Gravel burrowing ability in *Galaxias cobitinis*

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ABSTRACT

Galaxias cobitinis (lowland longjaw galaxias) is a recently described, critically threatened fish, which occurs predominantly in the gravel-bed Kauru River, North Otago, New Zealand. This river experiences frequent droughts, which are exacerbated by water abstraction, and is an important site for gravel abstraction. Loose cobbles with large interstitial spaces are important habitat for *G. cobitinis*. However, gravel abstraction has reduced overall particle size, and thus interstitial space, and has led to increased embeddedness and the area of river bed covered by sand. Furthermore, during low flow periods, the area of useable habitat can be reduced to isolated groundwater-connected pools. This study investigates the survival strategy of *G. cobitinis* in relation to these issues. We experimentally tested the ability of *G. cobitinis* to burrow through gravels of differing compositions collected from an area disturbed by gravel abstraction activities, and from an unmodified section of the river bed. *G. cobitinis* was able to burrow into both substratum types; however, burrowing capabilities were significantly greater in undisturbed substratum samples. The influence of stable or declining water levels was also tested; however, this did not influence burrowing propensity. Importantly, *G. cobitinis* had limited tolerance to periods without water. Collectively, our results indicate that drought survival may be dependent on the presence of large interstitial spaces, which provide a quickly accessible route through the gravels into subsurface or hyporheic flows. Habitat modification that leads to the loss of interstitial space and prolonged drought is likely to be detrimental to the persistence of *G. cobitinis* in the Kauru River.

Keywords: *Galaxias cobitinis*, lowland longjaw galaxias, gravel-bed stream, gravel burrowing, gravel abstraction, low flow, drought, survival strategies

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1. Introduction

Physical disturbance, particularly floods and droughts, are an important structuring force on streams and their biota (Power et al. 1988; Resh et al. 1988; Lake 2000, 2003). However, for organisms to persist in physically disturbed habitats, they must have access to refugia (Magoulick & Kobza 2003). During high flow events, many *Galaxias* (Galaxiidae) species may access refugia within the interstitial spaces of the streambed substratum (Woods 1963; McIntosh 2000). Similarly, burrowing into the unconsolidated, unsorted substratum of gravel-bed streams for short distances and short times, and possibly reaching the underlying water table, may improve the survival chances for *Galaxias* species during periods when surface flow is absent (Hartman 1990; Dunn 2003). However, survival will be dependent on a fish's ability to find a moist microhabitat and to persist until water returns (Meredith 1985; Magoulick & Kobza 2003). During drought, a fish needs to avoid desiccation, starvation, and the accumulation of nitrogenous wastes, as well as maintain gas exchange and metabolic function (Meredith 1985; McPhail 1999; Thompson & Withers 1999); a fish's survival is thus dependent on both the behavioural responses it displays and its inherent physiological tolerances.

Galaxias cobitinis McDowall & Waters (lowland longjaw galaxias), is a small (< 90 mm total length), elongate 'pencil galaxias' (*sensu* McDowall & Waters 2003). This species occurs predominantly within the drought-prone Kauru River, North Otago, New Zealand, which is a tributary of the Kakanui River; both these rivers are affected by gravel and water abstraction. Sections of the Kauru River gravel-bed regularly dry up, reducing habitat to a series of isolated pools during severe drought (McDowall & Allibone 2004). *Galaxias cobitinis* is currently ranked as nationally critically threatened by the Department of Conservation (DOC), due in part to extreme population fluctuations (Hitchmough 2002). Future conservation management of the species is addressed in the non-migratory galaxiid fishes recovery plan (DOC 2004). *Galaxias cobitinis* was described as a distinct species from *Galaxias prognathus* Stokell (upland longjaw galaxias) by McDowall & Waters (2002), using morphological and genetic methods. Since this species has only been described recently, much of its biology has been inferred from *G. prognathus*. Habitat preferences of adult *G. cobitinis* have been described by Baker et al. (2003), as riffles, with a mean water depth of 11 cm over a cobble/gravel substratum. Similarly, McDowall & Waters (2002: 49) associated *G. cobitinis* with riffle and run margins with less than c. 10 cm water depth, and a substratum of 'small- to medium-sized cobbles with plentiful interstitial spaces'. These interstitial spaces are considered to provide refuge during loss of surface flow, and it has been suggested that *G. cobitinis* may actively burrow down through gravel to groundwater as a drought survival strategy (Dungey 2002, 2003). Indeed, Dungey (2003) showed that on the resumption of flow, *G. cobitinis* densities were lower in areas where substratum provided little interstitial refuge than in areas of cobbles that were free of fine particles. Gravel abstraction can lead to a reduction in the mean particle size and interstitial space, and an increase in the amount of channel covered by sand (Shirvell 2002). These changes may affect fish movement, and thus influence the ability of *G. cobitinis* to survive drought.

The purpose of this study was to determine the ability of *G. cobitinis* to burrow through gravel and, specifically, whether fish could penetrate gravels modified by gravel abstraction. This was achieved by conducting behavioural experiments using substratum collected from an area of undisturbed river bed, and from a disturbed area that had experienced beach-skimming gravel abstraction. Declining water levels were also simulated to investigate whether this had an effect on burrowing behaviour. It was hypothesised that fish would be able to burrow more readily through gravels that had not been disturbed by gravel abstraction and that fish would burrow more quickly when water levels were declining.

2. Methods

2.1 EXPERIMENTAL SET-UP

Galaxias cobitinis were electrofished from the pool below the Kininmont Road culvert (2334195 E 5566455 N, New Zealand Map Grid) on the Kauru River on 7 February 2005. Fish were housed in two aerated 70-L containers at ambient air temperature. Aqua Plus® (Rolf C. Hagen, USA Corporation) and Antiseptic® (MasterPet Corporation Limited) were used to treat water, reduce handling stress to the fish, provide skin protection and artificial mucus, and reduce the risk of fungal and bacterial infections.

Two experiments (using a factorial design) were conducted at David Rodger's property (Kauru Hill) on 8 and 9 February 2005, to investigate the influence of substratum composition and water-level change on the gravel burrowing abilities of *G. cobitinis*. These two experiments followed identical procedures and thus represent replicates to test the reproducibility of results. The experimental set-up (Fig. 1) was modified from that of Dunn (2003), with fish being placed in bottomless substratum-filled buckets, which were located inside a larger bin whose water level could be experimentally manipulated by siphoning. Twelve 10-L plastic buckets with sections cut from their bases were used. Plastic mesh (16 × 16 mm) was placed inside the buckets to retain the experimental substrata, but allow fish passage out of the base of the buckets. These buckets were placed individually into 25-L clear plastic bins. To ensure identical set-ups, siphons were placed in all bins, even though only half of the bins had their water levels reduced during each experiment.

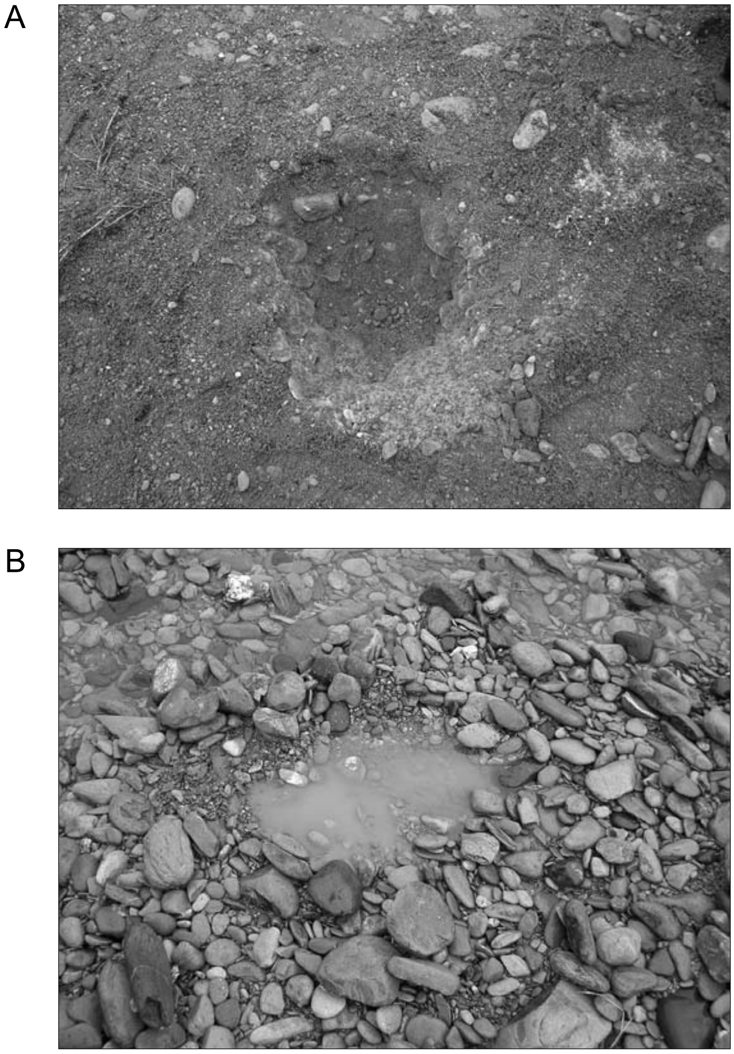
Substratum was collected on 7 February from two locations in the Kauru River. Six 'disturbed' substratum samples were taken from an area in the vicinity of 'Long Term Monitoring Site 2b' (Dungey 2003), where gravel abstraction and mechanical disturbance had occurred (Fig. 2A). Six 'undisturbed' substratum samples were collected from an unmodified area at 'Long Term Monitoring Site 2' (Dungey 2003; Fig. 2B). At the time of sampling, these areas were adjacent to, but not within, the wetted stream channel. Substratum was excavated and packed by hand in excess into 10-L buckets in the field, before being levelled to an average depth of 18.5 cm. Separate pits were excavated for each bucket sample.

Figure 1. Experimental set-up showing the 12 bins and buckets containing the substratum with their cloth covers. The six foremost buckets in the photo had their water levels reduced over the course of the experiment, draining into the length of spouting.

It was necessary to remove a fraction of fine sediment that otherwise would have become suspended in the water of the bins and obscured observations of fish. This was achieved by gently passing c. 2 L of water through each bucket. Substratum and interstitial volumes within each bucket were then calculated from the known volume of water displaced within a 25-L bin. This also served to further remove readily suspended fine particles. After the first experiment was completed, each bucket was emptied onto a tray and the substratum was repacked and again flushed to remove fines, in preparation for the second experiment.

Substratum-filled buckets were placed on wood blocks, raising them above the bin floor to allow fish passage out of their bases. Bins were then filled with water from a farm supply that had been treated with Aqua Plus® to remove any chlorine. Water temperature was monitored over the course of the experiments by an Onset Computer Corporation HOBO® data logger, which recorded a mean (± 1 SEM) temperature of 19.8 ± 0.003°C.

Figure 2. Riverside sampling pits in the Kauru River from which disturbed (A) and undisturbed (B) substratum samples were collected.



2.2 EXPERIMENTAL PROCEDURE

Mean (± 1 SEM) total length of *G. cobitinis* used in the experiments was 49.2 ± 0.4 mm. Four fish were randomly chosen from the experimental sub-population and placed in each bucket. Immediately following fish introduction, wetted cloth covers were secured over buckets, to stop fish escape, retain humidity, and reduce visual disturbance by workers. Once this was complete for all bins, siphoning was initiated to reduce water levels in the declining-water-level treatment (six buckets); siphon flow rates were adjusted using compression clips to attain similar rates between bins. Those bins that had stable water levels during Experiment 1 were siphoned to reduce water levels during Experiment 2. The positions of bins were also randomly reallocated between experiments.

The movement of fish through the gravel and into the bins was monitored by workers moving around the bins. Due to constraints of monitoring multiple bins, time of appearance was recorded in c. 5–10-minute intervals. The mid-point of each time period was used in statistical analyses. The recorded time taken to burrow through the gravel is conservative, as some fish inevitably remained in cover and were not detected until the end of the experiment. Furthermore, some fish had burrowed to the bottom of the gravel but did not find their way out into the bin, or had re-entered the gravel to find refuge.

Experiments were terminated once the water level dropped below the base of the buckets (Experiment 1: 90 minutes; Experiment 2: 82 minutes). Buckets were then removed from bins, and the gravel in those buckets that still contained fish was carefully excavated by hand; the depth of a fish's head was recorded as a measure of the depth burrowed.

2.3 STATISTICAL ANALYSIS

Two experimental variables were measured: the time taken for each individual fish to burrow through the gravel, and the depth to which each fish burrowed. Differences between substratum and water-level treatments in each individual experiment were tested using factorial analysis of variance (ANOVA), using Statistica 6.0 (StatSoft Inc.). Differences in the interstitial volume between substratum samples and experiments were also analysed using factorial ANOVA. Direct comparisons were made between experiments using regression analysis, for which the time taken for fish to completely burrow through the gravels was converted to a proportion of the experimental time. Those fish that did not burrow completely through the bucket were assigned a proportion of 1.

Upon completion of the experiments, substrata from three randomly chosen buckets in each substratum treatment was air dried, before being graded into fractions following the Wentworth scale (smallest sieve size used was 1 mm). Sample composition, based on the weight of fractions, was then analysed using GRADISTAT (Blott & Pye 2001), a computer program designed for the analysis of unconsolidated sediments.

3. Results

3.1 SUBSTRATUM ANALYSIS

There were significant differences in mean particle size (using the Folk & Ward (1957) method, as calculated in GRADISTAT; Appendix 1) between treatments ($F = 278.4$, df = 1, 4, $P < 0.001$); undisturbed substratum samples contained larger mean sized particles (mean ± 1 SEM: 94.1 ± 1.8 mm; very coarse gravel) than disturbed substratum samples (32.7 ± 3.2 mm; coarse gravel). Further, cumulative percentage frequencies of substratum-sample distributions indicated that while the composition of larger fractions was similar between the substratum treatments, disturbed substratum samples had a greater proportion of smaller fractions < 1 mm (Fig. 3). Grain-size distributions for the substratum treatments were either poorly (undisturbed) or very poorly (disturbed) sorted, with disturbed samples having a greater proportion of smaller particles. The increased amount of fine material in disturbed substratum was clearly evident in the field and during the experiment (Figs 2 & 4).

Figure 3. Cumulative percentage distribution of substratum samples (± 1 standard error) as calculated in GRADISTAT. Substratum fractions following the Wentworth scale are given in terms of ϕ (phi; $\phi = -\log_2$ diameter of particle (mm)), millimetres and descriptors.

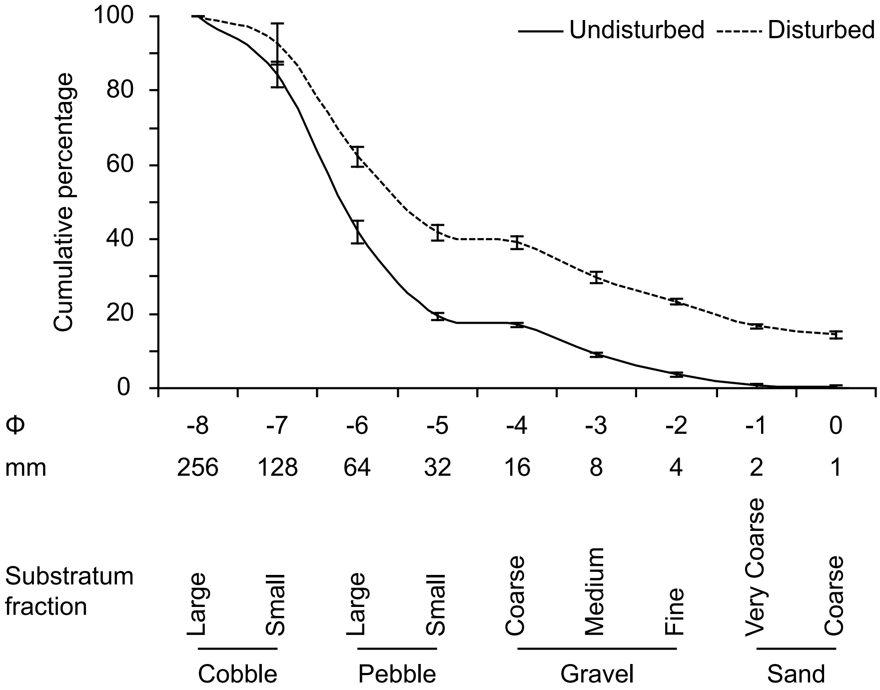
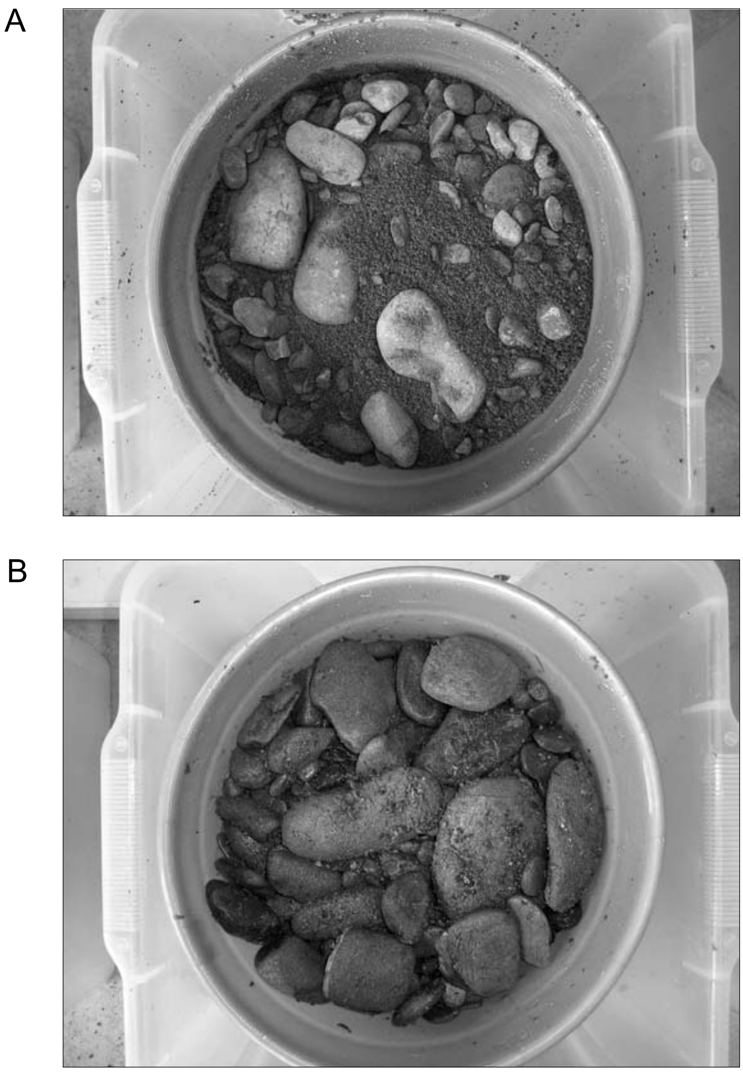


Figure 4. Disturbed (A) and undisturbed (B) substratum in buckets immediately prior to Experiment 1 after the initial flushing. Diameter of buckets is 28.5 cm (outside–outside edge).



Differences in substratum size composition were reflected in differences in the interstitial spaces of samples. Interstitial volumes in samples collected from areas disturbed by gravel abstraction were significantly less than those in undisturbed samples for both experiments (Fig. 5; Table 1). Although mean interstitial volumes for disturbed samples were larger in Experiment 2 than in Experiment 1 (Fig. 5), due to a greater flushing out of fines during the experimental set-up, this difference was not significant (Table 1).

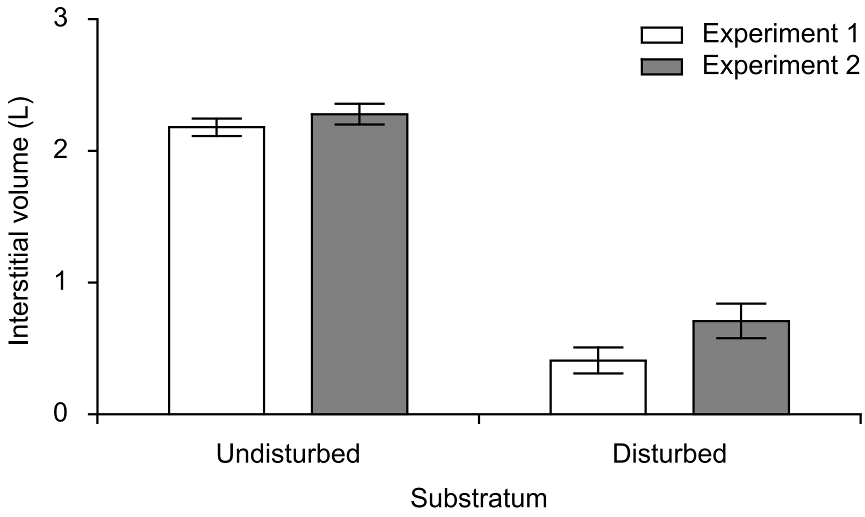


Figure 5. Mean (± 1 SEM) interstitial volume (L) for each substratum treatment and experiment.

TABLE 1. RESULTS OF FACTORIAL ANOVA EXAMINING INTERSTITIAL VOLUMES OF DIFFERENT SUBSTRATUM TREATMENTS (DISTURBED AND UNDISTURBED) BETWEEN AND WITHIN EXPERIMENTS.

SOURCE	df	SS	MS	*F*	*P*
Substratum	1	16.63	16.63	7.32	0.01*
Experiment	1	0.23	0.23	0.10	0.75
Substratum × Experiment	1	0.06	0.06	0.03	0.87
Error	21	47.73	2.27		

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