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Habitat preference of Teviot flathead galaxias (*Galaxias* "Teviot")

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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 help guide flow management decisions. HSCs have been developed for many of New Zealand's freshwater fishes; however, there are no specific HSCs for Teviot flathead galaxias (*Galaxias* "Teviot"). Teviot galaxias are currently classified in the New Zealand Threat Classification System as having a conservation status of Threatened: Nationally Critical. The present study aimed to calculate HSCs for *Galaxias* "Teviot" using data collected by the Department of Conservation. The HSCs generated from this work could then be applied to future flow assessments that use physical habitat models, such as the commonly used SEFA software.

HSCs were developed for water velocity, substrate index and water depth using habitat information collected from three Teviot River tributary streams near Lake Onslow containing *Galaxias* "Teviot". The data indicate a strong preference for low water velocity (<0.25 ± 0.08 ms^{-1}, mean ± SE) and marginal preference for smaller substrate (silt/mud to fine gravel ± 0.34). *Galaxias* "Teviot" displayed greater preference for shallower water depths (<0.4 ± 0.42m). Due to large standard errors associated with many of the categories for all variables, especially those categories with the greatest preference values, results of this study should be interpreted and used cautiously. To reduce the uncertainty associated with these HSCs and further improve understanding of the habitat preferences for *G*alaxias "Teviot", future habitat surveys should target the habitat categories with low replication.

1 Background

Information on habitat requirements of freshwater fishes is used to guide the management of 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 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 type). HSCs have been developed for many New Zealand fishes (Jowett and Richardson 2008), but not for the Teviot flathead galaxias, *Galaxias* "Teviot". *Galaxias* "Teviot" predominantly occurs in the Teviot River catchment, a left bank tributary of the Clutha River, with a single population known from a headwater tributary in the adjacent Taieri River. *Galaxias* "Teviot" has a conservation status of Threatened: Nationally Critical based on a small area of occupancy under the New Zealand Threat Classification System (Townsend et al. 2008; Dunn et al. 2018).

Habitat requirements of this species could be inferred from similar *Galaxias* species, but this could be misleading given the different habitat requirements found between other non-diadromous *Galaxias* species (Crow et al. 2010; Crow et al. 2014).

The aim of the present study was to calculate HSCs for *Galaxias* "Teviot" for water velocity, water depth and substrate index. Data collected by the Department of Conservation (DOC) were used to calculate HSCs that could be applied to future flow assessments using the software packages RHYHABSIM or SEFA (http://www.jowettconsulting.co.nz or www.sefa.co.nz, respectively)[1].

[1] Note, for clarity we refer to RHYHABSIM in the remainder of the report, but SEFA is also appropriate in all instances.

2 Methods

2.1 Field sampling

Three streams were sampled for *Galaxias* “Teviot” near Lake Onslow, Otago, during January 2022 (Table 2-1). Site 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 the sampling was designed to coincide with the summer low flow period so as not to interfere, as much as possible, with spawning and larvae/post-larval/juvenile rearing periods.

Table 2-1: Location of samples for *Galaxias* “Teviot” in the Teviot River catchment. Coordinates are for the midpoint of sampled reaches.

Stream	NZTM Easting	NZTM Northing
Lake Onslow Tributary 1	1334261	4950573
Teviot River Tributary 3	1329627	4949893
Teviot River Tributary 4	1330985	4949421

In each stream, a sampling reach containing a variety of instream habitat types were selected. Starting at the downstream end of the reach, a minimum of 14 transects were marked at 3 m intervals. A discharge gauging was conducted at the most downstream transect. Water velocity was measured at 0.6 m depth using a Marsh McBirney Flo-Mate 2000 electromagnetic current meter.

Within each transect, a 0.75 × 0.75 m quadrat was placed carefully within the stream 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 completed using a Kainga EFM 300 backpack electrofishing machine (NIWA Instrument Systems, Christchurch) in a downstream direction. Each pass consisted of five seconds of electrofishing machine current time, separated by a minimum electrofishing stoppage of five seconds between subsequent passes. After electrofishing, captured fish were anaesthetised with 2-phenoxyethanol and identified to species level 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 m depth) at the midpoint of the quadrat were also 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 was 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 density, rather than a calculated population estimate (e.g., the Carle and Strub (1978) method). With fish catches being low (i.e., a numerical average of 1.06 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 + %Debris*0.01 (Jowett and Richardson 1990).

Macrophytes, algae and bryophytes were included in the SI calculations under "debris". These were included in the substrate index because sites occupied by *Galaxias* "Teviot" were narrow and influenced by riparian and instream wetland vegetation present in the wetted channel.

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 *Galaxias* "Teviot". This software uses an approach consistent with that suggested in Jowett and Richardson (2008), which has previously been the method used to calculate HSCs for many New Zealand fishes. The developed suitability curves are forage ratios, where habitat use is adjusted for habitat availability, being 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 each 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 that expected by chance, a forage ratio less than 1.0 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 *Galaxias* "Teviot" in the present study, and it was assumed that greater fish densities were present in higher quality habitat areas (Jowett and Richardson 2008). To account for differences in fish densities between streams, data from each stream were standardised by dividing observed fish densities by the maximum density observed from the stream (Jowett and Richardson 2008). This converted all density data to a value between 0 and 1.

Forage ratios were calculated with observations binned by habitat values (e.g., bin 1= water velocity observations from 0 to <0.25 ms^{-1}, bin 2= water velocity observations from 0.25 to <0.5 ms^{-1}, 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 greatest water depth and velocity bins, which had three, two, one and one observations, respectively (note, no fish were caught within the last three bins/categories described). 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. To enable the data to be compatible with RHYHABSIM, each habitat variable required information linking a range of habitat values (e.g., depth 0.1, 0.3, 0.5, 0.7 m) 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 there were no observations for 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 dry areas do not provide aquatic habitat for fish.

3 Results

A total of 127 *G*. “Teviot” individuals were captured across the three streams (Table A-1). *Galaxias* “Teviot” were found in a similar number of quadrats in each stream (13–18), but Teviot River Tributary 4 had a slightly higher density than the other rivers. Of the 137 quadrats sampled, only 46 contained *Galaxias* “Teviot”. This study measured broad ranges of habitat variables, sampling water velocities of 0 to ≤1.09 ms^{-1} and water depths of 0.03 to ≤0.72 m.

Galaxias “Teviot” showed strong preference for low water velocity (Figure 3-1), marginal preferences for smaller substrate (Figure 3-2), and weak preference for shallower water depth (Figure 3-3) based on the available data. For all habitat categories except one, forage ratio values above 1.0 (indicating habitat preference) had standard errors that crossed below 1.0 and relative standard errors (RSE) were high (Appendix C). The exception was the water velocity category 0 to <0.25 ms^{-1}, for which the forage ratio was 1.36 and the standard error was 0.08 (Table C-1). For water depth, the greatest forage ratios also had the largest standard errors (Table C-2).

The greatest forage ratio for substrate index was in the category 2 to <4 with a forage ratio of 1.22 and a standard error of 0.38 (Table C-3). Overall, *Galaxias* “Teviot” showed a stronger preference for a lower substrate index which translates to a silt/mud to fine gravel dominated substrate (Jowett and Richardson 2008).

For water depth there were a larger number of samples collected in categories 0 to <0.2 m and 0.2 to <0.4 m with high forage ratios (0.99 and 1.01, respectively) and low standard errors (0.2 and 0.42, respectively) showing some preference by *Galaxias* “Teviot” for shallower water. Water depths of 0.4 to <0.6 m had the greatest forage ratio of 1.84 but a standard error of 2.45 giving an unreliable result (Table C-2).

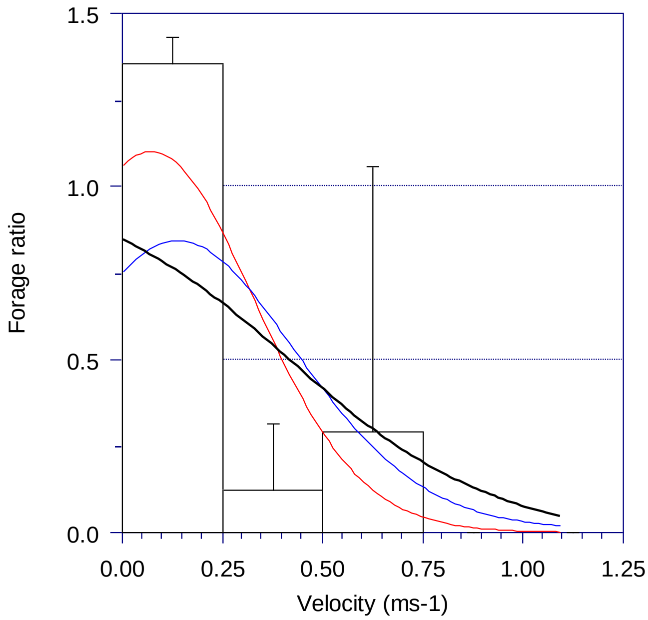

Figure 3-1: Water velocity preference by *Galaxias* “Teviot”. Data displayed as forage ratio values (+ standard error) for binned water velocity values. Kernel smoothed curves overlaid show the relative abundance of used habitat (red line), available habitat (blue line) and the selected habitat (i.e., 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 a velocity avoidance.

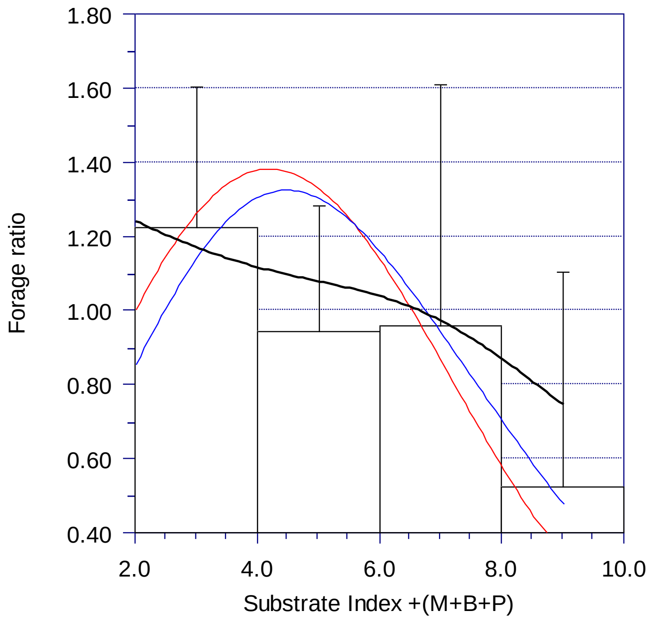

Figure 3-2: Substrate index preference by *Galaxias* "Teviot". Data displayed as forage ratio values (+ standard error) for binned water velocity values. Kernel smoothed curves overlaid show the relative abundance of used habitat (red line), available habitat (blue line) and the selected habitat (i.e., 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 substrate type preference while <1.0 indicates a substrate type avoidance.

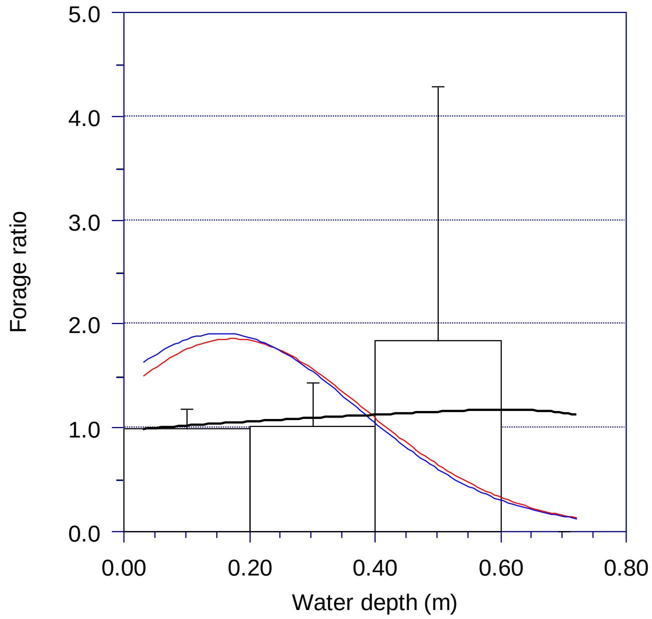

Figure 3-3: Water depth preference by *Galaxias* "Teviot". Data displayed as forage ratio values (+ standard error) for binned water velocity values. Kernel smoothed curves overlaid show the relative abundance of used habitat (red line), available habitat (blue line) and the selected habitat (i.e., habitat 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 depth preference while <1.0 indicates a depth avoidance.

4 Discussion and Future considerations

4.1 Habitat preferences of *Galaxias* "Teviot"

Galaxias "Teviot" displayed a strong preference for low water velocity (<0.25 ± 0.08 ms^{-1}, mean ± SE) and marginal preference for smaller substrate (silt/mud to fine gravel ± 0.34). *Galaxias* "Teviot" displayed greater preference for shallower water depths (<0.4 ± 0.42 m). However, a lack of deeper depths available at sites could result in preference bias.

High levels of uncertainty in this study can most likely be attributed to low replication within habitat categories. A study of *Galaxias* "southern" habitat preferences (Sinton et al. 2021c) noted that only categories containing ≥100 samples were likely to generate reliable estimates based on a relative standard error (RSE) of ≤20%. In this study, the two habitat categories for each water velocity and water depth that contained >90 samples had a RSE of ≤20%, but all habitat categories for substrate index had a RSE of <5% despite a low number of samples (15–49).

4.2 Comparison to other studies

Galaxias "Teviot" displayed preference for water velocity <0.25 ms^{-1}, with avoidance above this velocity, which is similar to *Galaxias* "southern" that has been shown to have preference for water velocity <0.45 ms^{-1} and avoidance above this velocity (Crow et al. 2010). Jowett and Richardson (2008) found Taieri flathead galaxias (*Galaxias depressiceps*) to occur at water velocities up to 0.6 ms^{-1}, with preference to velocities <0.3 ms^{-1}. Studies on *Galaxias* "Nevis" and *Galaxias* "southern", by Sinton et al (2021a, 2021c) found neutral preference for water velocity up to a range of 0.8 to <1.2 ms^{-1} for both species.

Adult Central Otago roundhead galaxias (*Galaxias anomalus*) tend to prefer shallower waters (Jowett and Richardson 2008), like the findings in this study of *Galaxias* "Teviot", showing preference of depths <0.2 m. However, Sinton et al. (2021a) found that *Galaxias* "Nevis" had the greatest forage ratios for greater depths of 0.3 to <0.6 m, like *Galaxias gollumoides* that displayed highest preference for depths of 0.4 m (Crow et al. 2014). The study of *Galaxias* "southern" by Sinton et al (2021c) found preference for depths of 0.4 to <0.5 m but given the high degree of uncertainty with *Galaxias* "southern" data, the preference was deemed unreliable.

Galaxias "Nevis", Galaxias affinis *paucispondylus* "Southland", and *Galaxias*" southern" all showed preference for large gravels and cobbles (Sinton et al. 2021a, 2021b, 2021c), whereas *Galaxias* "Teviot" preferred smaller substrates from silt/mud to fine gravel in this study, like *Galaxias gollumoides* and *Galaxias* "species D" that preferred sand and gravel substrate (Crow et al. 2014). This result for *Galaxias* "Teviot" is not unexpected as this species occupies habitats more wetland in nature compared to the typically larger gravel-bed river habitats of *Galaxias* affinis *paucispondylus* "Southland", and *Galaxias*" southern".

4.3 Future considerations

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

- Increase sampling in the habitat categories from the present study with 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 are 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 fishes may be more readily captured 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. This 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

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Appendix A *Galaxias* “Teviot” abundance at sites

Table A-1: Abundance of *Galaxias* “Teviot” captured from quadrats in each stream within the Teviot River catchment.

Stream	Number of quadrats sampled	Number of quadrats containing fish	Total number of fish caught	Fish density (number/m²)
Lake Onslow Tributary 1	42	15	30	0.71
Teviot River Tributary 3	65	18	43	0.66
Teviot River Tributary 4	30	13	54	1.8
TOTAL	**137**	**46**	**127**	**MEAN 1.06**

Appendix B Forage ratios for RHYHABSIM

Table B-1: *Galaxias* "Teviot" 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 (ms^{-1})	0.13	0.38	0.63	0.88	1.10
Water velocity weighting	1	0.09	0.21	0	0
Water depth value (m)	0.10	0.30	0.50	0.70	
Water depth weighting	0.54	0.55	1.00	0	
Substrate index value	3	5	7	9	
Substrate index weighting	1.00	0.77	0.79	0.43	

Appendix C HABSEL category and selectivity value tables

Table C-1: Water velocity HABSEL categories and associated forage ratio values for *Galaxias* "Teviot". A forage ratio of >1.0 indicates a water velocity preference while <1.0 indicates water velocity avoidance.

Water velocity (m/s) category	Number of samples	Forage ratio	Forage ratio standard error (SE)	Forage ratio relative SE (%)
0-<0.25	97	1.36	0.08	5.88
0.25-<0.5	33	0.12	0.19	158.33
0.5-<0.75	5	0.29	0.77	265.52
0.75-<1	1	0	0	0.00
1-<1.25	1	0	0	0.00

Table C-2: Water depth HABSEL categories and associated forage ratio values for *Galaxias* "Teviot". A forage ratio of >1.0 indicates a water depth preference while <1.0 indicates water depth avoidance.

Water depth (m) category	Number of samples	Forage ratio	Forage ratio standard error (SE)	Forage ratio relative SE (%)
0-<0.2	91	0.99	0.2	20.20
0.2-<0.4	41	1.01	0.42	41.58
0.4-<0.6	3	1.84	2.45	133.15
0.6-<0.8	2	0	0	0.00

Table C-3: Substrate index HABSEL categories and associated forage ratio values for *Galaxias* "Teviot". A forage ratio of >1.0 indicates a substrate index preference while <1.0 indicates a substrate index avoidance.

Substrate Index (+M+P+B) category	Number of samples	Forage ratio	Forage ratio standard error (SE)	Forage ratio relative SE (%)
2-<4	49	1.22	0.34	2.49
4-<6	53	0.94	0.26	1.77
6-<8	20	0.96	0.26	4.80
8-<10	15	0.52	0.14	3.47