Restoration of floodplain habitats for inanga (*Galaxias maculatus*) in the Kaituna River, North Island, New Zealand

Peter M. Ellery & Brendan J. Hicks*

Centre for Biodiversity and Ecology Research, Department of Biological Sciences, School of Science and Engineering, The University of Waikato, Private Bag 3105, Hamilton 3240, New Zealand.
*Corresponding author's e-mail: b.hicks@waikato.ac.nz

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Abstract

The Kaituna River on New Zealand's east coast is about 50 km long and drains lakes Rotorua and Rotoiti. An extensive flood control scheme, including stop-banks and gates, prevents flow of water from the lower river main channel to the original floodplain. In addition, a new, shortened channel (the Kaituna Cut) diverts the river directly to the sea instead of flowing through its original course into the Maketu Estuary. Minnow-trapping of inanga, common smelt, and bullies in 50 year-old ponds, recently constructed ponds, and riverine sites showed that new ponds were colonised by inanga within three months of construction. New ponds had higher catch rates than old ponds, and both new and old ponds had higher catch rates than the river, where no inanga were caught. Extrapolations from trap catch rates (2-13 inanga per 100 m^2), suggest that old ponds held about 8-20 inanga per 100 m^2, while in new ponds there were 24-67 inanga per 100 m^2. Our study suggests that constructed ponds can provide suitable habitat for inanga from the Kaituna River to rear to adulthood, and shows the importance of off-river habitat for New Zealand's most important whitebait species.

Keywords: inanga – *Galaxias maculatus* – habitat restoration – artificial ponds.

Introduction

Inanga, *Galaxias maculatus* (Jenyns 1842) is a globally widespread freshwater fish that is native to New Zealand, south-eastern Australia, South America and the Falkland Islands (McDowall 1990). The species has been characterised as one of the world's most widespread freshwater fish (Waters & Burridge 1999). Their diadromous juvenile stage (whitebait) enters New Zealand rivers principally in spring (September to November). Whitebait runs in New Zealand have declined in the last 40 years, and inanga comprise most of the run in many rivers (McDowall 1990). A combination of wetland drainage and flood control schemes have isolated inanga from their lowland rearing habitats, and are likely to have played some part in their decline.

The Kaituna River on the east coast of New Zealand is about 50 km long and drains lakes Rotorua and Rotoiti. It has been subjected to an extensive flood control scheme that involves stop-banks and gates to prevent flow of water from the main river channel to the original floodplain. In addition, the entrance of the river was diverted from its original course into the Maketu Estuary directly to the sea via a new, shortened channel at Te Tumu known as the Kaituna Cut (Figure 1). Little floodplain remains within the stop banks of the lower Kaituna River, and various flood control measures have resulted in 67 km of stop-bank, 88 km of canals and drains, seven pump stations and five flood gate structures (Goodhue 2007). Since settlement in 1880, extensive wetlands such as the Kaituna Swamp, the Waihi Swamp, and the Kaawa Swamp

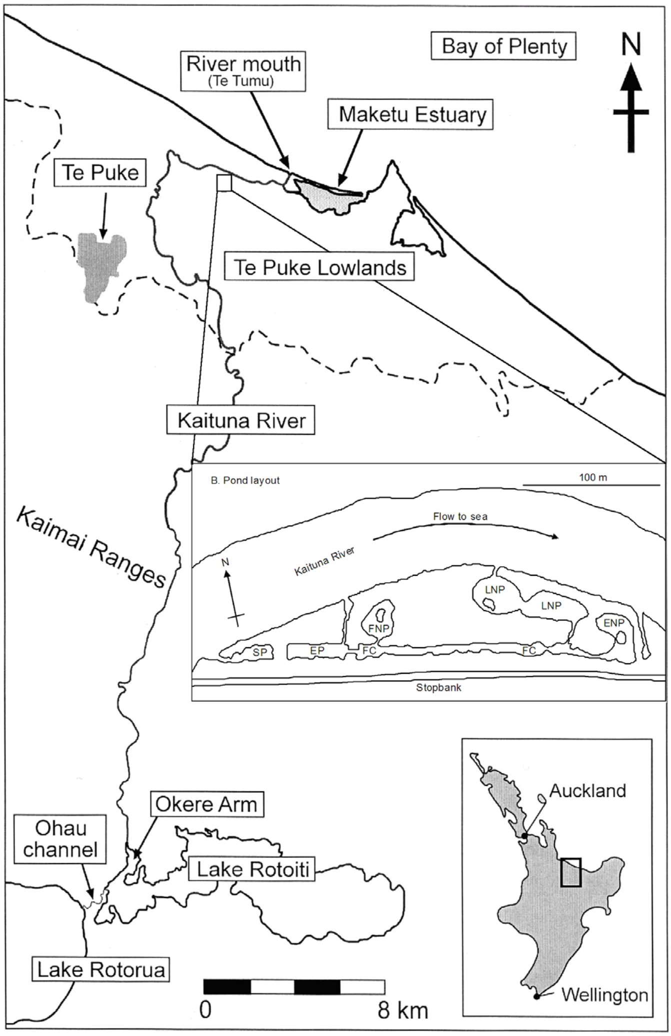

Figure 1. Location of the Kaituna River and study ponds in the North Island, New Zealand. Source: Goodhue (2007).

have been reduced to 248 ha, or less than 1 % of the original wetland (Ministry for the Environment 1997). The Kaituna River catchment covers 124,000 ha, with 48 % of this below the Lake Rotoiti outlet at Okere Falls. After falling 260 m through a steep narrow gorge, the lower river watershed of the Te Puke Lowlands includes the Mangorewa River, Waiari and Ohineangaanga Streams and Raparahoe and Kopuroa canals. Mean annual discharge of the Kaituna River at the sea is 49 $m^3 s^{-1}$.

In 1990, spawning grounds for the most common whitebait species, inanga (*Galaxias maculatus*), were identified on the lower Kaituna River. Generally, inanga are known to spawn within 1 km of the upstream end of the saltwater wedge (Mitchell 1990). In the Kaituna River, inanga have been observed spawning on both banks about 2 km upstream from the sea in and around the location of the old ponds (the Borrow Pits) in 1988, 1989, and 1990 (Mitchell 1990). Rearing inanga require low water velocities, avoiding velocities > 0.2 $m s^{-1}$, but have broad requirements for substrate and water depth > 0.25 m (Lamouroux & Jowett 2005). Feeding velocities are < 0.1 $m s^{-1}$ (Jowett 2002). Overhanging vegetation and other forms of cover further enhance inanga habitat (Richardson & Taylor 2002). Density dependent mechanisms appear to be more important than recruitment for determining inanga abundance in their study stream (Jowett & Richardson 2003).

Constructed ponds have been a focus of recent inanga habitat restoration, e.g., in the Te Wae Wae Lagoon area, South Island (Smith 2004), and on the Waiau River floodplain (Paterson & Goldsmith 2002). Traps have been used to evaluate the success of habitat restoration, and opinions have varied on the dependence of catch rate on various types of bait (e.g., Millar 2001, McDonald 2007). Few evaluations of the effect of baiting have been carried out.

The objectives of this study were to evaluate the influence of bait on inanga catch rates, to excavate new ponds next to existing ponds on a small apron of floodplain, to compare inanga catch rates in ponds and riverine sites, and to compare recruitment of inanga to newly constructed and older ponds as the migration and rearing season progressed (October to February).

Table 1. Water depths at high and low tides and approximate pond dimensions. Pond areas exclude the areas occupied by islands (30% of FNP, 25% of ENP, and 10% of LNP).

Site name	Site type	Code	*N* traps	Depth (m)		Pond dimensions		
				High tide	Low tide	Width (m)	Length (m)	Area (m^2)
River site	River	RS	10	1.5 - 2.2	0.4			
Estuary pond	Old pond	EP	0	1.1 - 1.8	0	11	44	490
Small pond	Old pond	SP	5	1.3 - 2.0	0.2	11	29	250
Feeder channel	Old pond	FC	15	1.3 - 2.0	0.2	11	167	1830
First new pond	New pond	FNP	6	1.7 - 2.4	0.6	22	29	360
East new pond	New pond	ENP	6	1.6 - 2.3	0.5	27	36	560
Long new pond	New pond	LNP	8	1.6 - 2.3	0.5	22	84	1330
Total			50					

Table 2. The influence of different baits on catch rates of inanga, common smelt, and bullies in artificial ponds in the lower Kaituna River floodplain between 29 June and 15 July 2007.

Bait	*N traps*	Inanga		Common smelt		Bullies	
		Mean	SE	Mean	SE	Mean	SE
Cheese	16	7.56	3.30	1.31	0.68	0.38	0.20
None	16	2.81	1.26	0.38	0.20	0.63	0.24
Cat biscuits	16	1.56	0.77	0.06	0.06	0.63	0.24
Vegemite	16	1.25	0.59	0.13	0.09	0.88	0.34

Methods

Study site

Before excavation of the new ponds, inanga spawning habitat was identified in the outflows of ponds known locally as the Borrow Pits, located on the true right of the Kaituna River (NZ map grid 2809675E, 6377740N, latitude 37.75175°S, longitude 176.39910°E; Figure 1). These ponds were created by the excavation of material to form the flood protection stop-bank in the mid 1950s. The area of the Borrow Pits is contained in a loop of riverbank on the river side of the flood protection stop-bank. No spawning was observed at the Borrow Pits in the autumns of 2000 and 2001, but in autumn 2002, pre- and post-spawning fish were trapped (Young & Ellery 2002).

The old ponds are relatively long and narrow (Figure 1). Estuary Pond (EP) and the Feeder Channel (FC) pond run parallel to the stop-bank, and water in FC is fed only through EP through a culvert. The Small Pond (SP) has its own connection to the river. EP completely dewaters at low tide, but FC and SP retain 0.1-0.2 m of water depth at most low tides (Table 1). FC had dense growth of a mixture of submerged and emergent aquatic macrophytes, including the oxygen weed *Lagarosiphon major*, parrot's feather *Myriophyllum aquaticum*, willow herb *Polygonum* sp., and reed sweetgrass *Glyceria maxima*.

Between 2003 and 2006, the Maketu Taiapure fenced off the floodplain surrounding the ponds from grazing animals, cleared gorse (*Ulex europaeus*), and planted some native vegetation. Three new ponds (First new pond, FNP; East new pond, ENP; and Long new pond, LNP) were constructed between 12 and 14 June 2007, and the culvert between EP and FC was removed (Figure 1). This isolated the area to be excavated from the river, giving the lowest possible water level for the period of the work and containing sediment produced by excavation within the Borrow Pits area. The pond areas in Table 1 exclude the areas occupied by islands (30% of FNP, 25% of ENP, and 10% of LNP). More detail on pond construction with photographs is provided in Ellery (2008).

Bait comparison trial

A trial was set up in SP at the upriver end of the Borrow Pits using 6 mm mesh Gee minnow traps. SP was not affected by the excavations. Eight traps were set per day for 30-60 minutes from 29 June to 15 July 2007 in the afternoon between 1230 and 1730 h. Because trapping started in mid-winter, when inanga appeared to become less active, feeding only briefly at dusk, most of this trapping encompassed twilight. On each of eight

Table 3. Total catch in different habitats on five trapping occasions in the Kaituna River and floodplain ponds from 30 October 2007 to 13 February 2008.

Site type	*N* traps	Total catch (*N* fish)			
		Inanga	Common smelt	Common bullies	Eels
New ponds	100	532	331	369	69
Old ponds	100	299	32	157	58
River	50	0	31	540	16
Total	250	831	394	1066	143

trapping occasions, two traps were set with each bait type: cheese, cat biscuits, yeast extract, or no bait as a control. Baits were applied as a 2-3 mm thick slice of a 40 by 80 mm block of Colby cheese crumbled into the trap, about 20 dry cat biscuits per trap, or a plastic sachet of Vegemite® yeast extract with the foil top removed. Over 8 trapping sessions, a total of 211 inanga, 29 common smelt (*Retropinna retropinna*) and 40 bullies. Both common bullies (*Gobiomorphus cotidianus*) and giant bullies (*G. gobioides*) were caught. Cheese as a bait caught more than 3 times as many inanga as any other bait type tested (Table 2), so all traps used in the habitat comparison were baited with cheese as described above.

Evaluation of artificial habitat use

To evaluate the use of artificial habitat, a combination of Gee minnow and collapsible traps were set in old artificial ponds, newly dug artificial ponds, and river sites within 100 m of the pond entrances. Traps were set overnight for 13-17 h on 30 October, 30 November, and 16 December 2007, and 16 January and 13 February 2008. During each trapping session, 10 traps were set at river sites, 20 traps were set in new ponds, and 20 traps were set in old ponds. In the river, traps were set in pairs, each pair about 75 m apart. Each pair was one Gee minnow trap and one collapsible trap set about 4-5 m apart. Of the 20 traps in the old

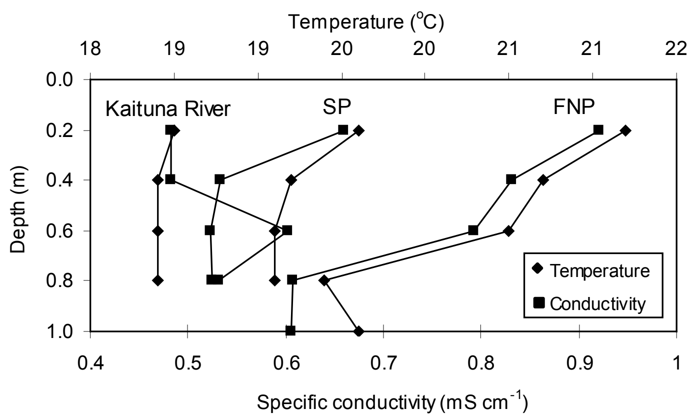

Figure 2. Distribution of electrical conductivity and temperature with depth in two artificially created floodplain ponds and in the Kaituna River on 17 Feb 2008. *N* = 1 for each measurement.

Table 4. Mean lengths of inanga caught in old and new artificial ponds in the lower Kaituna River floodplain between 30 Oct 2007 and 13 Feb 2008. Analysis of variance (ANOVA) compares means for old ponds and new ponds for each sampling date.

Date	Old pond			New pond			ANOVA		
	N	Mean	SE	*N*	Mean	SE	F	df	P
30 Oct 07	2	62.0	1.0	6	85.7	7.6	2.878	1,6	0.141
1 Dec 07	40	76.3	3.3	17	73.2	4.7	0.258	1,55	0.614
16 Dec 07	37	78.1	2.8	71	68.3	2.0	8.450	1,106	0.004
16 Jan 08	21	78.2	3.7	86	76.3	1.9	0.204	1,105	0.653
13 Feb 08	43	90.8	2.7	41	76.1	2.7	14.905	1,82	<0.001

ponds, SP had five, and the long, narrow FC had 15. In the new ponds, FNP had six, ENP had six, and LNP had eight. All traps were baited with Colby cheese.

The circular entrance rings of all collapsible traps were flattened to an oval of about 20 mm x 70 mm to minimise the entry of bigger common and giant bullies and eels (*Anguilla australis* and *A. dieffenbachii*). However, some predation of smaller fish in the traps was observed, so all fish in the traps, alive, dead, partial but identifiable, were counted as trapped. The trapping on 30 October 2007 was a morning set (0700-1400 h, mean set time 7 h). After that, all trap sessions were overnight (set 1700-2050 h, hauled 0800-1300 h the next day, mean set time 15 h). Traps were set on nights when there was a low tide evening and morning, and left to fish overnight, across the high tide. This ensured that the traps were set in water at low tide and therefore always submerged. All fish caught in traps were counted. Up to ten inanga from each trap were measured to fork length. Before measuring, inanga were partially anaesthetised by immersion in melted ice water. Recovery was almost instantaneous when fish were returned to ambient water temperatures.

To investigate to extent of tidal flushing and its influence on salinity in the ponds compared to the adjacent river, electrical conductivity and was temperature profiles were measured once on 17 Feb 2008 in two ponds and the river with a YSI EC300 conductivity meter.

Results

Halocline

Despite their shallowness (maximum depth 1.9 m), the pond FNP and SP exhibited a marked haloclines, with warmer, saltier water on the surface than on the bottom (Figure 2). In contrast, the Kaituna River where the traps were set (RS) was isothermal with a higher salinity close to the bottom than at the surface. This probably reflects a tidal wedge penetrating under the less dense freshwater.

Evaluation of artificial habitat use

The five trapping sessions in the artificially created ponds caught a total of 831 inanga, 394 smelt, 1,066 bullies and 143 eels. No inanga were caught in the river. More fish were caught in new ponds than in old ponds (Table 3). Low numbers of inanga were caught on 30 October 2007, but numbers increased on 30 November and thereafter (Figure 3A). In November, inanga catches were greater in pond habitats than in the river (Kruskal-Wallis

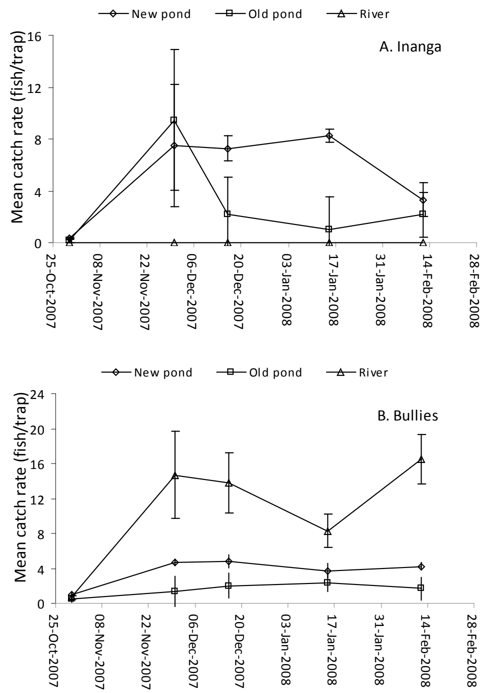

Figure 3. Mean catch rates (± SE) of inanga and a combination of common and giant bullies in old and new artificial ponds on the lower Kaituna River floodplain between 30 October 2007 and 13 February 2008.

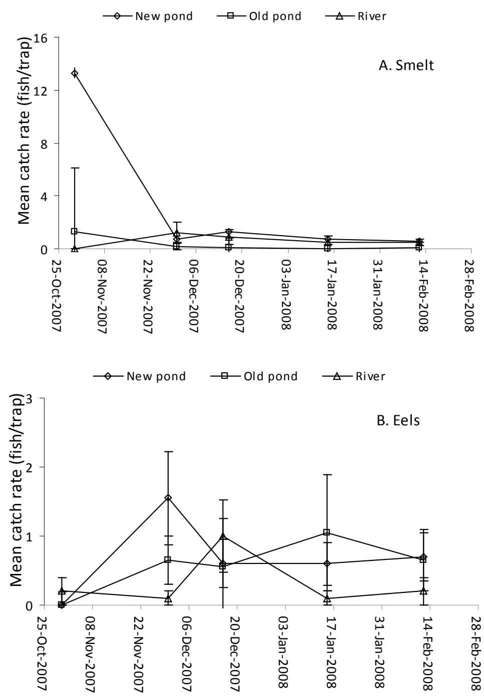

Figure 4. Mean catch rates (± SE) of common smelt and eels in old and new artificial ponds on the lower Kaituna River floodplain between 30 October 2007 and 13 February 2008.

P = 0.013). After October, bully catches were much greater in river than in the ponds (Figure 3B; Kruskal-Wallis $P <$ 0.001). From estimated pond areas (240-1,410 m^2) and the number of inanga trapped, we can estimate the minimum fish density. Mean catch rates of 2 fish/trap in old ponds and 8 fish/trap in new ponds suggest that densities could not have been less than 2-4 inanga per 100 m^2 in old ponds and 5-13 inanga per 100 m^2 in new ponds. Given the relatively few traps that were put in each pond (5-15), it is highly likely that actual densities could have been greater.

After initial large catches of common smelt in the new ponds in October, catches were low in both pond types and in the river for the remainder of the study (Figure 4A). Catches of eels (primarily shortfin; *Anguilla australis*) were always low (Figure 4B), probably because the small size of the trap entrances restricted entry.

Length analysis

From December 2007 to February 2008, inanga were larger in the old ponds than in the new ponds (Figure 5). These differences were significant only on 16 December 2007 and 13 February 2008 (Table 4). Differences in sizes were most likely caused by inanga moving upstream into the first pond inlets that they find, especially LNP, the most downstream pond entry. The smaller mean size in new ponds late in the season (Feb 2008) was probably caused by a school of inanga entering the new ponds but not the old ponds.

Discussion

Inanga in New Zealand commonly occupy lowland streams (Jowett 2002; Richardson & Taylor 2002), but in the lower Kaituna River flood protection structures have restricted access of juvenile inanga to habitats inland of stop-banks. This has increased the importance of the limited floodplain habitats within the stop-banks of the lower Kaituna River for rearing and spawning inanga. In view of the rapid occupancy of newly constructed ponds by inanga (within 3 months after construction), our results suggest that inanga in the Kaituna River will readily use artificially created ponds, and their continued occupancy in the ponds shows that they can provide suitable habitat for the rearing to adulthood.

We can extrapolate from trap catch rates on the basis that Gee minnow traps have been found to catch ~ 20 % of fish present (McDonald 2007). Using this 20% figure, we estimate that in old

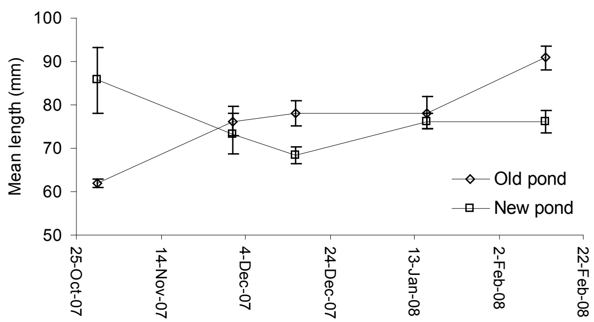

Figure 5. Mean lengths (± SE) of inanga caught in old and new artificial ponds on the lower Kaituna River floodplain between 30 October 2007 and 13 February 2008.

ponds, there were ~ 8-20 inanga per 100 m^2, while in new ponds there were 24-67 inanga per 100 m^2. This exceeds the densities estimated in ponds in the Te Wae Wae inanga restoration, in which spotlighting revealed up to 0.28 inanga per 100 m^2 (Paterson & Goldsmith 2002). In Paterson & Goldsmith's study, inanga were found in riverine sites at densities of 0.0002-0.807 inanga per 100 m^2. In our study, no inanga were caught in the Kaituna River, suggesting that riverine habitat in the main river was less suitable than constructed ponds, which further shows the importance of off-river habitat in the Kaituna River for New Zealand's most important whitebait species. Low water velocities are preferred by inanga (Lamaroux & Jowett 2005), and this might be the limiting factor in the Kaituna River. That the minnow traps in the river caught bullies and smelt successfully shows that the absence of inanga is a reliable result.

Pond construction on lowland floodplains is a viable way of restoring inanga populations. Salinity and temperature profiles show that brackish water is flushed into the ponds by the tides, while a layer of water with lower temperature and salinity remains at the bottom of the ponds. Our project shows that inanga, and associated species such as smelt and eels, will readily occupy constructed pond habitat that is connected to the river, even newly constructed ponds. The question that remains how much habitat restoration will be required to enhance the whitebait run significantly.

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