Effects of low flow on dwarf galaxias and their habitat in the Wairau River

Joe Hay

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ABSTRACT

Trustpower's proposed power scheme on the braided Wairau River, Marlborough, New Zealand, would divert up to 40 m^3/s of water through a 50-km canal, leaving a residual flow of 10–20 m^3/s in the affected reaches of the river. Two-dimensional flow modelling has predicted that at flows of 15–20 m^3/s, the flow in the affected reaches would be largely confined to the main channel, effectively eliminating shallow side-braid habitat, with an associated decline in available habitat for dwarf galaxias (*Galaxias divergens*), a small endemic fish that inhabits these side-braids. This report investigates changes in a population of dwarf galaxias as flow declined over one summer season, in habitats provided by a seep-fed side-braid of the Wairau River. The study confirmed that as flow dropped to approximately 20 m^3/s, habitat availability was reduced, and the braid became isolated from the main channel. This occurred alongside an apparent natural reduction in the abundance of dwarf galaxias, from a post-spawning abundance of predominantly juvenile fish. The ecology of dwarf galaxias appears to enable them to tolerate natural low-flow events. However, had this flow reduction occurred earlier in the year (or been sustained year round), it may have had a negative impact on the dwarf galaxias population. Side-braid habitat is likely to be vital for the survival of dwarf galaxias in the Wairau River, providing habitat, abundant invertebrate food and refuge from both physical and biological disturbances. Side-braids also appear to provide ideal foraging habitat for black-fronted terns (*Sterna albostriata*) which feed on dwarf galaxias and other small fishes during their breeding season. Ensuring that water abstraction at the proposed water intake does not cause the frequency and duration of occurrence of flows ≤ 22 m^3/s to exceed natural rates should avoid exacerbating low-flow impacts on dwarf galaxias and foraging area for black-fronted terns downstream.

Keywords: dwarf galaxias, *Galaxias divergens*, non-migratory galaxiids, habitat, flow, low flow, flow reduction, braided river, black-fronted tern, *Sterna albostriata*, Wairau River

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1. Introduction

This report investigates changes in a population of dwarf galaxias (*Galaxias divergens*) in a variety of habitats provided by a small, seep-fed side braid of the Wairau River, Marlborough (Fig. 1), as flow declined over the summer. The study aimed to increase the level of understanding of the potential responses of *G. divergens*, and their habitat, to reductions in river flow.

The need for more information about the flow requirements of *G. divergens* was prompted by Trustpower's proposal to develop a hydroelectric power scheme in the Wairau Valley. This hydro scheme would divert some of the Wairau River flow (up to 40 m^3/s; Trustpower 2005) into a canal which would feed through six new power stations before discharging back into the Wairau River approximately 50 km downstream. Trustpower is proposing seasonal minimum flows in the range 10–20 m^3/s for the affected section of river (Ryder & Keesing 2005).

2. What is known about dwarf galaxias?

Dwarf galaxias (*Galaxias divergens*) is a species of small freshwater fish, found in parts of the North and South Islands of New Zealand. It was first described from the Maruia River in the northern South Island by Stokell (1959). Dwarf galaxias have cryptic habits, making them difficult to study. Partly as a result of this, their ecology is poorly understood.

The dwarf galaxias is a member of the family Galaxiidae, best known in New Zealand for its sea-migratory (diadromous) members whose juveniles comprise whitebait runs. Dwarf galaxias is one of several non-diadromous members of the family (i.e. individuals complete their entire life-cycle in freshwater), so they do not contribute to the whitebait fishery. These fish are known as dwarf galaxias because of their diminutive size—they generally grow to only about 70 mm long (maximum length recorded is 87 mm; with fish from the north of the South Island tending to be larger than those elsewhere in New Zealand (McDowall 2000)). This compares with average lengths among closely related species of 80–85 mm (alpine galaxias, *G. paucispondylus*) and 100–120 mm (Canterbury galaxias, *G. vulgaris*) (McDowall 2000).

The scientific name—*Galaxias divergens*—alludes to morphological differences between this species and the majority of other members of the Galaxiidae (*G. divergens* has six rather than seven pelvic fin rays and 15 caudal fin rays; Stokell 1959; NIWA 2005).

Dwarf galaxias closely resembles the Canterbury galaxias (*G. vulgaris*), and the ranges of the two species overlap in Marlborough (McDowall 2000). The range of the dwarf galaxias extends from the Hokitika River catchment on the West Coast (Fig. 2) through Nelson and Marlborough, Wellington and Manawatu, and into the southern Hawke's Bay, with outlying populations in the Hauraki Plains and Bay of Plenty.

Recent genetic analyses have identified five genetically distinct populations within this range (Allibone 2000, 2002). The Wairau River fish belong to the most widespread of these populations, extending from southern Marlborough north to as far as Hawkes Bay, suggesting a land link between North Island and South Island rivers at some time in the past, probably when sea levels were low during the last glaciation.

Dwarf glaxias can be found living among cobble and gravel substrates in riffles of small streams, and in the shallow riffle margins of larger rivers, mainly in foothill catchments (McDowall 2000).

Individuals are thought to live 2–3 years (McDowall 2000), with female fish apparently outliving male fish. As a result, females tend to be numerically dominant in the second- and third-year age classes (Hopkins 1971). Dwarf galaxias generally mature at 2 years old, and spawn during spring (and possibly autumn) (McDowall 2000). In a study in Hinau Stream, Wairarapa (southern North Island), ripe fish were found from September to December, but not by mid-January (Hopkins 1971). Although their spawning sites have not yet been discovered, it is thought likely that they are in the same area as adult habitat (McDowall 2000). Approximately 100–250 eggs, each about 2 mm in diameter, are laid. Observations of eggs laid by captive fish in aquaria suggest that dwarf galaxias may lay their eggs singly, or in small groups attached to stones (Hopkins 1971) (cf. Canterbury galaxias, *G. vulgaris*, which lays its eggs in large masses on big stones; McDowall 2000), although this supposition is based on limited data.

Figure 1. Map of Wairau River showing study reach, flow recorder sites and the approximate location of the proposed power scheme.

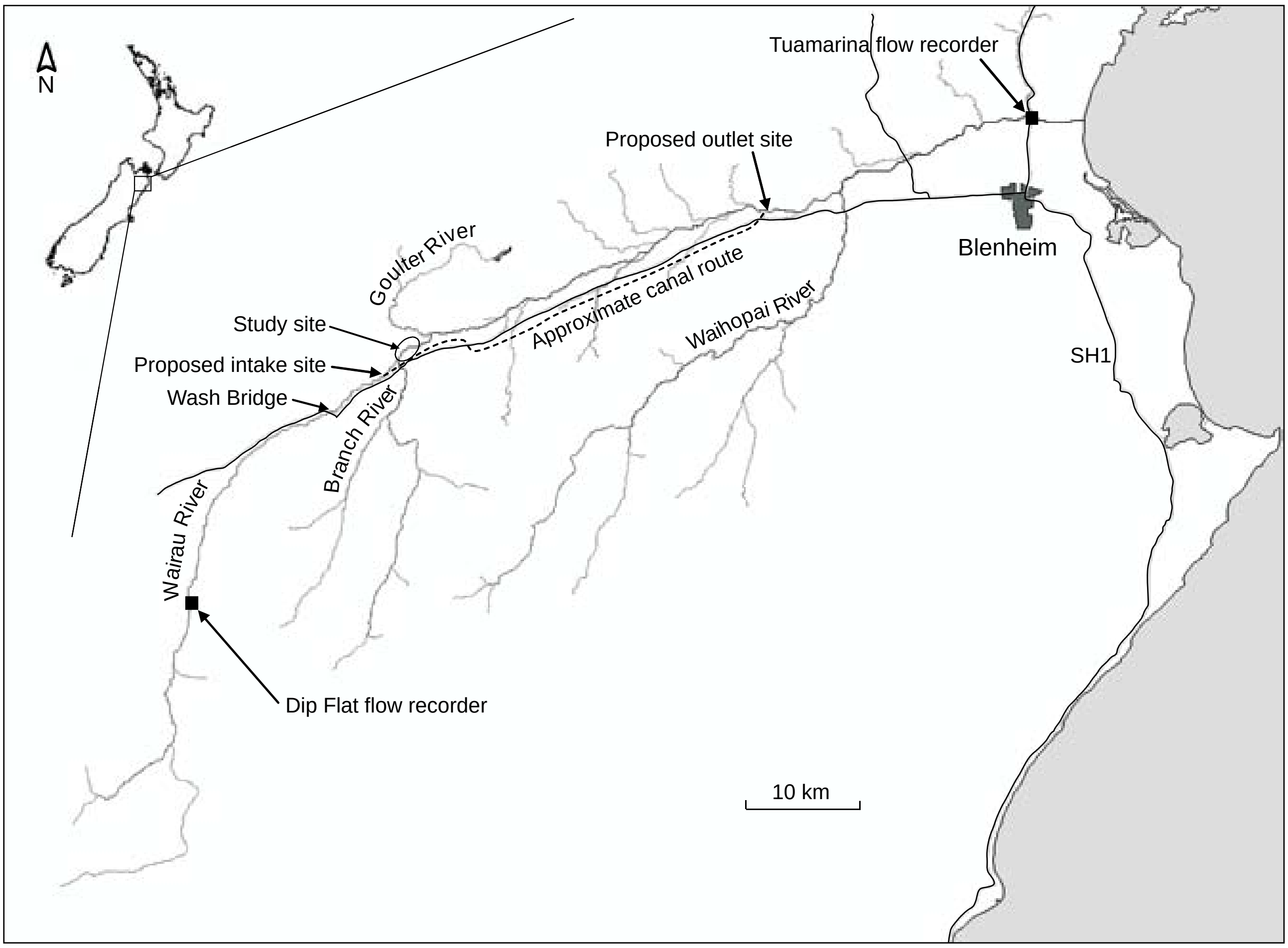
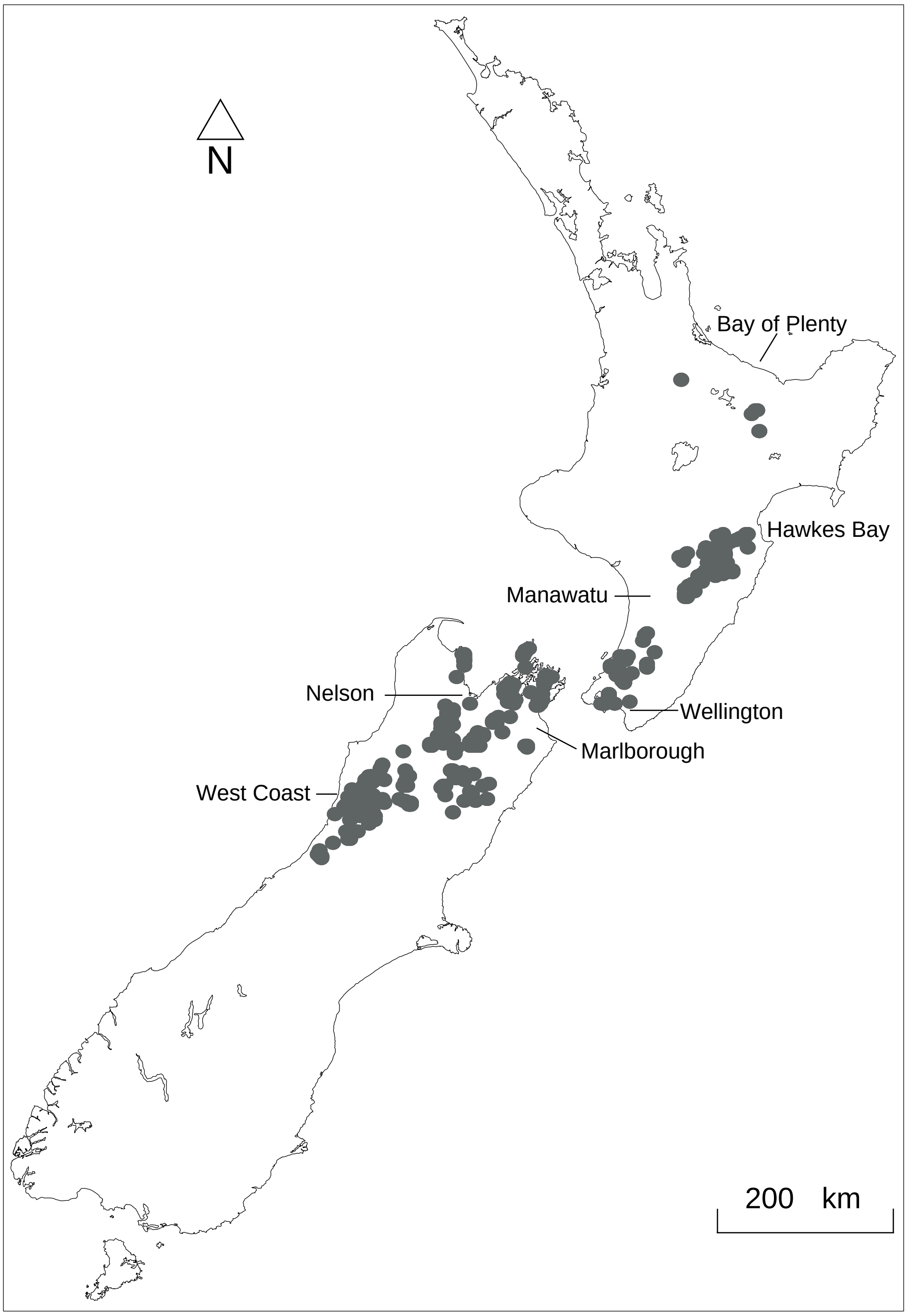


Figure 2. Dwarf galaxias (*Galaxias divergens*) distribution map, based on records from the New Zealand Freshwater Fisheries Database (administered by the National Institute of Water and Atmospheric Research; accessed on 21 Jan 2009).



Small shoals of larvae and juveniles may be found around stream margins during spring and summer (McDowall 2000). Hopkins (1971) found fry from late September until early March in Hinau Stream, but they were most abundant in November and December. Interestingly, Hopkins always found fry earlier in a small, isolated, spring-fed pool than in the main channel of the stream. Fry were seen in the spring-fed pool in September, but were not evident in the main channel until October. Hopkins also noted that fry were able to swim immediately upon hatching, and probably shoal straight after hatching as well.

Juveniles tend to hold station (i.e. maintain their location relative to the ground) in the water column during their early life, but become more benthic and cryptic at between 25 mm and 35 mm long (aged 2–3 months) (Hopkins 1971).

The diet of dwarf galaxias is mainly benthic invertebrates (especially chironomid fly larvae and *Deleatidium* mayfly nymphs) (McDowall 2000). However, terrestrial prey recorded in stomach contents suggests that the fish feed from the drift as well as the benthos (Hopkins 1971). Hopkins (1971) recorded a dietary shift from mainly chironomids eaten by small juveniles, to mainly *Deleatidium* as fish grew larger. He also noted that the stomachs were fullest in the afternoon, suggesting that dwarf galaxias are predominantly diurnal feeders.

In common with some other members of the Galaxiidae, adult dwarf galaxias are able to burrow into gravel, presumably to seek refuge from predators and extreme flow conditions. Under experimental conditions, dwarf galaxias, with their smaller body form, burrowed faster and deeper than larger alpine galaxias (*G. paucispondylus*), Canterbury galaxias, and upland bullies (*Gobiomorphus breviceps*) in response to reduced water levels (Hartman 1990). This adaptation presumably allows them to take refuge amongst moist gravels during relatively short-term drought events, as well as avoiding washout during floods.

Along with the majority of non-migratory Galaxiid species in New Zealand, dwarf galaxias is considered to be nationally threatened and is listed by the Department of Conservation (DOC) as being in 'Gradual Decline' (DOC 2004). A variety of causes have been implicated in the decline of the species, including landuse change, impacts of introduced species and water abstraction.

3. Methods

On 14 January 2005, nine reaches (15–58 m in length) in a seep-fed side-braid of the Wairau River (immediately downstream of its confluence with the Branch River; Fig. 1) were surveyed. The reaches were selected to cover the range of habitats that dwarf galaxias were observed to utilise in this braid. Three transects were located within each reach (at the top, middle and bottom of the reach). These were marked with 'dazzle' spray-paint and recorded using GPS, to facilitate their location on subsequent visits.

Flow in the Wairau River during this initial survey was approximately 75 m^3/s at Tuamarina and 26 m^3/s at Dip Flat (Fig. 1). The flow experienced at our sampling location would have been somewhere between these two recorded flows, but closer to the Dip Flat flow because of its proximity and the location of major tributary inflows (Fig. 1).

The survey involved placing a 0.25-m^2 quadrat approximately mid-channel at each transect. An observer then took up a position within viewing distance of each quadrat (i.e. one observer per quadrat) and waited for 3 minutes for fish to resume their normal activity. The area of river delineated by the quadrat was then observed for 5 minutes, and the maximum number of fish, of any given species, that was observed within the quadrat area, at any time during the monitoring period, was noted. This approach was adopted to avoid double counting of these sometimes highly-mobile fish as they moved in and out of the quadrat during the observation period. The resulting fish counts provide a relative index of abundance that can be used to make comparisons over time, rather than providing an estimate of actual fish abundance or density.

Observers also estimated the size of the fish they counted using a known scale to calibrate their estimates. This allowed the size-class composition of the counted fish to be estimated.

Physical habitat observations were also made for each reach. These included riparian cover, substrate composition, wetted width at each transect, reach length, water temperature at the top and bottom of each reach, maximum depth within each quadrat and water velocity at that point.

Surveys were repeated on 25 January, 1 March and 11 April 2005. River flows on these follow-up visits were approximately 30 m^3/s, 20 m^3/s, and 35 m^3/s respectively at Tuamarina, and 16 m^3/s, 13 m^3/s, and 20 m^3/s respectively at Dip Flat. It was intended to conduct the final survey at a lower flow. The recorded flow at Tuamarina available on the day of the last survey was 11 m^3/s, but the flow recorder was subsequently found to be faulty. Reliable flow recorder measurements for this site were subsequently obtained from another recorder at the site.

Water clarity was good during all of the surveys, although ripples on the water surface caused by wind gusts periodically disrupted visibility, particularly in the afternoons.

4. Results

4.1 PHYSICAL HABITAT

Between the first survey (14 January) and second survey (25 January), water levels had noticeably reduced only at the lower two reaches, those closest to the outlet into the main channel. There was a noticeable increase in the abundance of filamentous green and blue-green algae in most reaches.

By the third visit (1 March), the water level was noticeably reduced throughout the survey area, with two reaches (and one transect in another) totally dry (Fig. 3). One of these reaches was still dry during the final survey (11 April; Fig. 4, Table 1), despite the increase in flow recorded (Table 1). Drying had effectively isolated the whole side-braid from the main channel.

There was also a noticeable decrease in the abundance of filamentous algae in most reaches by the 1 March survey, and an increase in silt.

Between the third and fourth surveys, the survey area experienced a large flood (peaking at approximately 1100 m^3/s at Tuamarina). This changed the riverbed morphology (channel width, depth, substrate composition) to varying degrees at most of the survey reaches. It also removed filamentous algae and macrophyte cover from the majority of reaches. However, one survey reach appeared to have been largely untouched by the flood.

There was a marked reduction in the wetted area of most survey reaches during the first three surveys (Table 1), corresponding with reducing flows over this period. As flow dropped between the second and third surveys (from 16 m^3/s to 13 m^3/s at Dip Flat), the total wetted area in the surveyed reaches declined by approximately 28%. However, the changes in bed form associated with the large flood (between

Figure 3. The top survey reach as flow decreased over the four survey visits, 14 Jan 2005 (top left), 25 Jan 2005 (top right), 1 March 2005 (bottom left) and 11 April 2005 (bottom right).

Figure 4. The bottom survey reach which was dewatered as flow decreased during the summer, 25 Jan 2005 (left) and 11 April 2005 (right).

TABLE 1. CHANGES IN THE AREA OF AVAILABLE WETTED HABITAT IN THE SURVEYED REACHES OF A SEEP-FED SIDE BRAID OF THE WAIRAU RIVER, AS FLOW DECLINED THROUGH THE 2005 SUMMER SEASON.

SURVEY DATE (2005)	FLOW (m^3/s)		WETTED AREA (m^2) IN EACH REACH (numbered)								
	TUAMARINA	DIP FLAT	1	2	3	4 & 5	6	7	8	9	TOTAL
14 Jan	76	26	235.9	67.1	183.3	137.1	71.2	280.0	118.8	63.8	1157.2
25 Jan	30	16	248.8	70.2	183.3	134.0	71.2	246.4	103.5	48.1	1105.5
1 Mar	20	13	164.3	0.0	165.9	131.2	65.0	232.8	0.0	38.2	797.4
11 Apr	36	20	115.0	152.5	148.5	141.7	66.5	308.0	0.0	53.4	985.5

the third and fourth surveys) produced some broad shallow areas in reaches that had formerly been relatively narrow. This meant that the wetted areas recorded during this last survey were not directly comparable with those recorded on earlier visits. Similar decreasing trends were also evident in the depth and velocity records from the surveyed reaches, over the first three visits.

4.2 OBSERVED FISH BEHAVIOUR

Individual galaxiids, when disturbed, tended to dart around before taking cover; whereas several individuals, when disturbed at the same time, would often form shoals which would generally disperse after a few minutes. The individuals would then often hold station in the water column in much the same fashion as drift-feeding trout.

4.3 DWARF GALAXIAS POPULATION

The numbers of dwarf galaxias counted during the surveys declined over the summer (Fig. 5), although there was also a large degree of spatial variability in counts. Casual observations of fish abundance made by observers as they moved between reaches also indicated that overall abundance was declining. A decline in numbers is common in juvenile fish in their first year of life, due to density-dependent mortality and emigration (Elliot 1994; Begon et al. 1996).

The growth of the new season's cohort as the summer progressed was evident in the data (Fig. 5). Counts early in the season included a range of different-sized fish, from fry (< 15 mm in length) to adults, and with juveniles in the size range 26 mm and 40 mm particularly prevalent. However, by the last survey adults (> 50 mm) predominated and the fish smaller than 30 mm were no longer present. Hence, counts early in the season comprised large numbers of predominantly small fish, while counts in the later part of the season comprised smaller numbers of larger fish.

By the fourth visit (11 April), fish counts (as well as the numbers of fish seen shoaling by observers as they moved between sampling sites) were appreciably lower than on previous trips—in fact, fish were absent from all but a couple of isolated locations by the time of the last survey). This was despite river flows on the fourth visit being greater than they had been during the third visit. All but one of the observed fish in the last visit were of adult size (i.e. ≥ 60 mm long) (Fig. 5).

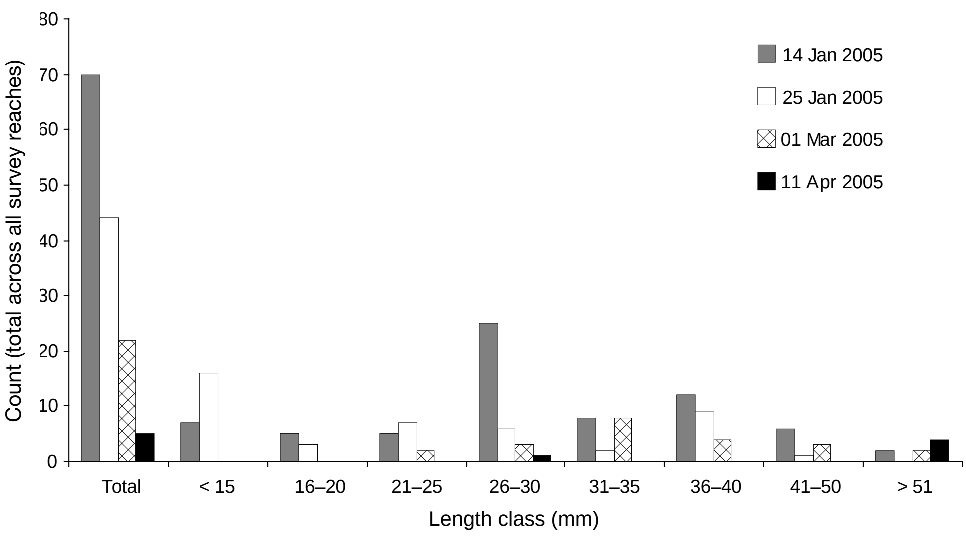


Figure 5. Changes in observed dwarf galaxias (*Galaxias divergens*) abundance and population structure during summer 2005.

As the summer progressed and sections of the surveyed area dried out, large shoals of dwarf galaxias were occasionally observed in pools upstream of the dry reaches. Dunn (2003) noted a similar occurrence, with alpine galaxias and Canterbury galaxias seen to concentrate in pools as a reach dried out, leading to apparent competition for space.

One adult dwarf galaxias was found floating dead below one of the reaches on the third survey visit (1 March). There was no evidence of injury and the cause of death was not apparent.

5. Discussion

This study showed that as flow at Dip Flat declined from 26 m^3/s to 13 m^3/s, the area of wetted habitat available to dwarf galaxias in a seep-fed side-braid of the Wairau River was substantially reduced, and the remaining wetted area became isolated from the main channel. In this case the flow reduction occurred naturally, as a result of low summer rainfall, and coincided with an expected natural decline in number of dwarf galaxias over their first summer of life (i.e. from an initial high post-spawning abundance of fry). In order to have persisted in this system, this species must be well adapted to frequently occurring low- and high-flow events. The flow range recorded at Dip Flat over this period was above the mean annual low flow for this site (approximately 8.6 m^3/s; Mitchell 2004), so flows as low as that recorded could be expected to occur in most years. It is unlikely, therefore, that the reduced flow recorded during this study had any significant long-term negative effect on the dwarf galaxias population in the Wairau River.

However, artificially reduced flows earlier in the season might be expected to have more of an impact. Extremes of flow (i.e. floods and droughts) during critical spawning and fry-rearing periods have been found to limit recruitment of non-migratory galaxiids, strongly influencing population size structure (Dunn 2003). Dunn (2003) observed high mortality among alpine galaxias and Canterbury galaxias in Dry Stream, Castle Hill, Canterbury, New Zealand, during low-flow events in spring. The effects of low flow may have compounded the already high stress levels associated with reproduction, resulting in increased mortality (Dunn 2003).

In common with other non-migratory galaxiids, dwarf galaxias appear to have physiological and behavioural adaptations that allow them to survive short-duration drying events. As mentioned above, dwarf galaxias are more proficient burrowers than their close relatives, alpine and Canterbury galaxias (Hartman 1990). The latter species have the ability to survive out of water for a week or more, if kept under moist conditions (Dunn 2003). It seems reasonable to expect that dwarf galaxias should have a similar ability. These sorts of adaptations would be necessary for the long-term survival of any fish species faced with the highly variable flows that many of New Zealand's hill country streams experience. However, these behavioural and physiological adaptations are only likely to be effective against relatively short-term low-flow events, and would probably not allow dwarf galaxias to endure chronic low flows caused by artificial flow diversions. The only viable survival option the fish would have under chronic low-flow conditions would be to move to more suitable habitat elsewhere, if it is available. In a braided river, emigration to deeper, permanent channels might increase predation risk from fish predators such as trout and eels.

The habitat provided by side braids may be of particularly high value for small fish living in large rivers such as the Wairau. Isolated side braids are less likely to experience the same frequency of floods as the main channel, and may therefore provide suitable flow refugia for fry. This effect was evident in our study following the large flood event of 25–27 March 2005. Although the majority of the surveyed reaches appeared to have been scoured to some degree and morphological changes were evident in places, one of the survey reaches was apparently unaffected. This reach still retained reasonably substantial filamentous algal growths, as well as reasonable numbers of dwarf galaxias, suggesting that it had acted as an effective flood refuge, even during this large flood. As a consequence of their stability, seep-fed side braids also generally have higher densities of the benthic invertebrates, which are the main food of dwarf galaxias (Hughey et al. 1989).

The refuge from high water velocities (during floods) provided by side braids is likely to be of particular value during the spawning season. In a study on factors affecting recruitment of alpine and Canterbury galaxias, Jellyman (2004) found that the amount of slow, backwater habitat available was one of the most important factors determining initial fry density. Young galaxiids have low velocity tolerance (10-mm-long fry are able to hold station against a velocity of only 0.1 m/s; Jellyman 2004), and therefore require the velocity refuge offered by slow backwater habitat to prevent them from being washed downstream. This corresponds well with observations made during the present study, where shoals of small fry were generally seen in lower-velocity water, out of the main current. Furthermore, Jellyman (2004) found that washout during flooding was a major cause of decline in fry density.

Side braids may also provide a refuge for dwarf galaxias from predatory fish, particularly trout. The shallow depths and seep-fed nature of many side braids may limit their accessibility to large trout, which are likely to be piscivorous (brown trout tend to become piscivorous when they grow > 300 mm long; Keeley & Grant 2001). The physical conditions experienced in side braids may also exclude trout (Dunn 2003). Water temperatures recorded during our surveys were as high as 27.7°C, well into the lethal range for brown trout (Elliot 1994). During the January surveys, the water temperature was almost universally > 19°C (brown trout are known to stop feeding at temperatures above 19°C; Elliot 1994), except for the top reaches, where all flow was seepage from the substrate and temperatures ranged between 14°C and 18°C.

A recent biological survey of the Wairau River, undertaken for Trustpower, found that '…secondary and tertiary braids and seepages in sampled reaches of the Wairau have very high native fishery values, strong macroinvertebrate communities, good quality water and healthy periphyton communities' (Ryder & Keesing 2005: 109). The authors suggested that these side-braid habitats are very important for galaxiids and bullies, along with other native fish species. In an earlier version of their report it was speculated that if habitat availability in these side-braids was reduced by lower flows, the remaining habitat would probably not be capable of maintaining the same biomass (Boffa Miskell & Ryder 2004).

Two-dimensional flow modelling (undertaken as part of the feasibility study for Trustpower's proposed hydro scheme) predicts that flowing water would be restricted to the main channel in the reaches affected by the abstraction when the overall river flow drops to between 15 and 20 m^3/s. Flows in this range would largely eliminate side-braid habitat at the upstream end of the reaches affected by abstraction. Further downstream, as input from tributaries increases the residual flow in the river, some side-braids are predicted to remain wetted. However, this remnant side-braid habitat is predicted to be largely isolated from the main channel over this flow range. Connectivity between side-braid habitat and the main channel is likely to be critical to the dispersal of juvenile dwarf galaxias, allowing them to colonise new areas of suitable habitat as these are created in the braided river system. The modelling predicted that reducing flow to these levels would result in a pronounced drop in habitat availability for dwarf galaxias (Ryder & Keesing 2005).

Our observations indicated that the side-braid was indeed beginning to be dewatered at flows in the order of 15–20 m^3/s, and that connectivity with the main channel was lost before flows reached these levels (i.e. at higher flows). In a report on the hydrology of the Wairau catchment, prepared as part of Trustpower's feasibility study, Mitchell (2004) presented the following regression for predicting flow (Q) at Wash Bridge (see Fig. 1 for location) from flow at Dip Flat:

$$Q_{\text{Wash Bridge}}\ (m^3/s) = 1.351\ Q_{\text{Dip Flat}}\ (m^3/s) - 0.6497\ (r^2 = 0.9505).$$

Mitchell used this relationship to predict flow at the proposed intake to the hydropower scheme by adding 0.3–0.6 m^3/s to account for a reasonably constant inflow between Wash Bridge and the proposed intake. Based on this method, the flow range 13–16 m^3/s at Dip Flat, over which partial dewatering of the side-braid was observed, causing the side-braid to become isolated from the main channel, would be equivalent to flows of approximately 17–22 m^3/s at the proposed hydro scheme canal intake.

This flow range (i.e. 17–22 m^3/s at the proposed intake) is substantially higher than the natural mean annual low flow (MALF) in the section of the Wairau River affected by the proposed hydro scheme (according to Hudson et al. (2004), the MALF in the reaches affected by the proposed scheme ranges between 10 m^3/s and 15 m^3/s, depending on the distance downstream[1]). Therefore, dwarf galaxias populations living in side-braids of the Wairau River must be adapted to drying events of this magnitude. However, while these populations of dwarf galaxias must be resilient to low-flow events of relatively short duration, this resilience may not be sufficient to enable them to survive such low levels over prolonged periods, particularly if flow reductions occur during the critical spawning and dispersal life stages. Further research is needed to ascertain the magnitude and duration of low-flow events that dwarf galaxias populations are able to tolerate. However, in the meantime, so long as flows $\leq 22\ m^3/s$ at the proposed water intake (equivalent to approximately 16 m^3/s at Dip Flat) do not exceed their natural frequency and duration of occurrence, then low-flow impacts on dwarf galaxias habitat and populations should not be exacerbated.

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[1] Flow accrues gradually as a river progresses downstream, due to natural inflows from streams and the substrate. Therefore, the flow at the top of a particular reach will normally be less than that at the bottom of the reach. As a result, mean annual low flow also increases downstream through the affected reach.

5.1 LINK WITH BLACK-FRONTED TERNS

The dwarf galaxias population in the Wairau River may be an important food source for birds. In particular, the aggregations of juvenile dwarf galaxias that occur in the river shallows during early summer may contribute to the breeding success of black-fronted terns (*Sterna albostriata*) nesting in the area. Food availability may be important in the timing of breeding seasons and in population regulation (through chick survival) in migratory birds (Hughey 1985).

The black-fronted tern is classified as 'Nationally Endangered' (Hitchmough et al. 2007). It breeds only on the braided rivers of the South Island, with the Wairau River being home to the largest known population (Keedwell 2002). The entire black-fronted tern population is estimated to number less than 10 000 birds (Keedwell 2002), with the Wairau River supporting a population of > 1000 of these. In the 2004/05 breeding season, the Wairau breeding population included at least four colonies in the area likely to be affected by reduced flows if Trustpower's proposed hydro scheme goes ahead (Bell 2005).

Although adult black-fronted terns feed mainly on aquatic insects, fish are an important food source for their chicks, comprising the bulk of their diet in terms of energy intake (Lalas 1977). The high energy content of fish makes them an attractive food source for chicks. This is particularly true for black-fronted terns, since they feed their young whole prey, rather than regurgitated prey, so the energy intake of chicks is limited by the time it takes for the parents to deliver prey items to the nest (Lalas 1977). Lalas calculated the maximum energy intake of chicks fed entirely on insects at 3–9 kJ/h. This equates to approximately 60–80 insects (i.e. 60–80 return trips to the nest for the adult bird), but is equivalent to only 0.7–2 fish. Thus, feeding chicks on fish reduces the number of trips to the nest an adult has to make, therefore minimising their energy expenditure.

Black-fronted terns are capable of handling only relatively small fish. The largest fish that Lalas (1977) saw successfully captured by a black-fronted tern was 80 mm long. Terns are also limited in the depth to which they can dive for prey; most fish are taken over a depth range 0.05–0.2 m, but some are taken up to a maximum of about 0.4 m (Lalas 1977). These criteria suggest dwarf galaxias should be an ideal prey species and shallow side-braids an ideal foraging habitat for black-fronted terns. Indeed, Lalas (1977) observed black-fronted terns catching galaxiid species (Longjaw galaxias (*G. prognathus*) and Canterbury galaxias), along with trout fry and upland bullies, in the Waitaki Catchment. He also noted that terns foraged for fish mainly along minor, slower-flowing side-braids, especially during September to November.

Black-fronted terns on the Wairau River are often seen hunting along the shallow margins of the river, the habitat best suited to dwarf galaxias. There have also been anecdotal reports of terns carrying small fish resembling dwarf galaxias, and these sightings coincided with the period that terns would be feeding chicks (J. Clayton-Greene & S. Cranwell, DOC, pers. comm.).

Breeding and chick-rearing by black-fronted terns coincides with the period when densities of juvenile dwarf galaxias are at their peak (Fig. 6). It appears to be relatively common for terns to breed near, and at times which coincide with, a rich food source provided by aggregations of juvenile fish. Taylor & Roe (2004) found that little terns (*Sterna albifrons sinensis*) breeding on Rigby Island, Gippsland Lakes, in south-east Australia, fed their chicks entirely on juvenile fish (with prey length ranging between 7.5 mm and 82.5 mm). Furthermore, breeding

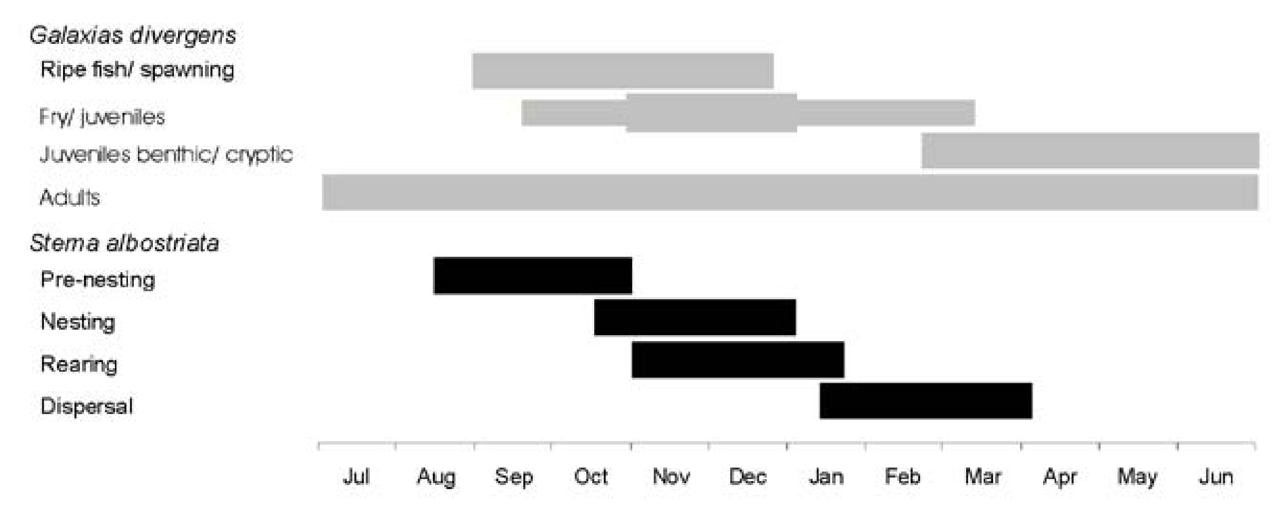

Figure 6. Comparison between the timing of dwarf galaxias (*Galaxias divergens*) and black-fronted tern (*Sterna albostriata*) life history stages.

success among these birds was significantly reduced in the season following mass mortality of juvenile pilchards, one of their most important prey species.

Nesting colonies of Caspian terns on the Columbia River, USA, were found to feed almost exclusively on salmonid smolts (Collis et al. 2002). These juvenile fish accounted for 73–81% of identifiable prey items in local Caspian tern diets, and were the primary prey item for entire tern breeding colonies, especially during pre-laying, laying and incubation (which coincided with the peak in seaward migration of smolts).

Variability in the availability of food has been associated with variations in both numbers of terns breeding and breeding success (Taylor & Roe 2004). Taylor & Roe (2004) postulated that short supply of food, and consequent longer periods away from the nest foraging, may lead to increased predation risk for nestlings and, ultimately, that food shortages might lead to the abandonment of colonies. In a study of black-fronted terns nesting over four years in the Ohau River, south Canterbury, Keedwell (2002) found at least 4.1% of chick mortality was attributable to starvation. Also, nest desertion during incubation accounted for 21.4% of nest failures in this study (Keedwell 2002). Nest desertion was second only to predation as a cause of nest failure (24.6% of failures).

Substantial decline in the availability of dwarf galaxias (as well as other small, shallow-water-dwelling fish species, e.g. upland bullies) in the proximity of black-fronted tern colonies in the Wairau River would risk reducing the breeding success of black-fronted terns. Flow reduction has the potential to do this through reduced habitat availability for dwarf galaxias. If flows were reduced to a level that confined flow to the main channel, eliminating side-braids, black-fronted terns would be confronted with a reduction in suitable foraging habitat. This would be compounded if the abundance of their prey (dwarf galaxias) was also reduced, as would be expected if the habitat provided by side-braids was eliminated. There is also evidence that nest predation pressure is greater in areas connected to the mainland than on islands in braided rivers (Pascoe 1995; Rebergen et al. 1998). This suggests that reduced flow could also have a direct impact on black-fronted terns, by removing the nesting refuges safe from ground-based predators that islands in active braided river systems provide. There is some limited evidence that nest predation rates on the Wairau River may be higher when levels of flow around islands are low (Bell 2005). However, further investigation is required to assess the veracity of this potential relationship.

6. Conclusions

Trustpower's proposal to abstract water from the Wairau River for a hydropower scheme would result in river flows being reduced significantly over approximately 50 km of the river. Two-dimensional flow modelling has predicted that if flow is reduced below 15–20 m^3/s, the residual flow in the river will be confined to the main channel, effectively eliminating shallow side-braid habitat, or isolating it from the main channel, with an associated decline in available dwarf galaxias habitat.

The present study tracked changes in the physical habitat and relative abundance of dwarf galaxias as flow declined over summer 2005 in a seep-fed side-braid. It confirmed that as flow dropped to approximately 20 m^3/s at the study reach, the area of available habitat in the side-braid was reduced (declining by approximately 28% as flows recorded at Dip Flat dropped from 16 m^3/s to 13 m^3/s, equivalent to approximately 22 m^3/s to 17 m^3/s at the proposed hydro scheme intake). This reduction in habitat area occurred alongside an expected natural reduction in the abundance of dwarf galaxias, from a high post-spawning abundance of predominantly juvenile fish. However, if this reduction in flow occurred earlier in the year (or was sustained year round), it would be likely to have a negative impact on the dwarf galaxias populations inhabiting side-braids.

As well as providing appropriate physical habitat and abundant invertebrate food species for dwarf galaxias, side-braid habitats likely provide a refuge for river-resident galaxiids from both physical (e.g. droughts and floods) and biological (e.g. predatory fish) disturbances. They may be of particular importance as a water velocity refuge for juvenile fish, which have limited swimming abilities. Side-braids also appear to provide ideal foraging habitat for black-fronted terns during their breeding season.

Further research is required to assess what level of habitat reduction might be tolerated by the dwarf galaxias populations in the Wairau River, and how habitat reduction might affect the productivity of these populations. More information is also required on the magnitude and duration of the low-flow events that these populations are capable of enduring. Finally, further investigation is needed into the role played by dwarf galaxias, and other small fishes found in shallow side-braid habitats, in the breeding success of the threatened black-fronted tern.

If flow reductions decrease the availability of edgewater habitat provided by shallow side-braids in the Wairau River, this would not only impact on dwarf galaxias, but also potentially affect the threatened black-fronted tern population. Assuming that other side-braids in the reaches affected by water abstraction for the proposed hydropower scheme have similar responses to low flows, our observations indicate that maintaining the natural frequency and duration of occurrence of flows $\leq 22\ m^3/s$ at the proposed water intake (equivalent to about 16 m^3/s at Dip Flat) should avoid exacerbating low-flow impacts on dwarf galaxias habitat and populations, as well as foraging area for black-fronted terns feeding on dwarf galaxias, in these reaches.

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8. References

Allibone, R.M. 2000: Population structure of *Galaxias divergens*, a widespread non-migratory galaxias in New Zealand. Paper presented at Fresh perspectives: joint conference of the New Zealand Limnological Society, the New Zealand Hydrological Society and the Meteorological Society of New Zealand, November 2000, Christchurch, New Zealand. www.niwa.cri.nz/rc/prog/freshbiodiversity/info/allibone

Allibone, R.M. 2002: Dealing with diversity dwarf galaxias style. *Water & Atmosphere 10*: 18–19.

Begon, M.; Harper, J.L.; Townsend, C.R. 1996: Ecology: individuals, populations and communities (third edition). Blackwell Science, Oxford, UK. 1068 p.

Boffa Miskell Ltd.; Ryder Consulting Ltd 2004: Proposed Wairau Hydroelectric Power Scheme: ecological investigations of the Wairau River main stem (final draft). Unpublished report. 73 p.

Bell, M. 2005: Breeding success of black-fronted tern on the Wairau River. Unpublished report prepared for the South Marlborough Area Office, Nelson/Marlborough Conservancy, Department of Conservation. February 2005. 10 p.

Collis, K.; Roby, D.D.; Craig, D.P.; Adamany, S.; Adkins, J.Y.; Lyons, D.E. 2002: Colony size and diet composition of piscivorous waterbirds on the lower Columbia River: implications for losses of juvenile salmonids to avian predation. *Transactions of the American Fisheries Society 131*: 537–550.

Elliott, J.M. 1994: Quantitative ecology and the brown trout. Oxford University Press, Oxford, UK. 286 p.

DOC (Department of Conservation) 2004: New Zealand non-migratory galaxiid fishes recovery plan 2003–13. *Threatened Species Recovery Plan 53*. Department of Conservation, Wellington. 45 p.

Dunn, N.R. 2003: The effects of extremes in flow on alpine (*Galaxias paucispondylus*) and Canterbury (*G. vulgaris*) galaxias. Unpublished MSc thesis, University of Canterbury, Christchurch. 174 p.

Hartman, G. 1990: Ability of some New Zealand fishes to burrow in gravel. *Freshwater Catch 44*: 15–16.

Hitchmough, R.; Bull, L.; Cromarty, P. (Comps) 2007: New Zealand Threat Classification System lists 2005. Department of Conservation, Wellington, New Zealand. 194 p.

Hopkins, C.L. 1971: Life history of *Galaxias divergens* (Salmonoidea: Galaxiidae). *New Zealand Journal of Marine and Freshwater Research 5*: 41–57.

Hudson, H.R.; McMillan, D.A; Grey, A. 2004: Hydraulic and habitat simulation, Wairau River, Marlborough (final draft). EMA 2004–02, Environmental Management Associates, Christchurch. 59 p.

Hughey, K.F.D. 1985: Hydrological factors influencing the ecology of riverbed breeding birds on the plains' reaches of Canterbury's braided rivers. Unpublished PhD thesis, University of Canterbury, Chistchurch, New Zealand. 255 p.

Hughey, K.; Fraser, B.R.; Hudson, L.G. 1989: Aquatic invertebrates in two Canterbury rivers related to bird feeding and water development impacts. *Science & Research Series No. 12.* Department of Conservation, Wellington. 61 p.

Jellyman, P.G. 2004: Fry survival of alpine (*Galaxias paucispondylus*) and Canterbury (*G. vulgaris*) galaxids. Unpublished BSc Hons thesis, University of Canterbury, Christchurch, New Zealand. 68 p.

Keedwell, R.J. 2002: Black-fronted terns and banded dotterels: causes of mortality and comparisons of survival. Unpublished PhD thesis, Massey University, Palmerston North, New Zealand. 194 p.

Keeley, E.R.; Grant, J.W.A. 2001: Prey size of salmonid fishes in streams, lakes, and oceans. *Canadian Journal of Fisheries and Aquatic Sciences 58*: 1122–1132.

Lalas, C. 1977: Food and feeding behaviour of the black-fronted tern, *Chlidonias hybrida albostriatus.* Unpublished MSc thesis, University of Otago, Dunedin, New Zealand. 164 p.

McDowall, R.M. 2000: The Reed guide to New Zealand freshwater fishes. Reed, Auckland, New Zealand. 224 p.

Mitchell, P. 2004: Wairau Valley hydo-electric power scheme feasibility report hydrology—final draft for comment. 03WAU/HYD-C, Riley Consultants, Takapuna, Auckland. 30 p. + appendix.

NIWA (National Institute of Water & Atmospheric Research) 2005: Atlas of New Zealand freshwater fishes. www.niwa.cri.nz/rc/freshwater/fishatlas/species/dwarf galaxias.htm

Pascoe, A. 1995: The effects of vegetation removal on rabbits (*Oryctolagus cuniculus*) and small mammalian predators on braided riverbeds of the Mackenzie Basin. Unpublished MSc. thesis, University of Otago, Dunedin. 118 p.

Rebergen, A.; Keedwell, R.; Moller, H.; Maloney, R. 1998: Breeding success and predation at nests of banded dotterel (*Charadrius bicinctus*) on braided riverbeds in the central South Island, New Zealand. *New Zealand Journal of Ecology 22*: 33–41.

Ryder, G.; Kessing, V. 2005: Proposed Wairau hydroelectric power scheme: ecological investigations of the Wairau River (Scope 2). Unpublished report prepared for Russell McVeagh on behalf of TrustPower Ltd. 104 p.

Stokell, G. 1959: Notes on galaxiids and eleotrids with descriptions of new species. *Transactions of the Royal Society of New Zealand 87*: 265–269.

Taylor, I.R.; Roe, E.L. 2004: Feeding ecology of little terns *Sterna albifrons sinensis* in south-eastern Australia and the effects of pilchard mass mortality on breeding success and population size. *Marine and Freshwater Research 55*: 799–808.

Trustpower 2005: Wairau Valley Hydroelectric Power Scheme, Volume 1—The assessment of environmental effects report, June 2005. 167 p.