Taihoro Nukurangi

Habitat preference of southern flathead galaxias

(*Galaxias* "southern")

Prepared for Department of Conservation

June 2021

Climate, Freshwater & Ocean Science

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NIWA CLIENT REPORT No: 2021155CH
Report date: June 2021
NIWA Project: DOC21502

Revision	Description	Date
Version 1.0	Final Report	22 June 2021

Quality Assurance Statement		
	Reviewed by:	Kristy Hogsden
	Formatting checked by:	Rachel Wright
	Approved for release by:	Helen Rouse

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Executive summary

Habitat suitability curves (HSCs) are commonly used to describe preferences of freshwater biota for water velocity, water depth, substrate, and other relevant habitat characteristics. Changes in flow affect these physical habitat characteristics, potentially altering habitat suitability for different biota. By generating quantified habitat suitability criteria these relationships can then be used to apply physical habitat models under different flow scenarios. The results from these scenarios can help guide flow management decisions. HSCs have been developed for many of New Zealand's freshwater fishes, but reliable HSCs are still required for southern flathead galaxias (*Galaxias* "southern"). *G.* "southern" has high intrinsic biodiversity value and is currently classified as 'Nationally Vulnerable' in New Zealand. HSCs were previously generated for *G.* "southern", but results indicated habitat preferences were relatively weak because of low replication in the dataset. The aim of the present study was to calculate updated HSCs for *G.* "southern". Data collected by the Department of Conservation were used to generate HSCs that could be applied to future flow assessments that use physical habitat models such as the commonly used RHYHABSIM software.

Habitat information from 2016 was added to data collected in 2020 to generate updated HSCs for water velocity, water depth and substrate index. No reliable preferences were observed for water velocity or depth due to a high degree of uncertainty within habitat categories. A possible preference was identified for the substrate index category 5 to <6, which indicated that the preferred substrate of *G.* "southern" may be large gravels and cobbles. The additional data from 2020 did result in lower standard errors for all habitat categories where habitat values were grouped with the same divisions between the two studies (i.e., water velocity and water depth). However, results should be interpreted and used cautiously as there still were large standard errors associated with all categories for all variables, especially those categories with the highest preference values. To reduce the uncertainty associated with these HSCs and further improve understanding of the habitat preferences for *G*. "southern", future habitat surveys should target the habitat categories with high standard errors and low sample replication.

1 Background

Information on habitat requirements of freshwater fishes is used to guide the management of Aotearoa New Zealand's freshwater resources. Studies on physical habitat requirements aim to identify the important flow-driven factors used, and/or preferentially selected, by target fish species (Jowett and Richardson 2008). Data on habitat can then be used by managers during flow assessments by examining how the availability of important habitat factors changes with differing flows. The relationships between habitat preference and flows can then be used to ensure fish habitat is maintained or enhanced under changing flow regimes or could help avoid situations where the availability of suitable habitat may become limiting (Jowett and Richardson 2008).

Habitat suitability curves (HSCs) are used to describe preferences of freshwater biota across environmental gradients (e.g., water velocity, water depth, substrate). HSCs have been developed for many New Zealand freshwater fishes (Jowett and Richardson 2008), but reliable HSCs are still required for some galaxias species, particularly those with limited distributions that make obtaining sufficient data difficult. HSCs were created for southern flathead galaxias (*Galaxias* "southern") by Sinton et al. (2016), however habitat preferences were relatively weak because of low replication in the dataset. Additional information on habitat preferences for *G*. "southern" is available (Crow et al. 2010), but not suitable for generating HSCs. *G*. "southern" occurs across the Southland Plains and on Stewart Island (NZFFD 2021) and has a high intrinsic biodiversity value with a threat ranking of 'Nationally Vulnerable' (Dunn et al. 2018). The absence of reliable HSCs for this species means that current flow assessments may not appropriately consider the habitat requirements of this fish. Although habitat requirements of *G*. "southern" could be inferred from fishes with similar morphology, this is likely to be misleading given the different habitat requirements found between other non-diadromous *Galaxias* species (Crow et al. 2010; 2014).

The aim of the present study was to recalculate HSCs for *G*. "southern" for water velocity, water depth and substrate index using data collected in 2016 (Sinton et al. 2016) combined with additional data collected in 2020. These data, all of which were collected by the Department of Conservation (DOC), were used to calculate HSCs that could be applied to future flow assessments using the software package RHYHABSIM or SEFA (http://www.jowettconsulting.co.nz or www.sefa.co.nz, respectively).

2 Methods

2.1 Field sampling

Eight streams were sampled for *G.* “southern” in Southland in March 2016 and November 2020 (Table 2-1). Stream selection was based on the taxon being previously known at locations, and where possible: (1) an understanding of the abundance of the taxon; (2) the presence of few other non-target species; and (3) access permission from landowners/managers. The timing of sampling was designed to measure habitat preferences during higher flow conditions in spring and lower flow conditions in autumn.

Table 2-1: Location of each waterway sampled for *Galaxias* "southern". Coordinates are for the midpoint of sampled reaches.

Sampling year	Catchment	Waterway	NZTM Easting	NZTM Northing
2016	Mataura River	Rob Roy Creek	1271309	4928311
2016	Oreti River	Gorge Burn	1228097	4972377
2016	Waiau River	Mararoa River	1212863	4952010
2016	Waiau River	Whitestone River	1201239	4961549
2020	Mataura River	Mataura River	1254246	4963801
2020	Oreti River	Oreti River	1228458	4932907
2020	Waiau River	Moat Creek	1201388	4957681

In each stream, a sampling reach containing a variety of instream habitat types was selected. Starting at the downstream end of this reach, a minimum of 30 transects were marked at 3 m intervals. A discharge gauging was conducted at the most downstream transect. Current velocity was measured at 0.6 x depth using a SonTek/YSI FlowTracker acoustic Doppler velocimeter (March 2016) or a Marsh McBirney Flo-Mate 2000 electromagnetic current meter (November 2020).

At each transect, a 0.75 x 0.75 m quadrat was carefully placed within the stream so as to cover the dominant flow, water depth, and substratum conditions. A 1 m wide push net was placed at the downstream edge of the quadrat. Three-pass electrofishing of the quadrat was then conducted using a Kainga EFM 300 backpack electrofishing machine (NIWA Instrument Systems) in a downstream direction. Each pass consisted of 5 seconds of electrofishing machine current time, separated by a minimum electrofishing stoppage of 5 seconds between subsequent passes. After electrofishing, captured fish were anaesthetised with 2-phenoxyethanol, and identified to species using the keys of McDowall (1990; 2000), if required, or knowledge of the taxa. Fish were measured to the nearest 0.5 mm maximum total length (TL). Fish were then placed in an aerated bucket of water to recover, before being released back into quiet areas of the stream.

Following electrofishing, the mid-point of the quadrat was recorded using a handheld GPS (Garmin 64s) and the distance from each bank to the mid-point of the quadrat was measured. Water depth and water velocity (at 0.6 x depth) at the midpoint of the quadrat were measured. Percentage substratum composition within the quadrat was estimated using the following size classes: bedrock (>4096 mm), boulder (256–4096 mm), cobble (64–256 mm), large gravel (8–64 mm), fine gravel (2–8 mm), sand (0.06–2 mm) and silt/mud (<0.06 mm). Percentage cover of all algal and macrophyte types were also estimated within the quadrat. Once measurements were complete, the next transect upstream was sampled for fish and habitat in the same manner.

2.2 Fish density estimates

The total number of fish in each quadrat (summed from the three passes) was used as a measure of fish density, rather than a calculated population estimate (e.g., the Carle and Strub (1978) method). With fish catches being low (i.e., numerical average of 0.76 fish per quadrat; Appendix A) population estimates were unable to be generated due to insufficient data.

2.3 Substrate index

A substrate index (SI) was calculated for each quadrat from estimates of percent substrate composition using the relationship:

SI= %Bedrock*0.08 + %Boulder*0.07 + %Cobble*0.06 + %Gravel*0.05 + %Fine Gravel*0.04 + %Sand*0.03 + %Silt*0.02 (Jowett and Richardson 1990).

Vegetation has previously been included in SI calculations (Jowett and Richardson 2008) but was excluded from this analysis as vegetation was absent from all quadrats and would have no effect on the SI.

2.4 Habitat suitability curve calculations

The programme HABSEL (Jowett 2011) was used to calculate HSCs for water velocity, water depth and substrate index using density data of *G*. "southern". This software uses an approach consistent with that suggested in Jowett and Richardson (2008), which has previously been the method used to calculate HSC for many New Zealand fishes. The developed suitability curves are forage ratios where habitat use is adjusted for habitat availability, which is consistent with the category III curves described in Bovee (1986). The forage ratio is an index that measures preference for a particular habitat category and is calculated as the average abundance of the target organism in a given habitat category divided by the average abundance in all habitats. A forage ratio greater than 1.0 indicates preferential habitat selection, where habitat use is greater than expected by chance, a forage ratio less than 1.0 are indicates habitat use is less common than expected by chance, and a value equal to 1.0 indicates neutral selection (Jowett and Davey 2007).

Density data were available for *G*. "southern" in the present study and it was assumed that higher fish densities were present in higher quality habitat areas (Jowett and Richardson 2008). To account for differences in fish densities between streams, fish data at each stream were standardised by dividing observed fish densities by the maximum density observed from the stream (Jowett and Richardson 2008). This converts all density data to a value between 0–1 for each stream.

Forage ratios were calculated with observations binned by habitat values (e.g., bin 1= water velocity observations from 0 to <0.4 m/s, bin 2= water velocity observations from 0.4 to <0.8 m/s, etc.; Appendix C). All binned groups were adjusted for each forage ratio such that each bin contained a minimum of four observations, except for the two highest substrate index values, which had two and one sample respectively. Forage ratio values (+ standard error) for binned habitat values were displayed for all habitat variables as bar charts. Forage ratio values (+ standard error) for binned habitat values were displayed for all habitat variables as bar charts. Kernel smoothed curves were used to display trends across the habitat categories for the calculated forage ratios. Kernel smoothed curves were also overlaid on each bar chart that showed the relative abundance of used and available data.

Forage ratio values for habitat categories were then converted to a table for use in RHYHABSIM (Appendix B). To enable the data to be compatible with RHYHABSIM, each habitat variable required information linking a range of habitat values (e.g., velocity 0.2, 0.6, 1.0, 1.4, 1.8 m/s) to a weighting value that indicates habitat preference. The habitat values were calculated from the median of the binned habitat categories on the forage ratios. The weightings were calculated by converting the forage ratio scores for each habitat category to a value ranging between 0 and 1. Habitat values for depth and velocity in the RHYHABSIM table started at 0 while SI values started at 1, despite no observations for these habitat values. This was done because a preliminary analysis in RHYHABSIM showed misleading results occurred if these variables had no data for these habitat values. A forage weighting value of 0 was set for SI index of 1–4 because no observations were completed for this habitat value and it was considered conservative to underestimate habitat quality in these areas. A depth of 0 was assigned a weighting value of 0 because fish cannot live in dry areas.

3 Results

A total of 185 *G.* "southern" were captured during the 2016 and 2020 surveys, with large variation in catch abundance occurring between waterways (e.g., 3 in the Mataura River vs. 97 in Moat Creek; Table A-1). Density of *G*. "southern" for each waterway ranged from 0.09 to 2.43 fish per m^2. Across all years and waterways, 93 of the 244 sampled quadrats contained *G*. "southern" (38%).

Analysis of combined 2016 and 2020 data found that *G*. "southern" showed weak preferences for water velocity and water depth, with most habitat categories just above or just below a forage ratio of 1.0 (note above 1.0 indicates habitat preference), and with all categories having standard errors crossing 1.0 (Figure 3-1, Figure 3-2). Relative standard errors were large for most water velocity and depth categories (Table C-1, Table C-2), and were similar or reduced in this study compared to 2016 (Appendix D).

G. "southern" showed neutral preference for water velocity categories 0 to <0.4 m/s through to 0.8 to <1.2 m/s, with forage ratio between 0.96 to 1.02 (Figure 3-1). Greater preference (forage ratio of 1.51) was observed for water velocity category 1.2 to <1.6 m/s, although there were relatively few samples in this category compared to other categories (i.e., 11 samples cf. 104 in the 0.4 to <0.8 category; Table C-1) and the standard error was large and overlapping with those of the other categories. No *G*. "southern" were caught in the two samples where velocity was above 1.6 m/s.

Forage ratios for water depth were lowest for the middle habitat category of 0.2 to <0.3 m, where data suggests possible avoidance, and highest for the 0.4 to <0.5 m category (Figure 3-2). As for water velocity, standard errors for all water depth categories were overlapping, and a large standard error was evident for the highest water depth category (Table C-2).

Substrate index was the only habitat variable where a potential preference for a particular habitat category by *G*. "southern" was found (Figure 3-3). The substrate index category of 5 to <6, had a forage ratio of 1.21 (standard error 0.14; Table C-3), with forage ratios for the two other categories lower than 1.0, and without overlapping standard errors. The substrate data comprised primarily boulders, cobbles, large gravel and small gravel, therefore a category of 5 to <6 is likely to represent a mixture of large gravels and cobbles.

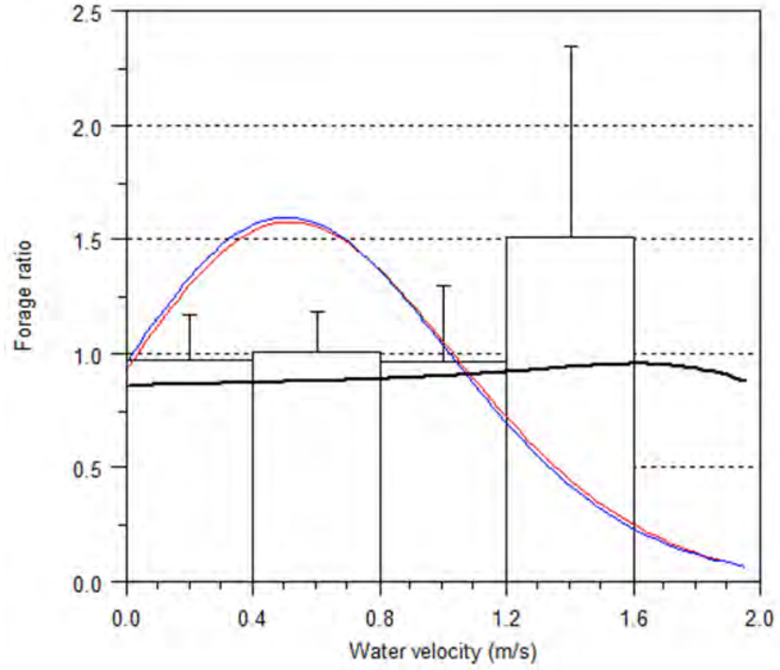

Figure 3-1: Water velocity preference by *Galaxias* "southern". Data displayed as forage ratio values (+ standard error) for binned water velocity values. Kernel smoothed curves overlaid show the relative abundance of used habitat (red line), available habitat (blue line) and the selected habitat (i.e., habitat suitability curve (HSC); black line). The HSC is the ratio of the used habitat curve divided by the corresponding available habitat curve. A forage ratio of >1.0 indicates a water velocity preference while <1.0 indicates velocity avoidance.

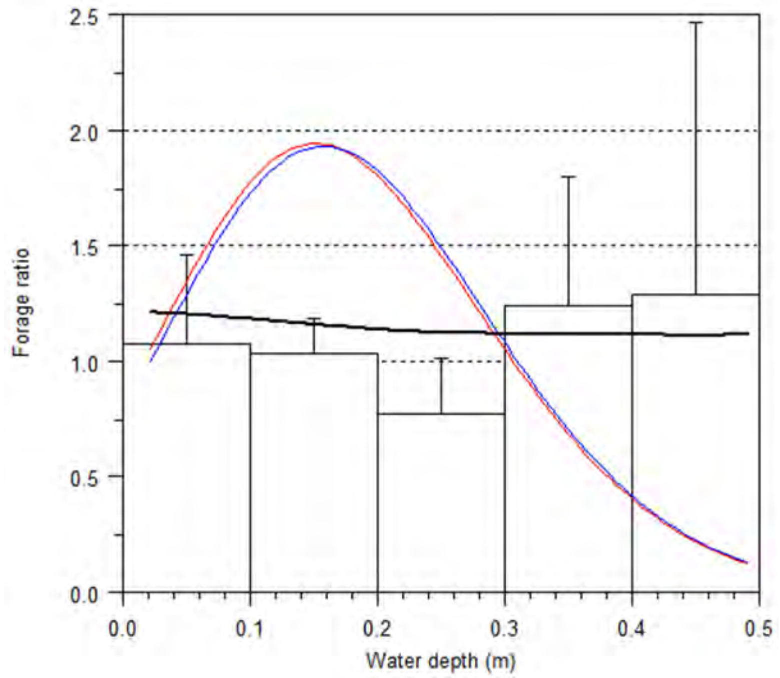

Figure 3-2: Water depth preference by *Galaxias* "southern". Data displayed as forage ratio values (+ standard error) for binned water depth values. Kernel smoothed curves overlaid show the relative abundance of used habitat (red line), available habitat (blue line) and the selected habitat (i.e., habitat suitability curve (HSC); black line). The HSC is the ratio of the used habitat curve divided by the corresponding available habitat curve. A forage ratio of >1.0 indicates a water depth preference while <1.0 indicates depth avoidance.

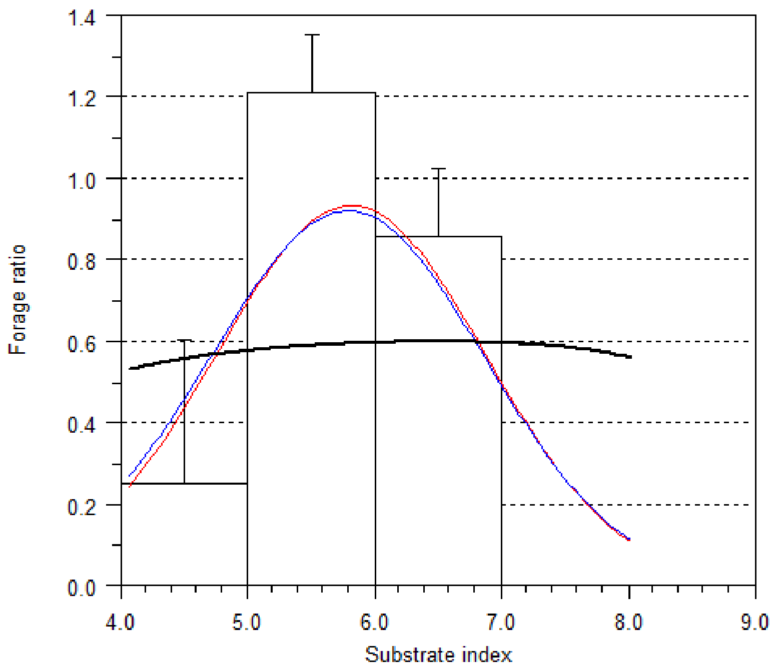

Figure 3-3: Substrate index preference by *Galaxias* "southern". Data displayed as forage ratio values (+ standard error) for binned substrate index values. Kernel smoothed curves overlaid show the relative abundance of used habitat (red line), available habitat (blue line) and the selected habitat (i.e., habitat suitability curve (HSC); black line). The HSC is the ratio of the used habitat curve divided by the corresponding available habitat curve. A forage ratio of >1.0 indicates a substrate index preference while <1.0 indicates substrate index avoidance.

4 Discussion and future considerations

4.1 Habitat preference of *Galaxias* "southern"

A potential preference for one substrate index category (i.e., category 5 to <6; representing large gravels and cobbles) was found for *G.* "southern", but the high degree of uncertainty meant that no reliable preferences were identified for water velocity or water depth. This result was despite the addition of new data to that used by Sinton et al. (2016), which represented a 58% increase in the number of samples compared to 2016. The additional data did result in lower standard errors for all habitat categories where bin divisions were the same between the two studies (i.e., water velocity and water depth). However, all but one of the habitat categories with a forage ratio above 1.0 had standard errors that crossed 1.0, meaning results should be used cautiously.

Low levels of replication within habitat categories is one potential contributor to the high degree of uncertainty observed in the present study. Preliminary analysis of uncertainty using relative standard error (RSE) showed that only the four habitat categories that contained more than 100 samples had a RSE of 20% or below. Additionally, if fish densities are low (e.g., <1 fish per m^2, as found in most streams in this study) there is an increased chance that no fish will be caught in samples of "preferred" habitats, further adding to the variability of results. Collinearity between habitat variables could further complicate interpretations of individual habitat variables, but this was not explored due to limitations in the HABSEL software.

4.2 Comparison to other studies

When compared to the previous habitat preference analyses by Sinton et al. (2016), water velocity forage ratios were similar for all categories except for category 0 to <0.4 m/s, where the forage ratio was higher in this study. In the 2016 study, the highest water velocity in the 2016 study was reversed in the 2020 data when analysed separately; however, data were relatively few in categories 1.2 to <1.6 m/s and above, with no samples collected in 2020 (Appendix D). Similarly, the 2016 data appeared to show an increasing preference for greater water depth, whereas 2020 data analysed alone seemed to show the opposite trend. Again however, there are few data in the higher categories (0.2 to <0.3 m and above) in 2020.

Different divisions for substrate index categories were used by Sinton et al. (2016), so direct comparison with this study was not possible; however, the patterns differed between the two studies, with the 2016 data showing the highest forage ratio for a larger substrate size (cobbles and boulders).

The differences in patterns of habitat preference for *G.* "southern" found in this study compared to two previous studies (Crow et al. 2010; Jowett and Richardson 2008) may be due to the broader ranges of habitat variables sampled in this study. For example, Crow et al. (2010) sampled habitats with water velocities up to 0.6 m/s and depths of 0.35 m, whereas this study sampled water velocities up to 1.95 m/s and depths up to 0.5 m.

This study found *G.* "southern" showed neutral preference for water velocity up to a range of 0.8 to <1.2 m/s, whereas a study by Crow et al. (2010) showed neutral selection for water velocity up to 0.35 m/s, with slight positive selection until 0.45 m/s and then avoidance above this velocity. In contrast, Jowett and Richardson (2008) found an increasing preference for water velocities over 0.6 m/s for flathead galaxias (a grouping which contains *G.* "southern"; Bowie et al. 2014), although most commonly occurred at velocities of 0.3 m/s.

Water depth preference was difficult to reliably interpret in this study. Crow et al. (2010) found an increasing preference by *G.* “southern” up to 0.28 m depth. In contrast, Jowett and Richardson (2008) showed flathead galaxias had a decreasing preference for depths up to 0.6 m, and were most commonly found at depths of 0.12 m.

Substrate Index was not used to quantify substrate size by Crow et al. (2010), so HSCs for substrate were not directly comparable; however, Jowett and Richardson (2008) found flathead galaxias had increasing preference for a substrate index up to 7, followed by a decrease in preference.

4.3 Future considerations

Patterns of habitat preference, for water velocity and depth in particular, were weak when compared with those observed for other species (e.g., torrentfish (*Cheimarrichthys fosteri*), Canterbury galaxias (*G. vulgaris*) or kōaro (*G. brevipinnis*) from Jowett and Richardson (2008)). To further improve understanding of the habitat preferences for *G*. “southern”, the following options could be considered.

- Increased sampling in the habitat categories from the present study that had low replication and/or high standard errors (see Appendix C). As many as 100 samples per category may be required to reduce uncertainty and provide meaningful results.
- Test the statistical significance of each preference curve using bootstrap re-sampling, which would further quantify the level of uncertainty in the HSCs.
- Explore collinearity between habitat variables, as there could be interactions between the variables which complicate interpretation. We recognise that this will not assist with RHYHABSIM analyses, which is unable to address collinearity, but would assist with management decisions.
- Investigate nocturnal habitat use. All data collected in the present study were sampled during the day but other studies have shown some native fish species may be more susceptible to capture during the evening (Crow et al. 2010; Graynoth et al. 2012). Shifts in habitat use between day and night have also been observed in other freshwater fishes in New Zealand, which has been shown to influence assessments of flow requirements (Davey et al. 2011). Consideration of nocturnal habitat requirements may produce more defensible flow recommendations for these species (Davey et al. 2011).

5 Acknowledgements

The assistance of Natasha Grainger and Chris Annandale in 2016 and Emily Funnel in 2020 (all Department of Conservation) in the field is greatly appreciated. We appreciate the permission from landowners and managers to access streams on their properties.

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Appendix A *Galaxias* "southern" abundance at sites

Table A-1: Abundance of *Galaxias* "southern" captured from quadrats in each waterway.

Year sampled	Catchment	Waterway	Number of quadrats sampled	Number of quadrats containing fish	Total number of fish caught	Fish density (number/m^2)
2016	Mataura River	Rob Roy Creek	47	4	4	0.09
2016	Oreti River	Gorge Burn	35	11	16	0.46
2016	Waiau River	Mararoa River	37	16	23	0.62
2016	Waiau River	Whitestone River	35	16	26	0.74
2020	Whitestone River	Moat Creek	40	31	97	2.43
2020	Mataura River	Mataura River	20	3	3	0.15
2020	Oreti River	Oreti River	30	12	16	0.53
		TOTAL	**244**	**93**	**185**	**MEAN 0.76**

Appendix B Forage ratios for RHYHABSIM

Table B-1: *Galaxias* "southern" forage ratios prepared for RHYHABSIM analysis. The category rows contain the median of the binned habitat categories and corresponding weighting rows contain the weighted forage ratio score for each habitat category (calculated by converting the forage ratio scores for each habitat category to a value ranging between 0 and 1).

Index	Values							
Water velocity category (m/s)	0	0.2	0.6	1.0	1.4	1.8		
Water velocity weighting	0	0.64	0.68	0.64	1.00	0		
Water depth value (m)	0	0.05	0.15	0.25	0.35	0.45		
Water depth weighting	0	0.92	0.75	0.63	0.96	1.00		
Substrate index value	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5
Substrate index weighting	0	0	0	0.21	1.00	0.71	0	0

Appendix C HABSEL category and selectivity value tables

Table C-1: Water velocity HABSEL categories and associated forage ratio values for *Galaxias* "southern". A forage ratio of >1.0 indicates a water velocity preference while <1.0 indicates water velocity avoidance. A forage ratio of zero occurs when no fish were found in that water velocity category.

Water velocity (m/s) category	Number of samples	Forage Ratio	Forage Ratio standard error (SE)	Forage Ratio relative SE (%)
0–<0.4	88	0.96	0.20	21
0.4–<0.8	104	1.02	0.17	17
0.8–<1.2	39	0.96	0.34	35
1.2–<1.6	11	1.51	0.84	56
1.6–<2.0	2	0	0	0

Table C-2: Water depth HABSEL categories and associated forage ratio values for *Galaxias* "southern". A forage ratio of >1.0 indicates a water depth preference while <1.0 indicates water depth avoidance. A forage ratio of zero occurs when no fish were found in that water depth category.

Water depth (m) category	Number of samples	Forage Ratio	Forage Ratio standard error	Forage Ratio relative SE (%)
0–<0.1	39	1.19	0.37	31
0.1–<0.2	124	0.97	0.15	15
0.2–<0.3	56	0.81	0.26	32
0.3–<0.4	20	1.24	0.55	44
0.4–<0.5	5	1.29	1.18	91

Table C-3: Substrate index HABSEL categories and associated forage ratio values for *Galaxias* "southern". A forage ratio of >1.0 indicates a substrate index preference while <1.0 indicates substrate avoidance. A forage ratio of zero occurs when no fish were found in that substrate index category.

Substrate index category	Number of samples	Forage Ratio	Forage Ratio standard error	Forage Ratio relative SE (%)
4–<5	11	0.25	0.35	140
5–<6	125	1.21	0.14	12
6–<7	105	0.86	0.17	20
7–<8	2	0	0	0
8–<9	1	0	0	0

Appendix D Comparison of 2016 and 2020 HABSEL category selectivity values and relative standard errors for water velocity and depth

Table D-1: 2016, 2020 and combined 2016 and 2020 water velocity HABSEL forage ratio values for *Galaxias* "southern". A forage ratio of >1.0 indicates a water velocity preference while <1.0 indicates water velocity avoidance. A forage ratio of zero occurs when no fish were found in that water velocity category.

Water velocity (m/s) category	Number of samples			Forage Ratio			Forage Ratio relative standard error (%)		
	2016	2020	2016+ 2020	2016	2020	2016+ 2020	2016	2020	2016+ 2020
0–<0.4	41	47	88	0.60	1.06	0.96	47	20	21
0.4–<0.8	68	36	104	1.08	0.97	1.02	21	28	17
0.8–<1.2	32	7	39	1.14	0.75	0.96	37	88	35
1.2–<1.6	11	0	11	1.79	0	1.51	54	0	56
1.6–<2.0	2	0	2	0	0	0	0	0	0
TOTAL	**154**	**90**	**244**						

Table D-2: 2016, 2020 and combined 2016 and 2020 water depth HABSEL forage ratio values for *Galaxias* "southern". A forage ratio of >1.0 indicates a water depth preference while <1.0 indicates water depth avoidance. A forage ratio of zero occurs when no fish were found in that water depth category.

Water depth (m) category	Number of samples			Forage Ratio			Forage Ratio relative standard error (%)		
	2016	2020	2016+ 2020	2016	2020	2016+ 2020	2016	2020	2016+ 2020
0–<0.1	12	27	39	0.73	1.14	1.19	84	31	31
0.1–<0.2	69	55	124	0.88	1.00	0.97	25	18	15
0.2–<0.3	49	7	56	0.97	0.62	0.81	31	26	32
0.3–<0.4	19	1	20	1.55	0	1.24	43	0	44
0.4–<0.5	5	0	5	1.53	0	1.29	90	0	91
TOTAL	**154**	**90**	**244**						