On a regional model for nocturnal habitat requirements of banded kokopu (*Galaxias fasciatus*) in the North Island, New Zealand

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ABSTRACT: In five streams of the North Island we sampled nocturnal habitat use by banded kokopu (by direct observation) and also habitat availability (by random sampling), in terms of mean water column velocity, surface water velocity, depth, substrate size, and cover type. Regional habitat suitability criteria (category II) and preference functions (category III) were calculated for all banded kokopu, adults and juveniles together. We tested the transferability of the regional habitat suitability criteria (i.e. optimal and suitable ranges) to the five study sites, and all produced positive results. Banded kokopu mainly occupied microhabitats with gravel substrates and a narrow range of water velocities (0.0–0.13 m/s). The preference functions also revealed a very narrow preference for shallow (< 0.4 m) and very slow waters (< 0.13 m/s). Transferability tests indicated that the global model of habitat suitability is valid on a regional scale, and the generalized preference functions derived are a valid tool for PHABSIM applications where in-site studies are not feasible and appropriate transferability tests are applicable.

1 INTRODUCTION

Often one of the main difficulties in determining an instream environmental flow regime is a lack of habitat suitability and preference criteria data for the species inhabiting these waterbodies. This lack of data has been recognized as presenting a significant dilemma in New Zealand waters when reduced flow issues arise (McDowall 1993).

The concept underlying the "habitat preference" is simply that if an organism is found in a higher proportion in the conditions of a particular environment compared to the total availability of those conditions, then it has actively selected for that set of conditions (Manly *et al.* 1993).

On a regional scale, successful suitability criteria have been obtained by several authors (e.g. Groshens & Orth 1993 and Lamouroux *et al.* 1999). Regional models are attractive tools for large-scale, multi-site management (Lamouroux *et al.* 1999), because sometimes it is not economically feasible for fisheries managers to develop habitat criteria for all the physical and biotic conditions that may influence fish habitat. However, few scientific publications have dealt with the transferability of habitat suitability criteria, and the procedure to assess the validity of regional models to different streams (e.g. Groshens & Orth 1993, Thomas & Bovee 1993, Newcomb

et al. 1997, Mäki-Petäis *et al.* 2002, Martínez-Capel & García de Jalón, unpubl.).

2 STUDY SITES AND SPECIES

The banded kokopu *Galaxias fasciatus* Gray (family Galaxiidae) is the most common large galaxiid in New Zealand and is endemic to that country. Typical habitat is in pools in slow-flowing, small 1st-order headwater streams and tributaries with reasonably extensive riparian vegetation. Banded kokopu are opportunistic predators, feeding largely on invertebrates (Main & Lyon 1988, Halstead 1994, Hicks 1997).

Table 1. Sample sizes used to determine nocturnal habitat use by banded kokopu (juveniles and adults separately) and habitat available in the five streams. The estimated stream discharge at each site is also included.

Stream name	Habitat use		Habitat available	Discharge (m^3/ s)
	Juveniles	Adults		
Heale	39	8	52	0.0089
Sawmill	2	76	74	0.0028
Swanson	14	31	49	0.0025
Taumatawahine	14	55	70	0.0057
Waipuna	18	34	39	n/d*

* n/d = no data available for this stream.

The five streams sampled in this study (Table 1) were in three major regions of the North Island; the Coromandel Peninsula, West Auckland and West Huntly (the Hakarimata Ranges). They had high densities of banded kokopu, and were ≤ 2nd order.

3 METHODS

The nocturnal habitat use by banded kokopu was determined over a series of nights by direct observation under spotlight illumination (McCullough & Hicks 2002). Available habitat was also sampled. It was considered reasonable to sample at night, because it is the time of the day when the species is most active in its habitat (see Orth 1987). Nocturnal observation by spotlight was also chosen by Main (1988) who studied kokopu and koaro in the South Island. Electric fishing was considered to be less efficient (McCullough 1998; McCullough & Hicks 2002) than spotlighting at night, which was executed using a cherry-red filtered 100 W spotlight. Working in an upstream direction along the stream banks, the positions of undisturbed individuals of banded kokopu were identified and a marker was placed directly underneath this position on the substrate. Individuals were classified into two main groupings; 0+ (total length ≤ 80 mm), and 1+ (fish > 80 mm).

The following day, the depth, nearby cover elements, and substrate size were noted for each of the kokopu positions. Mean water column velocities and surface velocities were also measured. Velocities were measured with an electromagnetic Marsh & McBirney 201D portable current meter. We randomly sampled habitat availability for the same five variables, with a number of points similar to the number of usage samples. Finally, stream discharge was estimated at the downstream point where nocturnal usage sampling had begun.

The elements providing cover were classified as following, (1) hollows between cobbles and other rocks; (2) undercut banks and overhang banks; (3) tree fern roots; (4) tree roots; (5) submerged vegetation; (6) overhanging vegetation; (7) instream debris and (8) no cover present. Substrate size classes used (in mm) were (1) silt/mud (< 0.062), (2) sand (0.062–2), (3) fine gravel (2–8), (4) gravel (8–64), (5) cobbles (64–264), (6) boulders (>264), (7) large boulders (>1024) and (8) bedrock (continuous rock).

We gathered all data (from 5 streams and 2 age classes) and obtained a regional model of habitat use (habitat suitability criteria, category II), based on non-parametric tolerance limits. The *optimal* and *suitable* ranges were defined as the central 50 % and 95% of the data distribution; *usable* values are suitable but not optimal (see Thomas & Bovee 1993). Based on this information, we tested transferability of the regional model to each stream, following two procedures. One proposed by Thomas & Bovee

(1993), who considered the alternatives optimal/usable and suitable/unsuitable, and also one by Groshens & Orth (1993) that considered the alternatives optimal/marginal and suitable/unsuitable to classify each sample of habitat use and availability. The frequencies calculated for those alternatives were used to build the contingency tables of the chi-square test (Conover, 1971). Both are very similar but can show different results in practice (Martínez-Capel & García de Jalón, unpubl.). We have considered the combined suitability of depth and velocity.

Before computing preference curves, we confirmed that the fishes really selected specific microhabitat conditions by applying the Kolmogorov-Smirnov two-sample test ($\alpha = 0.05$) to compare the frequency distributions of use and availability (see Groshens & Orth 1993). Where the test was positive, the preference index of a given variable interval was calculated as the forage ratio (see Bovee 1986). In this article we show a generalized preference curve for each variable, except surface velocity, and both age classes together. For a given variable, the generalized preference curve is the average of the curves obtained in all the streams, where each one was weighted by the number of habitat use observations (see Locke 1988).

4 RESULTS

By sampling for microhabitat available, we obtained water velocities ranging from 0.00 to 0.45 m/s in Heale Stream, 0.70 m/s in Swanson Stream, 0.45 m/s in Sawmill Stream (same maximum surface velocity), 0.48 m/s in Taumatawahine Stream (0.70 m/s for surface velocity) and 0.30 m/s in Waipuna Stream (with 1.1 m/s maximum surface velocity). The maximum depths measured in the five sites (respectively) were 0.26, 0.76, 0.50, 0.35, and 0.31 m.

By direct observation we obtained these sample sizes: 47 fishes in Heale Stream (52 for availability), 78 in Sawmill Stream (74 for availability), 45 in Swanson Stream (49 for availability), 69 fishes in Taumatawahine Stream (70 points for habitat availability) and 52 in Waipuna Stream (39 for availability). Therefore, the regional model for habitat suitability (category II) was based on 291 observations (except surface velocity, $N = 199$). Results are shown in Table 2.

Table 2. Optimal and suitable ranges of each variable that define the regional model of habitat suitability (category II).

Variable name	Optimal range	Suitable range
Depth (m)	0.08-0.22	0.02-0.44
Mean water column velocity (m/s)	0.00-0.04	0.00-0.13
Surface velocity (m/s)	0.01-0.06	0.00-0.14
Substrate type*	3–4	2-8
Cover type*	1–7	1-8

* Substrate and cover types are specified in Methods.

Optimal range for mean water column velocity was very narrow (0–0.04 m/s), and suitable values ranged from 0.0 to 0.13 m/s. The ranges defined for surface velocity were a little bit higher than for mean water column velocity. In general, the slow and shallow waters represented the main habitat used by the banded kokopu. However, the available microhabitat covered a wider range of conditions. We have considered that these study sites were appropriate for the study because maximum velocities noticeably exceeded the range of conditions used by the fish. We have observed similar results in terms of depth because the maximum depths were > 0.22 m in every case. Only two streams were deeper than 0.44 m, so the suitable range could widen if more samples were obtained in deeper streams. Gravel substrates were frequently used by banded kokopu, but neither substrate nor cover was limiting for the microhabitat use by the fish.

Transferability tests confirmed that these *regional habitat suitability criteria* describe the microhabitat conditions that are optimal and suitable in each study site because all gave positive results (Table 3). The five chi-square tests based on the concepts suitable/unsuitable gave probabilities < 0.01. The probabilities of the tests based on the optimal range were minor than 0.05, with clear differences between the two procedures, although these differences were not practical (i.e. there was no test failure in any case). The wider difference (0.032) occurred in Taumatawahine Stream, where $P = 0.033$ for optimal/usable and $P = 0.001$ for the optimal/marginal test.

Table 3. Probability of the chi-square tests performed in the five streams for different alternatives: optimal/usable, optimal/marginal and suitable/unsuitable.

Stream name	Optimal/ Usable	Optimal/ Marginal	Suitable/ Unsuitable
Heale	0.999	1.000	0.994
Sawmill	0.986	0.998	0.998
Swanson	0.968	0.991	0.997
Taumatawahine	0.967	0.999	1.000
Waipuna	0.978	0.990	0.991

These observations corroborate that the test designed by Thomas & Bovee (1993) has a higher threshold than that of Groshens & Orth (1993), as was observed by Martínez-Capel & García de Jalón, (unpubl.). We consider both tests equally suitable for assessing transferability, and even would be with $α = 0.1$. Based on previous works, both are difficult to pass (Thomas & Bovee 1993; Martínez-Capel 2000).

Thomas & Bovee (1993) observed that type-I errors increase when sample sizes decrease from 55 (habitat use) and 200 (habitat availability), and this type of error seem to be strongly related to the number of habitat use points. In our work, the minimum number of observations was 45 for habitat use and 39 for habitat availability. From the table provided in Thomas & Bovee's (1993) article, we have estimated a type-I error may be in the range of 2-15%.

There is no a specific test to assess transferability of habitat preference functions. However, some authors have applied the "standard" test and considered such functions when determining optimal and suitable ranges of a variable (Freeman *et al.* 1997, Martínez-Capel 2000). The success of the "standard" test requires a real selection of some specific conditions by the fish (i.e. a net positive difference between the proportion of habitat used and of available conditions). Therefore, from our point of view, the preference functions based on the same samples of habitat use and availability do not need any extra validation on a regional scale, but the transferability of the habitat suitability criteria is a satisfactory evidence of their validity.

The test to compare use and availability was positive in all cases for velocity ($P < 0.05$) and only failed in Heale Stream for depth ($P = 0.052$). However, substrate and cover only gave positive results in one case for each variable. We consider that the preference curves are valid for the first two variables, but substrate and cover seem to be randomly used by banded kokopu (i.e. they are not limiting factors). Figure 1 shows the generalized preference curves for depth and velocity, variables that are crucial in microhabitat selection by banded kokopu.

The preference curve for depth shows a clear correction of the habitat use through the forage ratio. While optimal depth ranges from 0.08–0.22 m, the
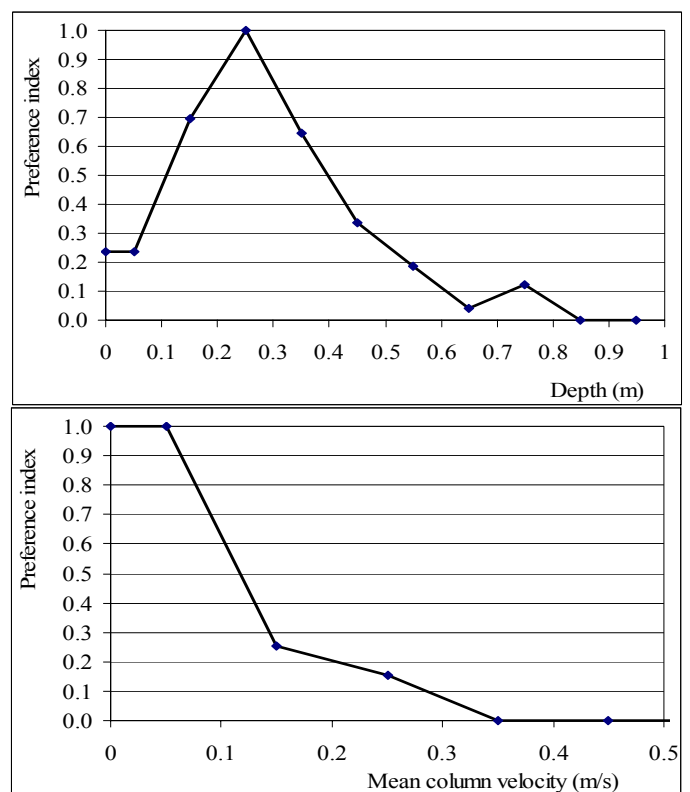

Figure 1. Generalized preference curves of depth (m) and mean water column velocity (m/s) for banded kokopu ($N = 291$).

maximum preference seems to be in deeper waters, between 0.2 and 0.3 m.

Other studies have concluded that some fishes prefer the maximum depths available (Martínez-Capel 2000) but it appears that this is not the pattern of habitat use by the kokopu. As other authors have mentioned, the depth used is related to the size of the fish (Copp 1992, Lamouroux *et al.* 1999), so the number of 0+ ($N = 87$) and 1+ ($N = 204$) individuals probably influenced our results. Because the observations were drawn from both 0+ and 1+ fish, we have assumed that the range of preferred depths (approximately from 0.10 to 0.40 m with preference index over 0.5) represents good microhabitat conditions for this species in both life stages.

However, the preference curve for velocity shows very little correction of the habitat use pattern. The range of suitable conditions (> 0.5) is similar for both data, and the maximum preference (index = 1) is within the range of 0.0–0.05 m/s.

5   CONCLUSIONS

– Habitat use sampling by nocturnal direct observation is a valuable technique for the banded kokopu, which is habitually active at night.
– This species generally uses and prefers microhabitats that are not deep (< 0.44 m) and have slow mean water column velocities (< 0.13 m/s).
– The highest preference for all the fish studied (0+ and 1+ age classes together) are in the interval of $0.1 – 0.3$ m deep and $0.0 – 0.05$ m/s for mean water column velocity.
– Transferability tests (chi-square test of independence) have demonstrated that the regional model of habitat suitability (habitat use criteria, category II), based on the combined suitability of depth and velocity, is valid in describing the optimal and suitable range of microhabitat conditions for banded kokopu.
– It is possible to obtain regional models of habitat suitability, and the corresponding habitat preference functions, which are a valid tool for PHAB-SIM applications on a regional scale, particularly where *in situ* studies are not feasible and correct transferability test, are applicable.

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