than water, which makes the oxygen easier to extract. Clearly, leaving the water is an extreme measure that could place fish at risk of predation or desiccation in their natural environment. However, it may be an effective adaptation for short-term pulses of hypoxia, especially where cover is available.

In the surfacing behaviour seen in these experiments fish could be either breaking the surface to gulp air, or moving up to breathe in the surface water where oxygen levels are higher than those in the rest of the water column. Although both behaviours are energetically expensive because fish must maintain position at the surface, aquatic surface respiration allows fish to survive during periods of low oxygen.

Torrentfish were the only species that did not respond to low levels of oxygen by surfacing. Although most remained sedentary on the bottom at 1 ppm, the rate of gill ventilation increased noticeably. Torrentfish generally inhabit shallow, fast-flowing water that is well oxygenated. It seems that they have not needed to develop strategies of surfacing in order to reach more highly oxygenated water. Their apparent tolerance of low oxygen environments is therefore surprising.

Future research

To function within their environments fish must be able to grow, survive, feed and reproduce. This study has concentrated on the survival of juveniles of some common native fish species during exposure to a constant level of dissolved oxygen. To set dissolved oxygen criteria for New Zealand's freshwater fish species, more species need to be tested and similar tests carried out with other life stages, especially eggs and larvae, which are known to be more sensitive than later stages (USEPA 1986). The effects of fluctuating dissolved oxygen levels (to mimic diurnal swings) should also be considered.

The sublethal effects of hypoxia, which could include reduced development and growth rates and avoidance behaviour that may result in fish leaving affected habitats, also need to be examined. It is important to recognise that levels of oxygen that have no apparent effect may become lethal when coupled with toxicants or other compounding factors. ■

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Further reading

Alabaster, J.S. & Lloyd, R. (1980). *Water Quality Criteria for Freshwater Fish.* Butterworths & Co., London. 297p.

USEPA (1986). Ambient Water Quality Criteria for Dissolved Oxygen. United States Environmental Protection Agency. Washington, DC.

NATIVE FRESHWATER FISH

Who ordered the *Austrosimulium* on *Egeria*?

Jody Richardson

Dave West

Glenys Croker

What's the favourite food of native fish? For inanga and smelt, two-winged flies seem to top the bill, at least in one North Island stream.

IT'S TRUE, *Austrosimulium* on *Egeria*, spiders surrounded by *Hygraula* coulis, or crunchy *Potamopyrgus* smothered in *Paracalliope* gravy ... these tasty treats and more were all on the menu for native fish at the Whakapipi Stream cafe. But who ate what, when, and which fish had the biggest helping?

Over the past year, Whakapipi Stream has been the focus of a multi-disiplinary NIWA study investigating interactions between water chemistry, aquatic plants, invertebrates and fish in an impacted lowland environment. In this article, we present a preliminary analysis of our summer diet studies on common smelt and inanga, and examine how the diets of these fish are influenced by the invertebrate community in this tributary of the Waikato River.

Study site

Whakapipi Stream drains agricultural land south of Pukekohe. A soft, muddy substrate, a lack of bankside shade, dense summer growths of aquatic plants such as *Egeria* (oxygen weed), and deep, slow-flowing, discoloured water characterise the stream.

The fish community inhabiting Whakapipi Stream is dense and varied. In summer, fish numbers ranged from over 250 to almost 600 fish per 100 m^2, with up to nine species being recorded. This easily exceeds the national average of 28 fish per 100 m^2 and five species per site, and is considered high even for low-elevation sites (see *Water & Atmosphere 4*(3):17–19). The community was dominated by inanga, shortfin eel and common bully in summer, with many migrating juvenile fish being caught early in the season. In winter, common bully predominated, while inanga virtually disappeared. Common smelt were present all year in relatively low numbers.

Methods

Inanga and common smelt for diet analysis were caught by seine netting, anaesthetised with benzocaine and preserved in 10% formalin. Samples of other fish species were also collected and preserved, but have not yet been analysed. After dissecting out the stomach, the degree of fullness on a scale of 0 (empty) to 100 (completely full) was estimated. The stomach contents were then examined with a dissecting microscope and the invertebrates identified in as much detail as possible. For each fish, the number of animals assigned to each taxonomic group was counted; these were combined into various categories and summed for the whole sample to determine the predominant food items. The length, weight and sex of each fish were also recorded.

Invertebrates were collected in December 1996 and March 1997 from three habitats within the stream:

- submerged woody debris was scrubbed;
- aquatic weed samples were washed;
- the substrate in a single, shallow run was sampled using a Surber sampler – a net apparatus commonly used for collecting invertebrates in stream ecology studies.

Samples collected from each habitat type were pooled and the animals were identified.

The composition of the invertebrate community in each habitat type was compared with the diet of the fish. We wanted to see whether:

- fish were feeding predominantly in one habitat type;
- fish simply ate items in the same proportion as their overall occurrence;
- fish were selecting some items in preference to others.

The diets of inanga and smelt were also compared to determine whether partitioning of the food resource took place.

Results

The percentage of fish which had empty stomachs varied, as did the mean degree of fullness and average number of food items per fish stomach (Table 1), but there was no clear pattern in these variables for either species. Overall there was a low percentage of empty stomachs and a relatively high degree of fullness. Samples were usually collected in the late afternoon and often contained freshly eaten items, indicating that smelt and inanga feed during the day.

Both smelt and inanga preyed on a variety of food items, although the larvae and pupae of Diptera (two-winged flies) generally comprised the majority of the summer diet (see graph A). The Diptera larvae and pupae were mostly chironomids (Orthocladiinae with a few *Maoridiamesa* sp.) or *Austrosimulium* sp. (sand flies). Smelt tended to eat more terrestrial items (mainly adult Diptera) than inanga, while inanga ate a wider variety of aquatic items classified as "other", including *Oxyethira albiceps* (purse caddis), *Latia neritoides* (freshwater limpets) and *Hygraula nitens* (a moth larvae).

The diet of both species varied over time but more so for inanga than for smelt. For example, inanga preyed heavily on *Oxyethira albiceps* in March 1996 (59%), ate mostly Diptera larvae in December 1996 (83%), but added limpets in March 1997 (29%). Diptera larvae and pupae consistently dominated the diet of smelt in March and December 1996, but in

Sampling in Whakapipi Stream.

Table 1. Diet data for smelt and inanga from three summer samples. Mean degree of fullness and the average number of food items per fish were calculated with the empty stomachs excluded.

Date	Species	N	Percent empty	Mean degree of fullness	Average number of food items per fish
3/96	smelt	21	5	45.3	13.4
	inanga	20	0	91.5	18.5
12/96	smelt	24	8	76.3	8.0
	inanga	31	23	67.5	5.3
3/97	smelt	9	0	65.6	6.2
	inanga	27	26	73.0	8.7

Table 2. Invertebrate numbers from three habitat types in Whakapipi Stream in December and March.

	December 1996	March 1997
Number on weeds	2624	6251
Number on wood	32	56
Number on substrate	3290	13689
Total	5946	19996

1997 terrestrial items (32%) and *Oxyethira albiceps* (21%) were also important.

On any given sampling occasion, there was a clear indication that smelt and inanga were partitioning the food resource with the dominant item for either species always being different from the dominant item for the other species. This trend was least clear in March 1997, when both species ate the whole range of food items in almost equal proportions.

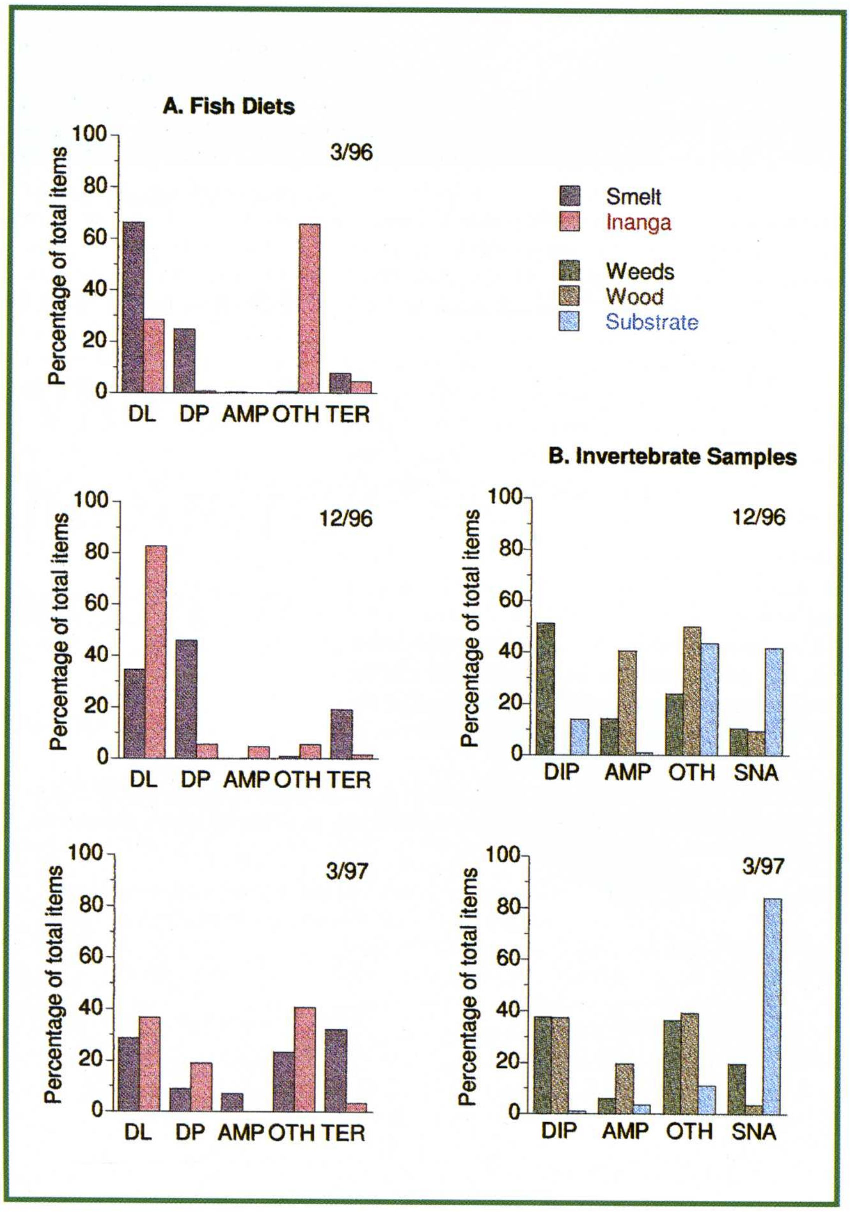
Comparing the fish diets with the invertebrate samples gave some insight into where the fish were feeding and whether fish were actively selecting certain items within any habitat type. Suprisingly, neither the percentage of fish with empty stomachs, the degree of fullness, nor the average number of food items per fish (Table 1) changed much between December and March although total invertebrate numbers increased over three-fold (Table 2).

The diet of both species appeared to reflect most closely the composition of the community which lived on aquatic weeds, where there was a high percentage of Diptera (see graph B). In March, the weed community was quite similar to the wood community. However, an examination of the species grouped together as "other" on weeds showed that 26% of this group was composed of *Latia neritoides*, which is close to the 29% occurrence of this species in inanga diets at the same time. Clearly, both smelt and inanga avoided feeding on the substrate, which is in keeping with their pelagic life style (i.e., inhabiting the middle and upper layers of water).

Diptera were usually actively selected, but smelt and inanga appeared to avoid snails (e.g., *Potamopyrgus*), although some were always present on weeds. When the percentage of Diptera decreased in March, smelt and inanga increased their feeding on other items such as amphipods (freshwater crustaceans, including *Paracalliope*), *Oxyethira albiceps*, limpets and terrestrial animals, the latter of which presumably occurred in the drift. Shrimp (*Paratya curvirostris*) are an abundant animal in Whakapipi Stream and, having a pelagic habit, are available to smelt and inanga. However, neither species ate shrimp, perhaps because they are relatively large, difficult to capture and have a spiny exoskeleton. Despite their similar life styles and preference for feeding on weeds, smelt and inanga partition the food resource and actively select or avoid certain items. When Diptera decreased, so did their occurrence in the diets, thus indicating that prey availability determines food preferences to some degree.

So, who did order the *Austrosimulium* on *Egeria?* Chances are it was the inanga.

... and as for the crunchy *Potamopyrgus* smothered in *Paracalliope* gravy, we think that probably belongs to the table with the common bullies. Further investigation may confirm our suspicions. ■



The diet of smelt and inanga (A) in Whakapipi Stream compared to the composition of the invertebrate community on weeds, wood and the substrate (B).
DL= Diptera larvae; DP = Diptera pupae; AMP = amphipod; OTH = other aquatic items; TER = terrestrial items; DIP = Diptera larvae and pupae; SNA = snails.

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