of habitat for each of the three species was calculated for a range of flows using the computer programme RHYHABSIM (Jowett 1999).

3. Results

3.1 FLATHEAD GALAXIAS

A total of 368 locations (135 by visual observation and 233 by electric fishing) was sampled in flathead streams, giving a total of 432 adult fish and 432 juvenile fish (Tables A1–A4, Appendix 1). Juvenile fish were found at a mean depth of 0.27 m (Table 4), with 82% in depths of 0.05–0.35 m (Fig. 2). In comparison, adult flatheads were found in slightly shallower waters, with a mean depth of 0.19 m (Table 4) and 82% in depths of less than 0.25 m (Fig. 2). Although most adult flathead galaxias were found in depths less than 0.25 m, neither adults or juveniles exhibited a strong preference for these depths and were abundant (preference > 0.6) at depths of up to 0.6–0.8 m (Fig. 3). As explained in the

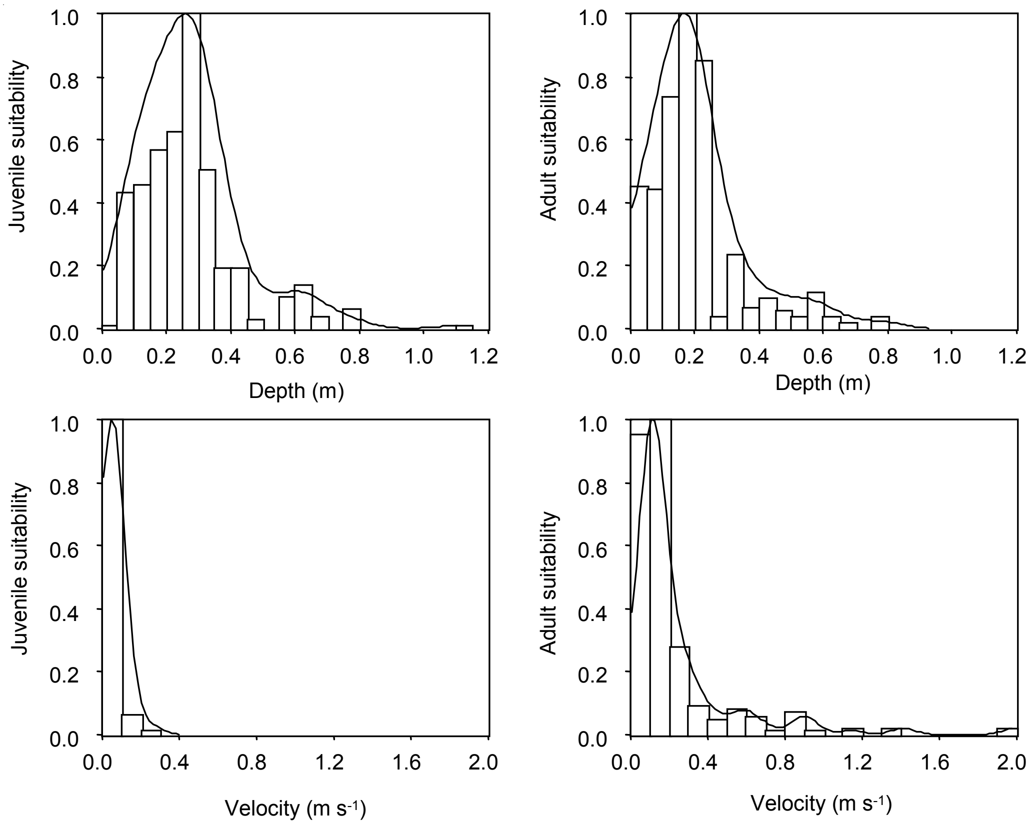


Figure 2. Normalised frequency histograms and kernel smoothed distributions (black line) of depth and velocity used by juvenile (*left*) and adult (*right*) flathead galaxias, (*G. depressiceps*).

TABLE 4. MEAN DEPTHS AND VELOCITIES (± STANDARD DEVIATION) USED BY ADULT AND JUVENILE FLATHEAD GALAXIAS.

	DEPTH (m)	VELOCITY (m s^{-1})
Juveniles (N = 432)	0.27 ± 0.15	0.03 ± 0.04
Adults (N = 432)	0.19 ± 0.14	0.21 ± 0.28

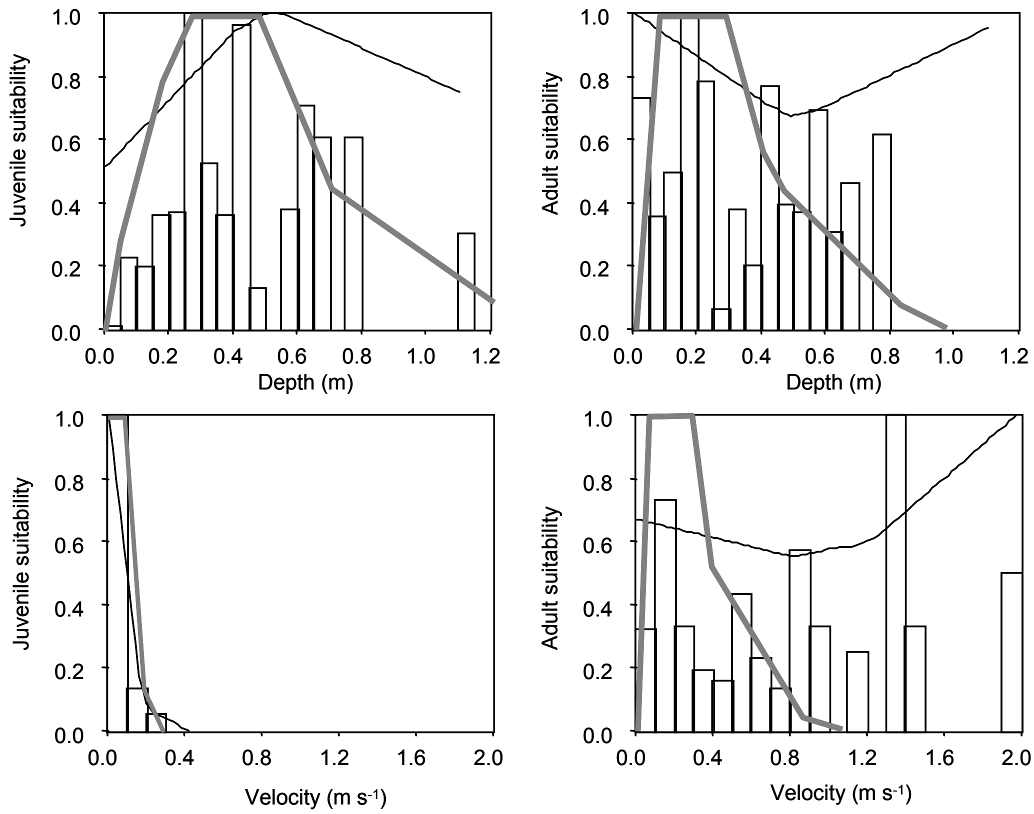


Figure 3. Normalised histograms and kernel smoothed distributions (black line) of depth and velocity preference (based on the average fish abundance per sample in each habitat interval) for juvenile (*left*) and adult (*right*) flathead galaxias, (*G. depressiceps*). Grey shaded lines show the habitat suitability curves.

methods, determination of final habitat suitability curves was based on both observed habitat use (Fig. 2) and habitat preference as calculated from fish abundance (Fig. 3), taking the number of samples collected in each depth range into consideration. Optimum depths for juvenile flathead galaxias were considered to be between 0.25 and 0.45 m. Optimum depths for adult flathead galaxias were considered to be between 0.1 and 0.25 m.

The mean velocity of locations occupied by juvenile flathead galaxias was 0.03 m s^{-1} (Table 4), with 93% of juveniles in velocities of less than 0.1 m s^{-1} (Fig. 2). Adult fish were found in higher velocities than juveniles, with 48% of adults found in velocities of 0.1–0.2 m s^{-1} (Fig. 2). Adult flathead galaxias did not demonstrate a strong preference for low water velocities and, although relatively abundant (0.7) at velocities of 0.1–0.2 m s^{-1}, they were also abundant at velocities greater than 1 m s^{-1} (Fig. 3). However, few adult fish (10) were found at high velocities (> 1 m s^{-1}) and these were usually amongst boulders. We believe that these fish were probably sheltering behind or under boulders, and the velocity measurement was taken between boulders rather than at the fish location. The optimum velocity for juvenile flathead galaxias was less than 0.1 m s^{-1}, whereas optimum velocities for adults were between 0.05 and 0.25 m s^{-1}.

The habitat types utilised by flatheads were related to their velocity preferences. Juvenile fish were found most commonly in pools (77%), with 21% in runs or the edges of runs, and the remainder in riffles or riffle edges

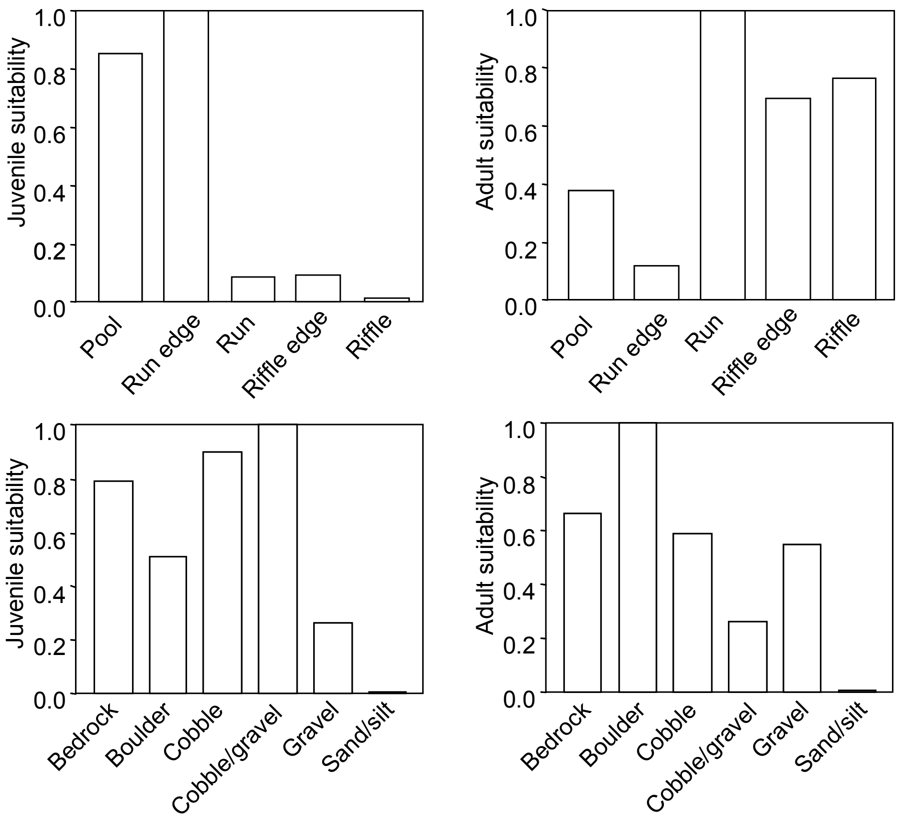


Figure 4. Suitability of habitat type and substrate for juvenile (*left*) and adult (*right*) flathead galaxias, (*G. depressiceps*).

(Table A4, Appendix 1). The average abundance of juvenile flatheads was slightly higher in run edges than in pools (Fig. 4). Adult flatheads were found mostly in run and riffle habitat (77%), with 17% of adults being found in pools (Fig. 4 and Table A4, Appendix 1).

Adult and juvenile flatheads occupied all large substrate types (bedrock, boulder, cobbles and gravels), with adults most abundant in boulders and juveniles most abundant in cobble/gravel (Fig. 4). Silt/sand and vegetation were rare in the reaches sampled and did not appear to be used by either adult or juvenile fish.

3.2 ROUNDHEAD GALAXIAS

A total of 528 locations was sampled in roundhead streams (357 by electric fishing and 171 by visual observation), giving 2405 juvenile fish and 358 adult fish (Tables A5–A8, Appendix 1). Juvenile fish were found at an average depth of 0.26 m (Table 5), with over 57% of juvenile in depths of 0.1–0.3 m (Fig. 5). Over 78% of adult fish were found in depths ranging from 0.05–0.15 m, with an average depth of 0.11 m, significantly different to that of juvenile fish (Mann-Whitney, $P < 0.001$).

Histograms and kernel smoothed distributions of habitat preference showed that the average fish abundance per sample in each habitat interval was greatest for juveniles at depths of 0.4–0.5 m, and for adults at depths of less than 0.2 m

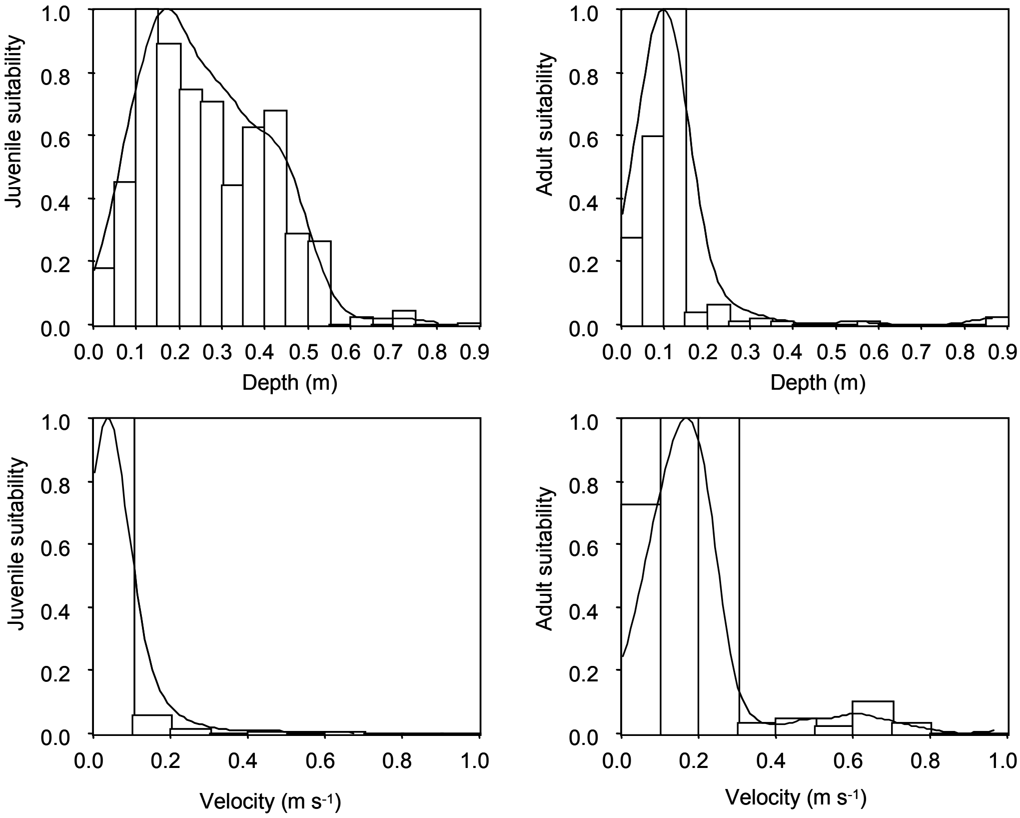


Figure 5. Normalised frequency histograms and kernel smoothed distributions (black line) of depth and velocity used by juvenile (*left*) and adult (*right*) roundhead galaxias, (*G. anomalus*).

(Fig. 6). Histograms and kernel smoothed distributions of juvenile abundance (Fig. 6) indicated that juveniles preferred slightly deeper water than the frequency of use (Fig. 5) suggested.

As with flathead galaxias, juvenile roundheads were found in low velocity water (Fig. 5), with over 92% of fish found in velocities between 0 and 0.1 m s^{-1}. Adult roundhead galaxias were found in higher velocities than juveniles, with 67% of fish found in the velocity range of 0.1–0.3 m s^{-1} (Fig. 5). The average velocity of adult fish locations was higher than that of juvenile fish (Table 5) and significantly different (Mann-Whitney, $P < 0.001$). Considering both habitat use and abundance, optimum velocities for adult roundheads were in the range 0.15–0.3 m s^{-1}, whereas optimum juvenile velocities were less than 0.1 m s^{-1} (Fig. 6).

The low velocity preference of juveniles reflects their use of pool habitat, with 81% of juvenile fish found in pools (Fig. 7). About 20% of juvenile fish were associated with run edges where slow velocities and backwaters would occur. Adult fish were mostly found in runs and rarely in pools. However, they were

TABLE 5. MEAN DEPTHS AND VELOCITIES (± STANDARD DEVIATION) USED BY ADULT AND JUVENILE ROUNDHEAD GALAXIAS.

	DEPTH (m)	VELOCITY (m s^{-1})
Juveniles (N = 2405)	0.26 ± 0.14	0.03 ± 0.07
Adults (N = 358)	0.11 ± 0.10	0.17 ± 0.16

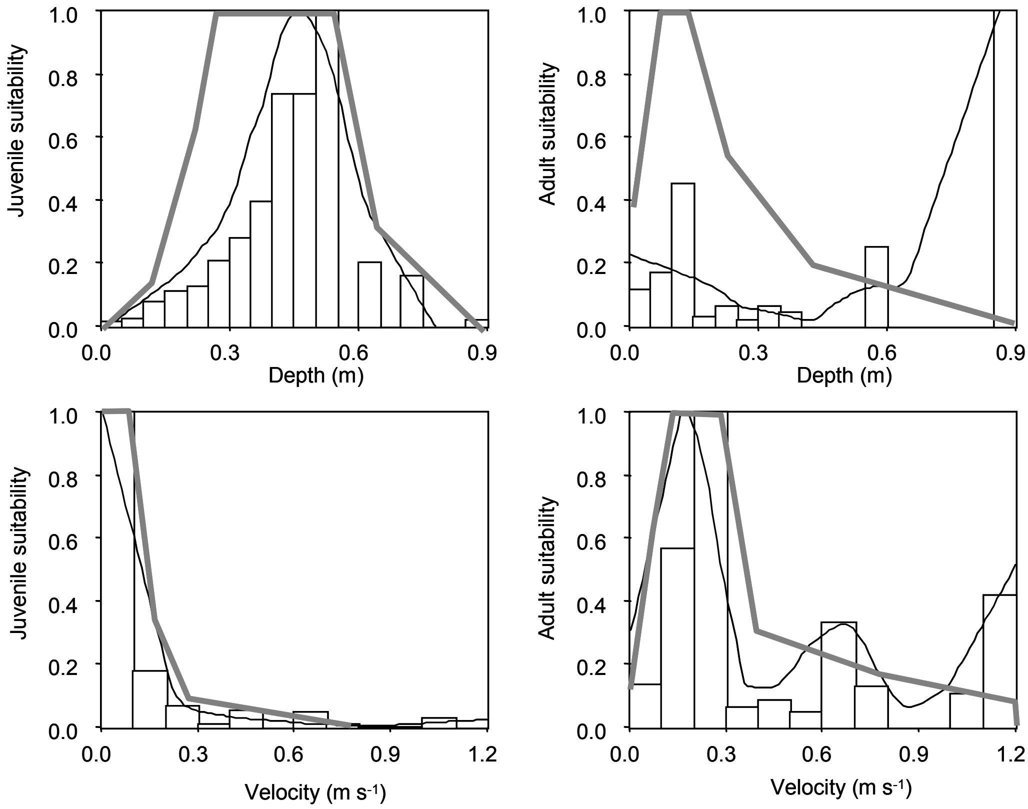


Figure 6. Normalised histograms and kernel smoothed distributions (black line) of habitat preference (based on the average fish abundance per sample in each habitat interval) for juvenile (*left*) and adult (*right*) roundhead galaxias, (*G. anomalus*) for depth and velocity. Grey shaded lines show the habitat suitability curves.

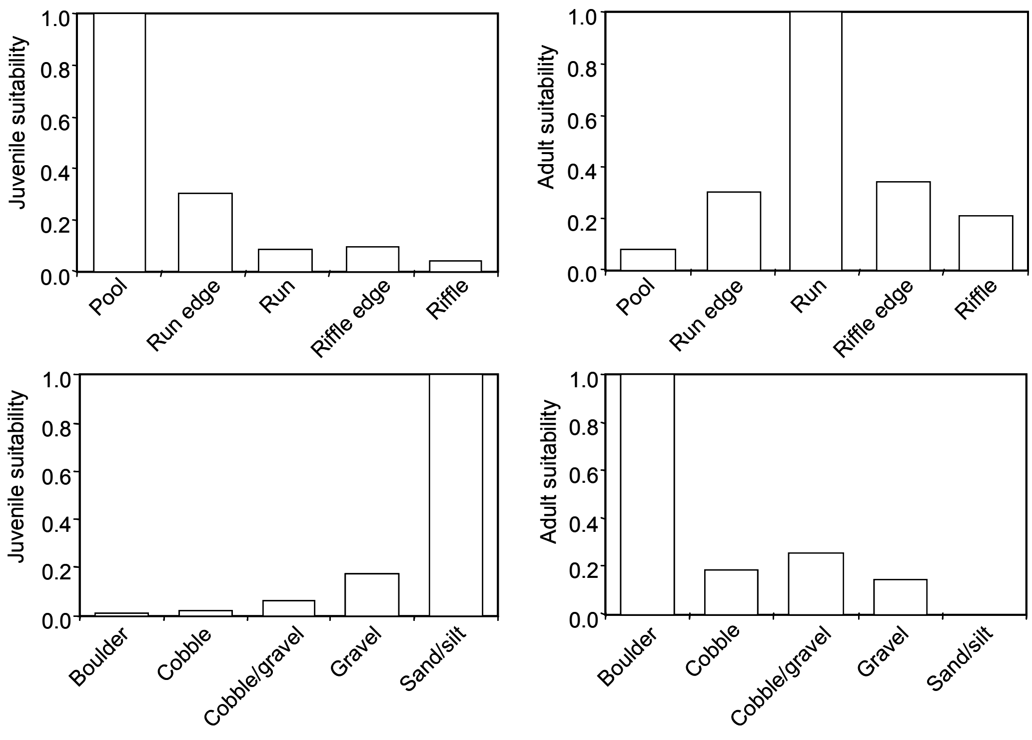


Figure 7. Suitability of habitat type and substrate for juvenile (*left*) and adult (*right*) roundhead galaxias, (*G. anomalus*).

found in the edges of runs and riffles (Fig. 7), where water velocities are low and similar to those in pools, suggesting that substrate is also influencing habitat selection.

Juvenile roundhead galaxias were mostly associated with sand/silt substrate, whereas adult fish were associated only with larger substrates, and highest densities were amongst boulders (Fig. 7).

3.3 LOWLAND LONGJAW GALAXIAS

A total of 399 locations was sampled in the Kauru River (384 by electric fishing and 15 by visual observation), giving 79 juvenile fish and 109 adult fish (Tables A9–A12, Appendix 1). Over 83% of juvenile fish were found in depths of 0.2–0.3 m (Fig. 8), with an average depth of 0.21 m (Table 6). In contrast to juveniles, adult fish used significantly shallower depths (Mann-Whitney, $P < 0.001$), with a mean depth of 0.11 m and 83% of fish in depths less than 0.15 m (Fig. 8). Histograms and kernel smoothed distributions of habitat preference (Fig. 9) were similar to the habitat use frequency distributions in Fig. 8 for both adult and juveniles. Habitat suitability curves were constructed so that they encompassed these distributions.

Juvenile fish were generally found in slow moving waters, with 78% of fish found in velocities less than 0.1 m s^{-1} (Fig. 8), and in an average velocity of

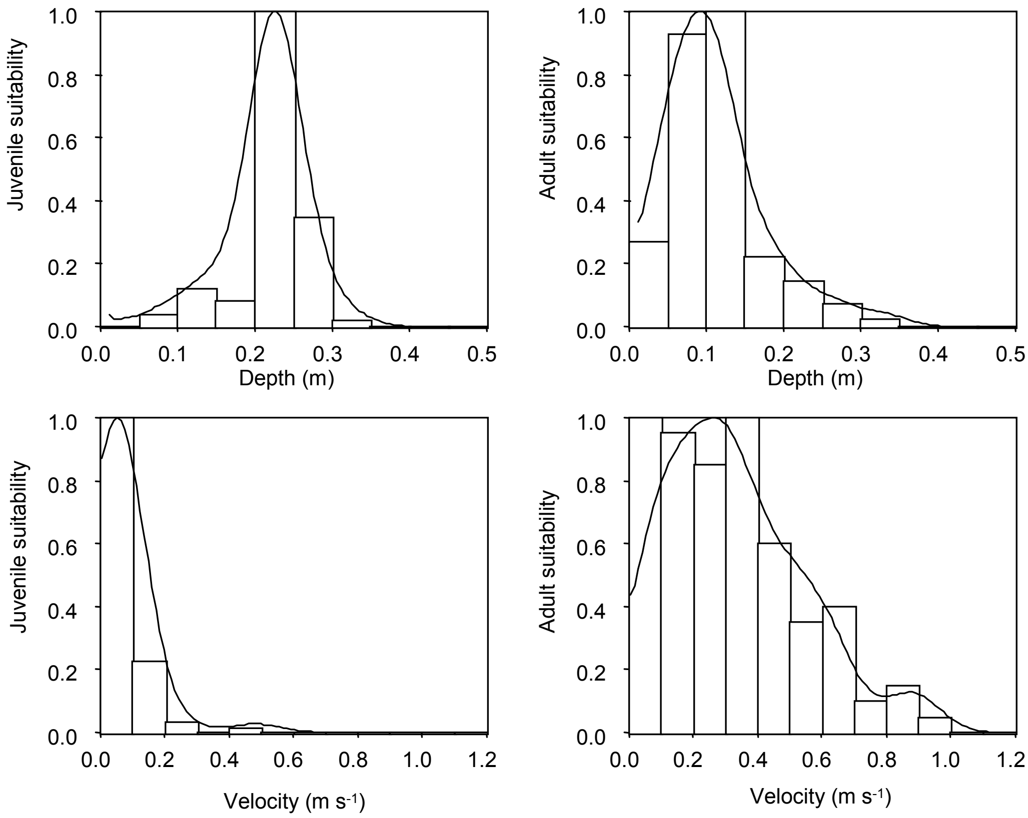


Figure 8. Normalised frequency histograms and kernel smoothed distributions of depth and velocity used by juvenile (*left*) and adult (*right*) lowland longjaw galaxias, (*G. cobitinis*).

TABLE 6. MEAN DEPTHS AND VELOCITIES (± STANDARD DEVIATION) USED BY ADULT AND JUVENILE LOWLAND LONGJAW GALAXIAS.

	DEPTH (m)	VELOCITY (m s^{-1})
Juveniles (N = 79)	0.21 ± 0.04	0.06 ± 0.06
Adults (N = 109)	0.11 ± 0.06	0.31 ± 0.21

0.06 m s^{-1} (Table 6). In contrast, adult fish were using a wider range of velocities, with fish found in velocities ranging from 0–0.9 m s^{-1} (Fig. 8) and in an average velocity of 0.31 m s^{-1}. Histograms and kernel smoothed distributions of velocity preference (Fig. 9) were generally similar to the habitat use frequency distributions in Fig. 8, although adult fish tended to prefer higher velocities (> 0.5 m s^{-1}) than indicated by their habitat use distribution (Fig. 8). Optimum velocities for juvenile lowland longjaw galaxias were less than 0.1 m s^{-1}, whereas optimum adult velocities were 0.1–0.5 m s^{-1} (Fig. 9).

The habitat types used reflected velocity preferences, with juvenile fish almost exclusively found in pools and runs, and adult fish found mainly in riffles (Fig. 10 and Table A12, Appendix 1).

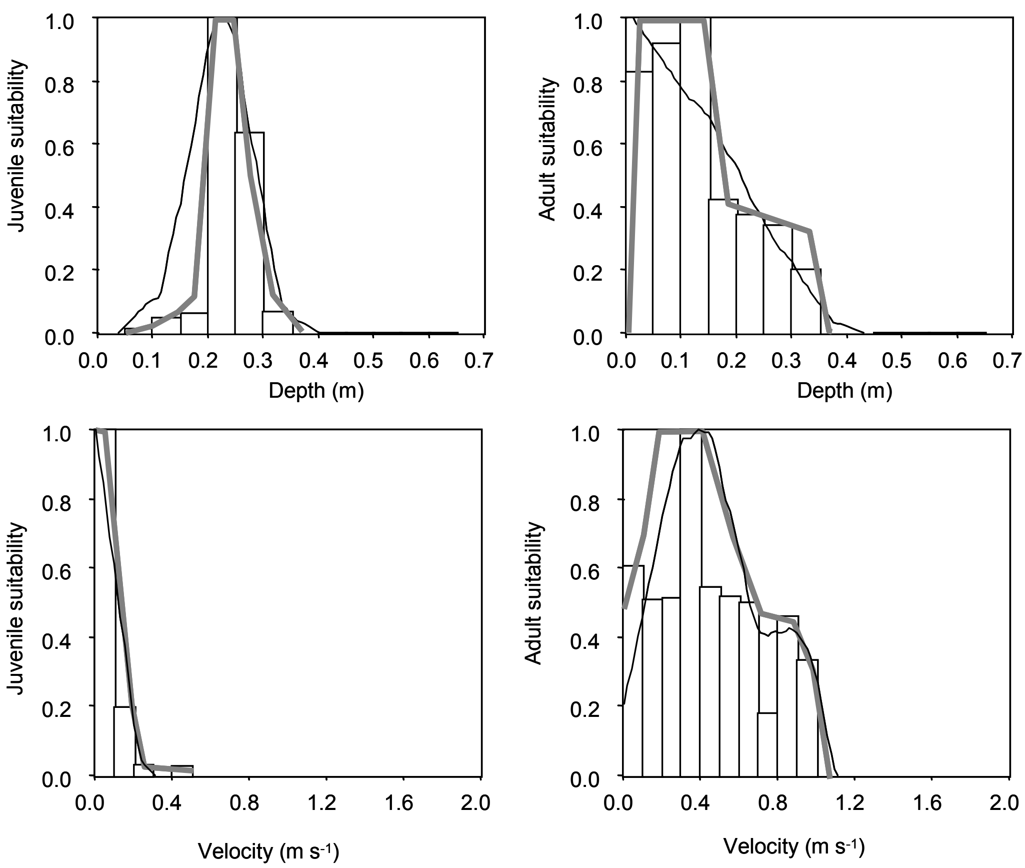


Figure 9. Normalised histograms and kernel smoothed distributions (black lines) of depth and velocity preference (based on the average fish abundance per sample in each habitat interval) for juvenile (*left*) and adult (*right*) lowland longjaw galaxias, (*G. cobitinis*). Grey shaded lines show the habitat suitability curves.

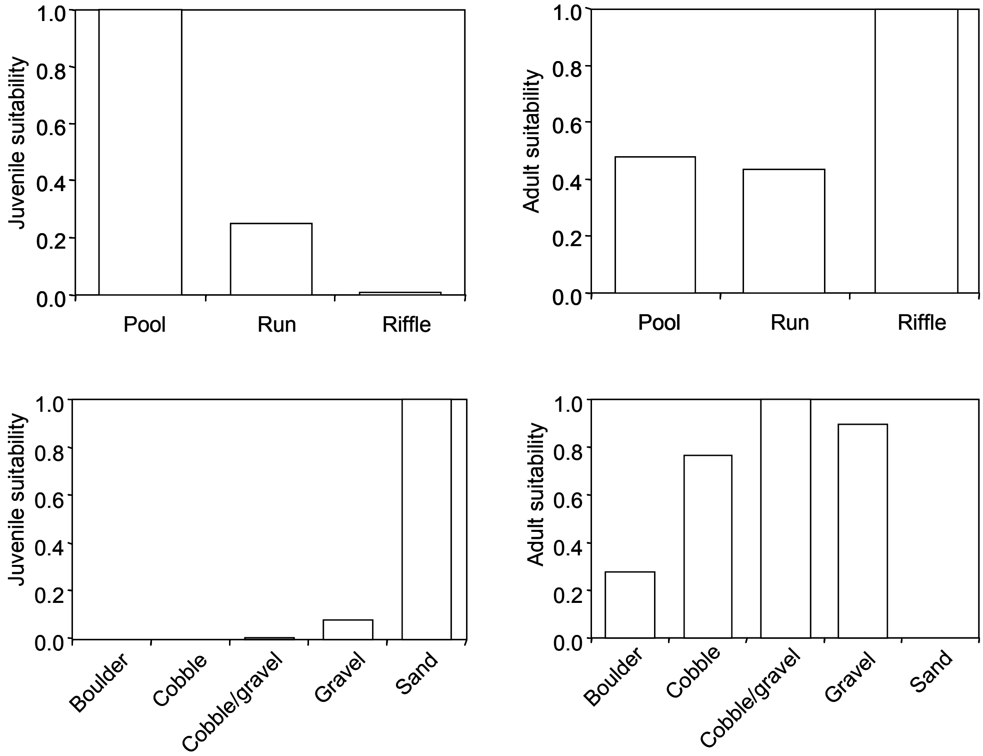


Figure 10. Suitability of habitat and substrate categories for juvenile (*left*) and adult (*right*) lowland longjaw galaxias (*G. cobitinis*).

The substrate types used by lowland longjaw galaxias reflected the habitats and velocities, with adult fish found mostly in cobble and/or gravel substrates and juvenile fish almost exclusively found in areas containing sand (Fig. 10).

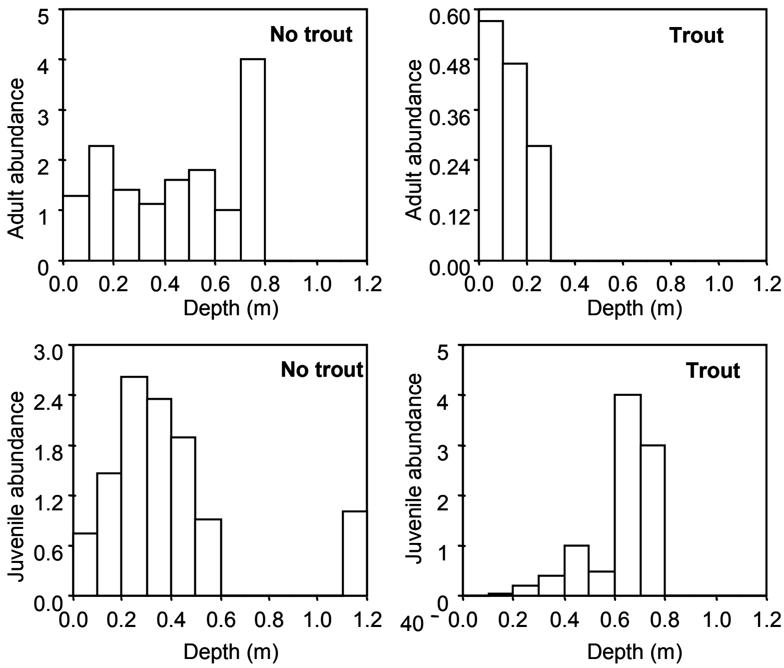
3.4 DAY AND NIGHT HABITAT USE

When we spotlighted at night for roundhead galaxias in the Kye Burn, juvenile and adult fish were seen in the habitats that they had occupied during the day. No night observations were carried out for flathead galaxias. Night observations in the Kauru River failed to locate any adult longjaws in pools, or slow runs and river margins, suggesting that they were in the riffles where they were found during the day. It is likely that the same habitat is used as a refuge and feeding area by roundhead and lowland longjaws, both day and night.

3.5 CO-OCCURRENCE OF FLATHEAD GALAXIAS AND BROWN TROUT

Streams without trout were sampled at 239 locations for 385 adult and 394 juvenile flathead galaxias. Streams with trout were sampled at 129 locations and only 47 adult and 38 juvenile flatheads were found (Tables A13–A16, Appendix 1). The relatively small number of flatheads found co-existing with trout suggests that trout might be influencing flathead abundance, and that

Figure 11. Variation in abundance of flathead galaxias with depth for adults (*above*) and juveniles (*below*) in streams without trout (*left*) and in streams where trout are present (*right*).



comparisons in habitat use between streams with and without trout should be regarded as tentative because of the small sample size.

The abundance of adult flatheads in streams with no trout was relatively constant at 1–2 fish per sampling location in depths ranging up to 0.7 m (Fig. 11). However in streams with trout, no adult flatheads were found in depths greater than 0.3 m, even though deeper water was sampled with a similar effort to that in streams that did not contain trout, suggesting that adult flatheads were avoiding water deeper than 0.3 m when trout were present. Juvenile flatheads were found over a range of depths in streams both with and without trout (Fig. 11), and there did not appear to any avoidance of deep water.

The presence of trout did not influence the velocities used by either adult or juvenile flatheads. Adult flathead galaxias utilised a wide range of velocities, in streams both with and without trout, whereas juvenile flatheads were found in low water velocities in streams both with and without trout (Fig. 12).

Adult flatheads were most abundant in riffles of streams containing trout, whereas in streams with no trout they were most abundant in runs and some were even found in pools (Fig. 13). Juvenile flatheads were found in pools in streams both with and without trout. The high preference for run edges by juvenile flatheads in streams without trout and the low preference in streams with trout is probably the result of the small number of samples (5%) collected from run edges rather than an effect of trout presence.

Adult flatheads were found in substrates ranging from bedrock to gravel, in streams both with and without trout (Fig. 14). Juvenile flatheads were more common in gravel substrate in streams with trout than without. However, gravel was present in pools at the sites with trout, whereas gravel was only present in runs and riffles of the sites without trout. Given the preference of juveniles for pool habitat, the apparent preference for gravel in streams with

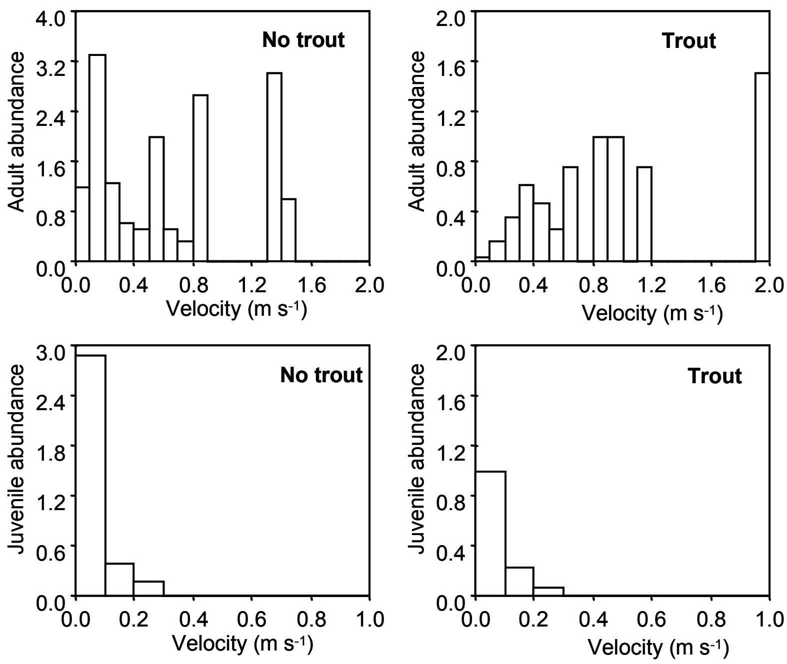


Figure 12. Variation in abundance of flathead galaxias with velocmity for adults (*above*) and juveniles (*below*) in streams without trout (*left*) and in streams where trout are present (*right*).

trout is more likely to be the result of the association between pool habitat and gravel at sites with trout rather than juvenile galaxias preferring gravel substrate when trout are present.

Overall, the presence of trout appears to have confined adult flatheads to shallow (< 0.3 m) riffles, whereas without trout they also utilised deeper runs and pools. With the small sample size, we were unable to ascertain whether the presence of trout had any effect on habitat use by juvenile flatheads and sites may have differed in ways other than just the presence and absence of trout.

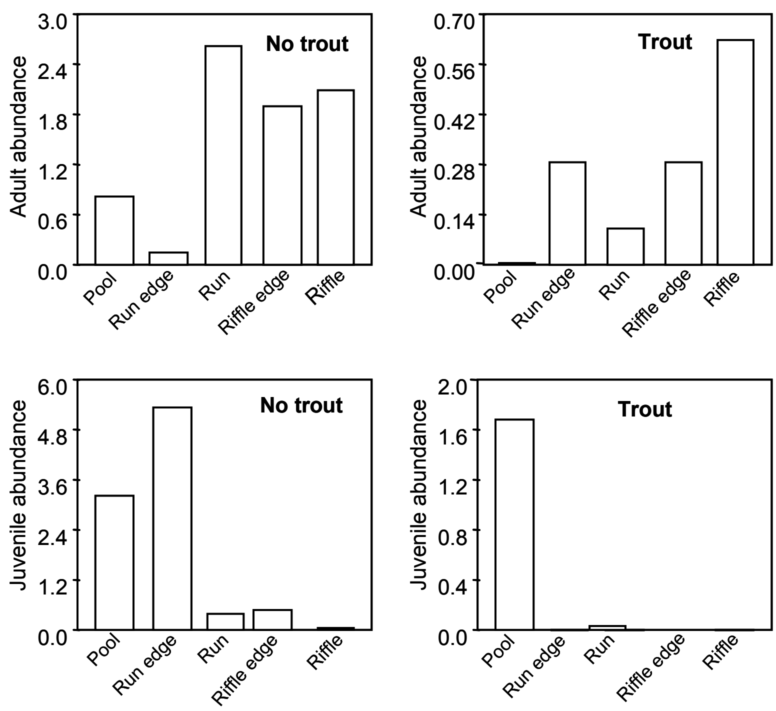


Figure 13. Variation in abundance of flathead galaxias with habitat type for adults (*above*) and juveniles (*below*) in streams without trout (*left*) and in streams where trout are present (*right*).

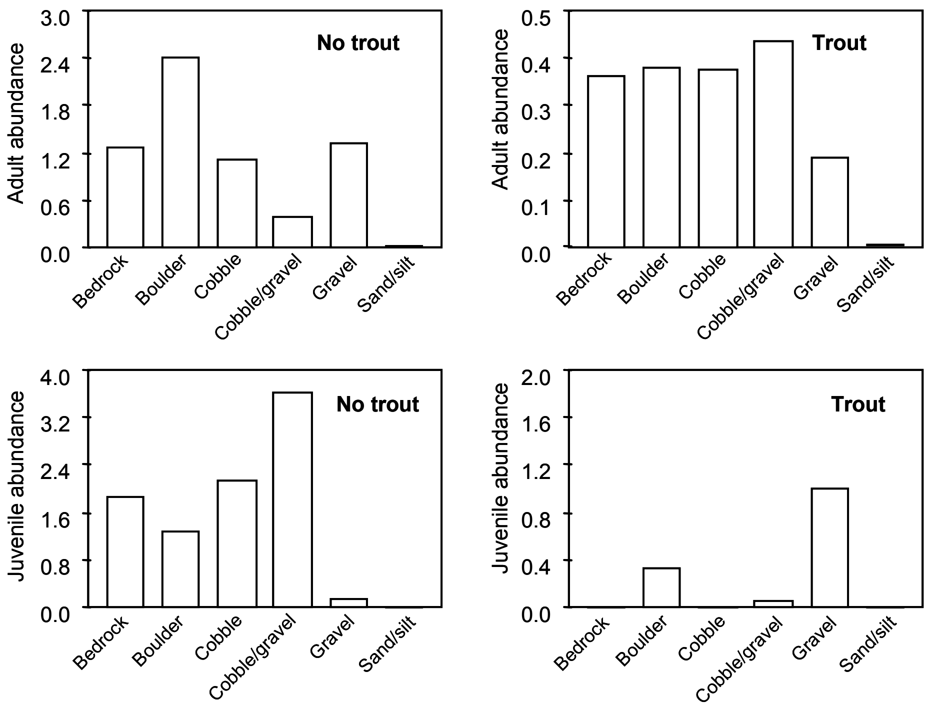


Figure 14. Variation in abundance of flathead galaxias with substrate for adults (*above*) and juveniles (*below*) in streams without trout (*left*) and in streams where trout are present (*right*).

3.6 APPLICATION OF HABITAT SUITABILITY CURVES TO STREAM EXAMPLES

Instream habitat survey data were used to demonstrate how the area of habitat suitable for non-migratory galaxias varies with flow in four small streams. The method of calculation is described in detail in Jowett (1999) and Milhous et al. (1989). An instream habitat survey comprises a series of cross-sections measured in a range of habitat types, such as pool, run, and riffle, and calibrated so that the water level at each cross-section can be predicted for a range of flows. Predicted water levels are then used to calculate water depths and velocities at each point on each cross-section. The suitability of depth, velocity, and substrate is evaluated on a scale of 0 (unsuitable) to 1 (suitable) using appropriate habitat suitability curves (e.g. Fig. 4). The overall suitability of the point is the product of the depth, velocity and substrate suitability and is multiplied by the stream area it represents to give the weighted usable area (WUA).

One of the four streams used as examples was the Cardrona River in Otago. It is an unconfined alluvial river similar to, but slightly larger than, the Kye Burn. The other three streams were in the Waitakere Ranges of Auckland. Of more than 100 streams surveyed, these were considered to be the most similar to streams containing flatheads, with confined channels and large substrate. Instream habitat surveys of all streams were carried out at normal summer flows. Weighted usable area was calculated only for adult galaxiids because their velocity requirements are greater than those for juveniles.

When the instream habitat survey of the Cardrona River was carried out, the stream flow was 1.6 $m^3 s^{-1}$, with an average width, depth and velocity of 11.3 m, 0.2 m, and 0.55 $m s^{-1}$, respectively. The amount of habitat (WUA) for adult

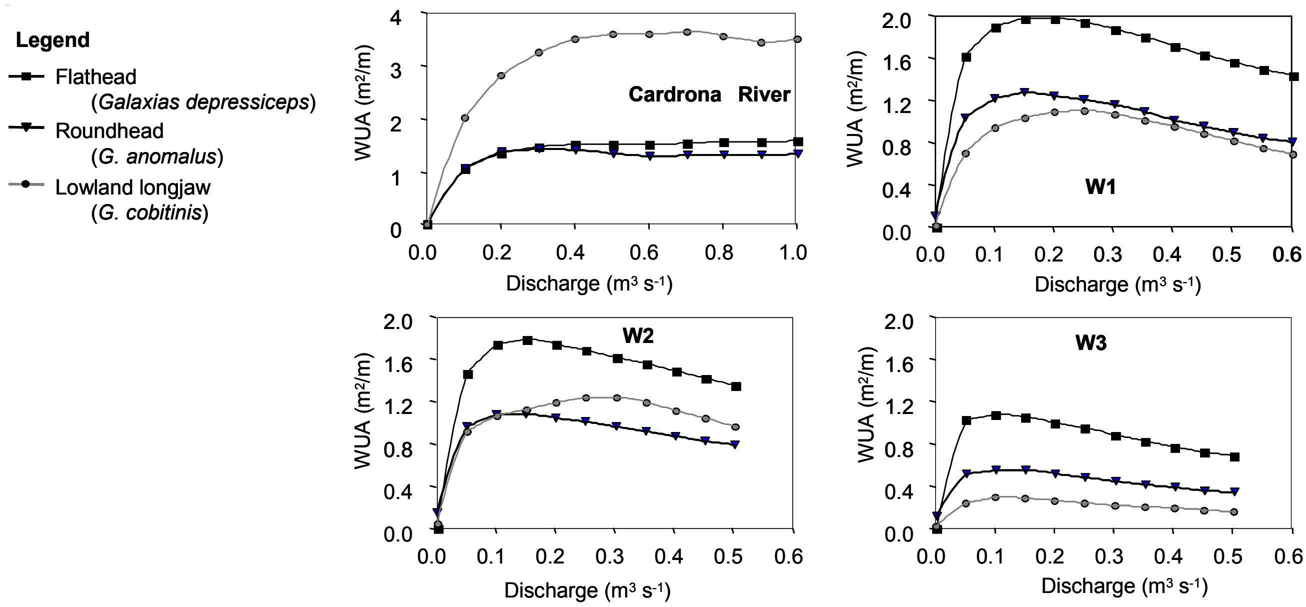


Figure 15. Relationships between the area of suitable habitat (weighted usable area (WUA) in m^2 per m of river length) and flow in four streams.

flathead and roundhead galaxias increased as flows increased to 0.2 $m^3 s^{-1}$ and remained relatively constant as flows increased further (Fig. 15). Flow requirements for adult lowland longjaw galaxias were slightly higher than for the other two species, with maximum longjaw habitat provided by flows of 0.4–0.7 $m^3 s^{-1}$.

The first Waitakere stream (W1) had an average width of 5.2 m, with an average depth and velocity of 0.2 m and 0.25 m s^{-1}, respectively, at a flow of 0.2 $m^3 s^{-1}$. Maximum habitat was provided by flows of 0.15 $m^3 s^{-1}$ for roundhead galaxias, 0.15–0.2 $m^3 s^{-1}$ for flatheads, and 0.15–0.25 $m^3 s^{-1}$ for lowland longjaw galaxias.

The second Waitakere stream (W2) was 7 m wide on average, with an average depth and velocity of 0.4 m and 0.17 m s^{-1}, respectively, at a flow of 0.33 $m^3 s^{-1}$. Maximum habitat was provided by flows of 0.1–0.3 $m^3 s^{-1}$, with flows of 0.1 $m^3 s^{-1}$, 0.15 $m^3 s^{-1}$, and 0.3 $m^3 s^{-1}$ providing maximum habitat for roundhead, flathead, and lowland longjaw galaxias, respectively.

The last Waitakere steam (W3) was the most confined of the four streams, with an average width of 4.5 m and average depth and velocity of 0.45 m and 0.32 m s^{-1}, respectively at a flow of 0.64 $m^3 s^{-1}$. Maximum habitat for all three species was provided by a flow of 0.1 $m^3 s^{-1}$ in this stream (Fig. 15).

Overall, the three well-confined Waitakere streams showed well-defined habitat maxima, whereas in the alluvial Cardrona River the amount of habitat increased with flow up to a maximum at 0.3–0.5 $m^3 s^{-1}$ depending on the species, and then tended to remain constant as flows increased further. The lack of distinct maxima is a characteristic of alluvial rivers that flow in an unconfined gravel bed and increase in width significantly as the flow increases.

4. Discussion

4.1 HABITAT USE

Juveniles of all three non-migratory galaxiid species (roundhead, flathead, and lowland longjaw) were most commonly found in pools and occasionally along the edges of runs and riffles, where there was low-velocity water. Sand and silt was usually the predominant substrate type at locations where juvenile galaxiids (except flathead) were found. Adult fish were usually found in runs and riffles and were associated with larger substrates and higher water velocities than juveniles. These habitat preferences are consistent with a shift from the pelagic lifestyle of juveniles to the benthic existence of adults. Riffle areas contain large substrates that provide benthic fish with visual isolation and shelter from the current and predators.

The streams containing flathead galaxias were dominated by bedrock or boulder substrates and tended to be generally narrower and steeper than the wide alluvial streams that contained roundhead or lowland longjaw galaxias. The habitats occupied by adult flathead galaxias tended to be more diverse than those occupied by the other two species, with flatheads making use of pools and a wide range of water depths and velocities.

Preference curves describe the range of water depths, velocities, and substrates that provide suitable habitat for fish. Substrate size is hydraulically related to water depth and velocity and it is difficult to determine whether fish locations are selected on the basis of cover, depth or velocity. Cover is an important component of habitat for most adult galaxiids, whether it is provided by in-stream debris or overhanging banks as for the large galaxiids or by cobble substrate in riffles for the smaller galaxiids. A study of Canterbury galaxias in the Waipara River (Jowett 2001) showed fish movement from runs to riffles as the velocity in runs reduced, suggesting that velocity was important. Depth may be less important. For example, four adult roundhead galaxias were found in a 0.9 m deep pool with cobble substrate, and their density suggested a high preference for this depth (Fig. 6). However, we believe that more than one measurement of high fish density in deep water is required to justify the assumption that deep water habitat is preferred over shallow riffles where most of the fish were found.

The non-migratory Canterbury galaxias is believed to be closely related to flathead and roundhead galaxias (Allibone et al. 1996). Juvenile Canterbury galaxias are found in pools and adults are predominantly riffle dwellers. In a survey of larger rivers, Jowett & Richardson (1995) found that Canterbury galaxias were most commonly found in riffles; 80% of fish were in depths less than 0.25 m, with 70% in velocities less than 0.3 m s^{-1} and c. 20% of fish in velocities of 0.3–0.6 m s^{-1}. Preference curves indicated that Canterbury galaxias prefer shallow water (< 0.3 m) and medium water velocities (< 0.6 m s^{-1}) (Jowett & Richardson 1995).

Low water velocities are preferred by some galaxiid species. Giant kokopu were rarely found in water velocities exceeding 0.1 m s^{-1} (Bonnett & Sykes 2002). Adult shortjawed kokopu preferred velocities of less than 0.05 m s^{-1} (McDowall et al. 1996). Inanga were feeding in velocities of 0.03–0.07 m s^{-1} (Jowett 2002), and McCullough (1998) found adult banded kokopu in velocities of 0–0.02 m s^{-1} and juvenile banded kokopu in velocities of 0.04–0.06 m s^{-1}. In contrast, Richardson & Jowett (1995) found that adult koaro were most abundant in cascades and riffles, in locations with a median velocity of 0.61 m s^{-1} and no apparent upper limit.

Although the three galaxiid species in this study were found predominantly in low-velocity habitats, fish densities in high water velocities were occasionally similar to those in low velocities (e.g. Figs 3 and 9). The non-diadromous galaxiid complex in Otago is believed to have derived from the diadromous koaro (Waters & Wallis 2001) and there are some similarities in adult habitat use. Some flathead galaxias were found in high water velocities and boulder substrates that are characteristic of koaro habitat and lowland longjaw galaxias were abundant over a range of velocities. However, all three non-diadromous species, especially juveniles, also made use of areas of low water velocity and this may be a behavioural adaptation that allows them to survive the periods of low flow that are common in Otago.

4.2 BROWN TROUT INTERACTIONS WITH GALAXIIDS

We found only three sites in the Taieri River catchment where brown trout and flathead galaxias co-exist: the Linn Burn, Taieri River at Canadian Flat, and Three O'clock Stream. Only at the latter site do the two species co-occur at moderate to high densities (Allibone 1997). Our data show that adult flatheads were most abundant in riffles when brown trout are present, but were more evenly spread across a wider range of habitats when trout are not present. Similar behaviour has been suggested for koaro. Koaro are most common in swift, shallow water, especially tumbling torrents (McDowall 1990), but have been observed in pools in areas where trout are absent (Hayes 1996; Chadderton & Allibone 2000).

The area of Three O'clock Stream where flatheads coexist with brown trout is a spawning/rearing area for brown trout, containing resident juvenile trout up to 150 mm in length. Brown trout less than 150 mm are rarely piscivorous (Mittelbach & Persson 1998) and are unlikely to prey upon adult non-migratory galaxiids (McIntosh 2000). However, the presence of brown trout appeared to encourage adult flatheads to use riffle habitat even though the abundance of piscivorous trout was low. Kalleberg (1958) describes the aggressive nature of juvenile salmonids and how visual isolation can limit aggressive interactions. Thus, the change in habitat use by flathead galaxias may be the result of interspecific competition for space, with riffle habitats providing greater isolation of individuals than run or pool habitats.

4.3 IMPLICATIONS FOR FLOW MANAGEMENT

Application of habitat suitability to four streams, ranging in width from 4.5 to 11 m, showed that the flow/habitat relationships for flathead and roundhead galaxias were similar, as one would expect from the similarity of habitat suitability curves. The flow that provided maximum habitat for the lowland longjaw was generally slightly higher than the flow that provided maximum habitat for the other two species, because habitat suitability curves indicated that longjaw galaxias preferred slightly higher velocities than the other two species.

Juvenile habitat suitability curves were not applied to these example streams because juvenile non-migratory galaxiids were usually found in isolated pools or stream margins. Because the velocity preferences of the adult galaxiids in this study were higher than those of juveniles, flow requirements for adults will also be higher. We believe that a flow that is suitable for adults will also maintain the pools and margins used by juveniles.

Studies of flow and habitat requirements in c. 60 New Zealand rivers (Jowett 1996a) suggest that flow requirements can be generalised for a particular species, depending on their velocity and depth preference. Generally low flows tend to produce shallow low-velocity water, so that maximum habitat for a species that prefers shallow slow-flowing water is often provided by a relatively low flow. For example, maximum habitat for juvenile trout tends to be provided by flows of 1–2 $m^3 s^{-1}$, whereas maximum habitat for adult brown trout tends to be provided by flows of 6–15 $m^3 s^{-1}$, because they are found in deeper swifter water than juvenile trout. The application of an in-stream habitat model to four example streams suggests that low flows of 0.3 $m^3 s^{-1}$ or so would maintain near optimum habitat for non-migratory Otago galaxiids, with flow requirement increasing with stream size. Minimum flows of this order have been recommended for the maintenance of native fish habitat in a number of small streams and rivers (e.g. Jowett 1994a, b, 1996b), but it is recommended that specific flow recommendations be based on site-specific in-stream habitat survey data.

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Appendix 1

CALCULATIONS OF HABITAT USE

TABLE A1. SAMPLING FREQUENCY AND WATER DEPTH FOR ADULT AND JUVENILE FLATHEAD GALAXIIDS.

		ADULT		JUVENILE	
DEPTH INTERVAL (m)	SAMPLING FRE-QUENCY	FISH FRE-QUENCY	AV. NO. OF FISH PER SAMPLE	FISH FRE-QUENCY	AV. NO. OF FISH PER SAMPLE
0–0.05	29	46	1.59	1	0.03
0.05–0.1	58	45	0.78	43	0.74
0.1–0.15	70	81	1.07	45	0.64
0.15–0.2	47	96	2.17	56	1.19
0.2–0.25	51	87	1.71	62	1.22
0.25–0.3	30	6	0.13	99	3.30
0.3–0.35	29	24	0.83	50	1.72
0.35–0.4	16	5	0.44	19	1.19
0.4–0.45	6	10	1.67	19	3.17
0.45–0.5	7	6	0.86	3	0.43
0.5–0.55	5	4	0.80	0	0.00
0.55–0.6	8	16	1.50	10	1.25
0.6–0.65	6	0	0.67	14	2.33
0.65–0.7	2	2	1.00	4	2.00
0.7–0.75	0	0	0.00	0	0.00
0.75–0.8	3	4	1.33	6	2.00
0.8–0.85	0	0	0.00	0	0.00
0.85–0.9	0	0	0.00	0	0.00
0.9–0.95	0	0	0.00	0	0.00
0.95–1	0	0	0.00	0	0.00
1–1.05	0	0	0.00	0	0.00
1.05–1.1	0	0	0.00	0	0.00
1.1–1.15	1	0	0.00	1	1.00

TABLE A2. SAMPLING FREQUENCY AND WATER VELOCITY FOR ADULT AND JUVENILE FLATHEAD GALAXIIDS.

		ADULT		JUVENILE	
VELOCITY INTERVAL ($m\ s^{-1}$)	SAMPLING FRE-QUENCY	FISH FRE-QUENCY	AV. NO. OF FISH PER SAMPLE	FISH FRE-QUENCY	AV. NO. OF FISH PER SAMPLE
0–0.1	160	154	0.96	401	2.51
0.1–0.2	74	162	2.19	25	0.34
0.2–0.3	45	45	1.00	6	0.13
0.3–0.4	26	15	0.58	0	0.00
0.4–0.5	17	8	0.47	0	0.00
0.5–0.6	10	13	1.30	0	0.00
0.6–0.7	13	9	0.69	0	0.00
0.7–0.8	5	2	0.40	0	0.00
0.8–0.9	7	12	1.71	0	0.00
0.9–1	2	2	1.00	0	0.00
1–1.1	0	0	0.00	0	0.00
1.1–1.2	4	3	0.75	0	0.00
1.2–1.3	1	0	0.00	0	0.00
1.3–1.4	1	3	3.00	0	0.00
1.4–1.5	1	1	1.00	0	0.00
1.5–1.6	0	0	0.00	0	0.00
1.6–1.7	0	0	0.00	0	0.00
1.7–1.8	0	0	0.00	0	0.00
1.8–1.9	0	0	0.00	0	0.00
1.9–2	2	3	1.50	0	0.00

TABLE A3. SAMPLING FREQUENCY AND SUBSTRATE CATEGORIES FOR ADULT AND JUVENILE FLATHEAD GALAXIIDS.

		ADULT		JUVENILE	
SUBSTRATE CATEGORY	SAMPLING FRE-QUENCY	FISH FRE-QUENCY	AV. NO. OF FISH PER SAMPLE	FISH FRE-QUENCY	AV. NO. OF FISH PER SAMPLE
Bedrock	48	51	1.06	69	1.44
Boulder	162	261	1.61	148	0.91
Cobble	68	64	0.94	111	1.63
Cobble/gravel	46	19	0.41	84	1.83
Gravel	42	37	0.88	20	0.48
sand/silt	2	0	0.00	0	0.00

TABLE A4. SAMPLING FREQUENCY AND HABITAT CATEGORIES FOR ADULT AND JUVENILE FLATHEAD GALAXIIDS.

		ADULT		JUVENILE	
HABITAT CATEGORY	SAMPLING FRE-QUENCY	FISH FRE-QUENCY	AV. NO. OF FISH PER SAMPLE	FISH FRE-QUENCY	AV. NO. OF FISH PER SAMPLE
Pool	114	75	0.66	333	2.92
Riffle	129	175	1.36	2	0.02
riffle edge	17	21	1.24	5	0.29
Run	88	157	1.78	23	0.26
run edge	20	4	0.20	69	3.45

TABLE A5. SAMPLING FREQUENCY AND WATER DEPTH FOR ADULT AND JUVENILE ROUNDHEAD GALAXIIDS.

		ADULT		JUVENILE	
DEPTH INTERVAL (m)	SAMPLING FRE-QUENCY	FISH FRE-QUENCY	AV. NO. OF FISH PER SAMPLE	FISH FRE-QUENCY	AV. NO. OF FISH PER SAMPLE
0–0.05	103	48	0.47	67	0.65
0.05–0.1	153	104	0.68	172	1.12
0.1–0.15	97	175	1.80	379	3.91
0.15–0.2	62	7	0.11	338	5.45
0.2–0.25	45	11	0.24	283	6.29
0.25–0.3	26	2	0.08	268	10.31
0.3–0.35	12	3	0.25	168	14.00
0.35–0.4	12	2	0.17	236	19.67
0.4–0.45	7	0	0.00	257	36.71
0.45–0.5	3	0	0.00	110	36.67
0.5–0.55	2	0	0.00	100	50.00
0.55–0.6	2	2	1.00	0	0.00
0.6–0.65	1	0	0.00	10	10.00
0.65–0.7	0	0	0.00	0	0.00
0.7–0.75	2	0	0.00	16	8.00
0.75–0.8	0	0	0.00	0	0.00
0.8–0.85	0	0	0.00	0	0.00
0.85–0.9	1	4	4.00	1	1.00

TABLE A6. SAMPLING FREQUENCY AND WATER VELOCITY FOR ADULT AND JUVENILE ROUNDHEAD GALAXIIDS.

		ADULT		JUVENILE	
VELOCITY INTERVAL ($m\ s^{-1}$)	SAMPLING FRE-QUENCY	FISH FRE-QUENCY	AV. NO. OF FISH PER SAMPLE	FISH FRE-QUENCY	AV. NO. OF FISH PER SAMPLE
0–0.1	269	87	0.32	2225	8.27
0.1–0.2	88	120	1.36	130	1.48
0.2–0.3	50	120	2.40	27	0.54
0.3–0.4	26	4	0.15	2	0.08
0.4–0.5	29	6	0.21	13	0.45
0.5–0.6	25	3	0.12	0	0.00
0.6–0.7	15	12	0.80	6	0.40
0.7–0.8	13	4	0.31	1	0.08
0.8–0.9	3	0	0.00	0	0.00
0.9–1	4	0	0.00	0	0.00
1–1.1	4	1	0.25	1	0.25
1.1–1.2	1	1	1.00	0	0.00
1.2–1.3	1	0	0.00	0	0.00

TABLE A7. SAMPLING FREQUENCY AND SUBSTRATE CATEGORIES FOR ADULT AND JUVENILE ROUNDHEAD GALAXIIDS.

		ADULT		JUVENILE	
SUBSTRATE CATEGORY	SAMPLING FRE-QUENCY	FISH FRE-QUENCY	AV. NO. OF FISH PER SAMPLE	FISH FRE-QUENCY	AV. NO. OF FISH PER SAMPLE
Boulder	44	128	2.91	10	0.23
Cobble	107	58	0.54	61	0.57
Cobble/gravel	107	81	0.76	164	1.53
Gravel	216	91	0.42	882	4.08
Sand/silt	54	0	0.00	1288	23.85

TABLE A8. SAMPLING FREQUENCY AND HABITAT CATEGORIES FOR ADULT AND JUVENILE ROUNDHEAD GALAXIIDS.

		ADULT		JUVENILE	
HABITAT CATEGORY	SAMPLING FRE-QUENCY	FISH FRE-QUENCY	AV. NO. OF FISH PER SAMPLE	FISH FRE-QUENCY	AV. NO. OF FISH PER SAMPLE
Pool	154	26	0.17	1957	12.71
Riffle	185	84	0.45	90	0.49
Riffle edge	58	43	0.74	70	1.21
Run	78	170	2.18	85	1.09
Run edge	53	35	0.66	203	3.83

TABLE A9. SAMPLING FREQUENCY AND WATER DEPTH FOR ADULT AND JUVENILE LOWLAND LONGJAW GALAXIIDS.

		ADULT		JUVENILE	
DEPTH INTERVAL (m)	SAMPLING FRE-QUENCY	FISH FRE-QUENCY	AV. NO. OF FISH PER SAMPLE	FISH FRE-QUENCY	AV. NO. OF FISH PER SAMPLE
0–0.05	35	11	0.31	0	0.00
0.05–0.1	109	38	0.35	2	0.02
0.1–0.15	108	41	0.38	6	0.06
0.15–0.2	56	9	0.16	4	0.07
0.2–0.25	42	6	0.14	49	1.17
0.25–0.3	23	3	0.13	17	0.74
0.3–0.35	13	1	0.08	1	0.08
0.35–0.4	5	0	0.00	0	0.00
0.4–0.45	3	0	0.00	0	0.00
0.45–0.5	1	0	0.00	0	0.00
0.5–0.55	1	0	0.00	0	0.00
0.55–0.6	2	0	0.00	0	0.00
0.6–0.65	0	0	0.00	0	0.00
0.65–0.7	1	0	0.00	0	0.00

TABLE A10. SAMPLING FREQUENCY AND WATER VELOCITY FOR ADULT AND JUVENILE LOWLAND LONGJAW GALAXIIDS.

		ADULT		JUVENILE	
VELOCITY INTERVAL ($m\ s^{-1}$)	SAMPLING FRE-QUENCY	FISH FRE-QUENCY	AV. NO. OF FISH PER SAMPLE	FISH FRE-QUENCY	AV. NO. OF FISH PER SAMPLE
0–0.1	66	20	0.30	62	0.94
0.1–0.2	75	19	0.25	14	0.19
0.2–0.3	66	17	0.26	2	0.03
0.3–0.4	40	20	0.50	0	0.00
0.4–0.5	44	12	0.27	1	0.02
0.5–0.6	27	7	0.26	0	0.00
0.6–0.7	32	8	0.25	0	0.00
0.7–0.8	22	2	0.09	0	0.00
0.8–0.9	13	3	0.23	0	0.00
0.9–1	6	1	0.17	0	0.00
1–1.1	1	0	0.00	0	0.00
1.1–1.2	0	0	0.00	0	0.00
1.2–1.3	4	0	0.00	0	0.00
1.3–1.4	2	0	0.00	0	0.00
1.4–1.5	0	0	0.00	0	0.00
1.5–1.6	0	0	0.00	0	0.00
1.6–1.7	0	0	0.00	0	0.00
1.7–1.8	0	0	0.00	0	0.00
1.8–1.9	1	0	0.00	0	0.00

TABLE A11. SAMPLING FREQUENCY AND SUBSTRATE CATEGORIES FOR ADULT AND JUVENILE LOWLAND LONGJAW GALAXIIDS.

		ADULT		JUVENILE	
SUBSTRATE CATEGORY	SAMPLING FRE-QUENCY	FISH FRE-QUENCY	AV. NO. OF FISH PER SAMPLE	FISH FRE-QUENCY	AV. NO. OF FISH PER SAMPLE
Boulder	23	2	0.09	0	0.00
Cobble	78	19	0.24	0	0.00
Cobble/gravel	166	53	0.32	3	0.02
Gravel	122	35	0.29	37	0.30
Sand	10	0	0.00	39	3.90

TABLE A12. SAMPLING FREQUENCY AND HABITAT CATEGORIES FOR ADULT AND JUVENILE LOWLAND LONGJAW GALAXIIDS.

		ADULT		JUVENILE	
HABITAT CATEGORY	SAMPLING FRE-QUENCY	FISH FRE-QUENCY	AV. NO. OF FISH PER SAMPLE	FISH FRE-QUENCY	AV. NO. OF FISH PER SAMPLE
Pool	17	3	1.29	22	1.29
Riffle	214	79	0.01	2	0.01
Run	168	27	0.33	55	0.33

TABLE A13. SAMPLING FREQUENCY AND ADULT FLATHEAD GALAXIIDS DENSITIES IN RANGES OF WATER VELOCITY (m s^{-1}) IN STREAMS WITH AND WITHOUT BROWN TROUT. Velocity intervals with no samples in streams with and without brown trout are not shown.

VELOCITY RANGE	WITHOUT BROWN TROUT			WITH BROWN TROUT		
	NO. OF SAMPLES	NO. OF FISH	AV. NO. OF FISH PER SAMPLE	NO. OF SAMPLES	NO. OF FISH	AV. NO. OF FISH PER SAMPLE
0–0.1	129	153	1.19	31	1	0.03
0.1–0.2	48	158	3.29	26	4	0.15
0.2–0.3	32	40	1.25	14	5	0.36
0.3–0.4	10	6	0.60	15	9	0.60
0.4–0.5	4	2	0.50	13	6	0.46
0.5–0.6	6	12	2.00	4	1	0.25
0.6–0.7	2	1	0.50	12	9	0.75
0.7–0.8	3	1	0.33	1	0	0.00
0.8–0.9	3	8	2.67	4	4	1.00
0.9–1	0	0	0.00	2	2	1.00
1.1–1.2	0	0	0.00	4	3	0.75
1.2–1.3	0	0	0.00	1	0	0.00
1.3–1.4	1	3	3.00	0	0	0.00
1.4–1.5	1	1	1.00	0	0	0.00
1.9–2	0	0	0.00	2	3	1.50

TABLE A14. SAMPLING FREQUENCY AND JUVENILE FLATHEAD GALAXIIDS DENSITIES IN RANGES OF WATER VELOCITY (m s^{-1}) IN STREAMS WITH AND WITHOUT BROWN TROUT. Velocity intervals with no samples in streams with and without brown trout are not shown.

VELOCITY RANGE	WITHOUT BROWN TROUT			WITH BROWN TROUT		
	NO. OF SAMPLES	NO. OF FISH	AV. NO. OF FISH PER SAMPLE	NO. OF SAMPLES	NO. OF FISH	AV. NO. OF FISH PER SAMPLE
0–0.1	129	370	2.87	31	31	1.00
0.1–0.2	48	19	0.40	26	6	0.23
0.2–0.3	32	5	0.16	14	1	0.07
0.3–0.4	10	0	0.00	15	0	0.00
0.4–0.5	4	0	0.00	13	0	0.00
0.5–0.6	6	0	0.00	4	0	0.00
0.6–0.7	2	0	0.00	12	0	0.00
0.7–0.8	3	0	0.00	1	0	0.00
0.8–0.9	3	0	0.00	4	0	0.00
0.9–1	0	0	0.00	2	0	0.00
1.1–1.2	0	0	0.00	4	0	0.00
1.2–1.3	0	0	0.00	1	0	0.00
1.3–1.4	1	0	0.00	0	0	0.00
1.4–1.5	1	0	0.00	0	0	0.00
1.9–2	0	0	0.00	2	0	0.00

TABLE A15. SAMPLING FREQUENCY AND ADULT FLATHEAD GALAXIIDS DENSITIES IN RANGES OF WATER DEPTH (m) IN STREAMS WITH AND WITHOUT BROWN TROUT. Depth intervals with no samples in streams with and without brown trout are not shown.

	WITHOUT BROWN TROUT			WITH BROWN TROUT		
DEPTH RANGE	NO. OF SAMPLES	NO. OF FISH	AV. NO. OF FISH PER SAMPLE	NO. OF SAMPLES	NO. OF FISH	AV. NO. OF FISH PER SAMPLE
0–0.1	59	75	1.27	28	16	0.57
0.1–0.2	68	154	2.26	49	23	0.47
0.2–0.3	61	85	1.39	29	8	0.28
0.3–0.4	26	29	1.12	10	0	0.00
0.4–0.5	10	16	1.60	3	0	0.00
0.5–0.6	11	20	1.82	4	0	0.00
0.6–0.7	2	2	1.00	4	0	0.00
0.7–0.8	1	4	4.00	2	0	0.00
1.1–1.2	1	0	0.00	0	0	0.00

TABLE A16. SAMPLING FREQUENCY AND JUVENILE FLATHEAD GALAXIIDS DENSITIES IN RANGES OF WATER DEPTH (m) IN STREAMS WITH AND WITHOUT BROWN TROUT. Depth intervals with no samples in streams with and without brown trout are not shown.

	WITHOUT BROWN TROUT			WITH BROWN TROUT		
DEPTH RANGE	NO. OF SAMPLES	NO. OF FISH	AV. NO. OF FISH PER SAMPLE	NO. OF SAMPLES	NO. OF FISH	AV. NO. OF FISH PER SAMPLE
0–0.1	59	44	0.75	28	0	0.00
0.1–0.2	68	100	1.47	49	1	0.02
0.2–0.3	61	159	2.61	29	6	0.21
0.3–0.4	26	61	2.35	10	4	0.40
0.4–0.5	10	19	1.90	3	3	1.00
0.5–0.6	11	10	0.91	4	2	0.50
0.6–0.7	2	0	0.00	4	16	4.00
0.7–0.8	1	0	0.00	2	6	3.00
1.1–1.2	1	1	1.00	0	0	0.00