NATIVE FRESHWATER FISH

Native fish survival during exposure to low levels of dissolved oxygen

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Preliminary experiments in progress at NIWA have revealed that juveniles of some of our native fish species are remarkably tolerant of low levels of dissolved oxygen.

MANY NATIVE FISH SPECIES in New Zealand undertake extensive migrations to and from the sea and, for these species, lowland streams are important migratory pathways and habitat. However, these streams often lack shade and have high nutrient loads, which can result in excessive plant growth and large daily oscillations in temperature, pH and dissolved oxygen during summer. These conditions are potentially lethal to fish.

This article outlines some of the responses observed in experiments which are examining the toxicity of low levels of oxygen to fish.

The work forms part of a larger NIWA study that is assessing plant production in lowland streams and its role in the ecology of lowland systems.

Fish respiration

Most fish acquire oxygen by pumping water across the gills. Oxygen is absorbed across the fine membranes of gill filaments into the bloodstream and is then distributed to the tissues. A reduction in external dissolved oxygen levels can result in low oxygen availability to tissues (called "hypoxia") and this may force fish to make physiological and behavioural changes to compensate. These changes include:

- leaving the water completely to respire in air ("aerial respiration");
- gulping air from above the water surface;
- surface respiration in which the fish skim the top few millimetres of water that have an appreciably higher oxygen content, even in severely deoxygenated water.
- adjustments in activity:
  - either reduced activity as energy is focused on increasing the volume of water passed over the gills to maximise oxygen extraction;
  - or increased activity that may allow the fish to escape from the low-oxygen environment.

These mechanisms may be adequate for short-term exposure to low oxygen levels, but as severity and duration increase, the costs in terms of energy expenditure and vulnerability to predation also increase.

In some species, oxygen may be absorbed across the skin to supplement oxygen absorbed at the gills. Generally, the skin of such species is relatively thin and has a good blood supply. Eels and galaxiids (whitebait) are scaleless, so are well adapted to this type of breathing.

Since most fish cannot regulate their body temperature, they are controlled by the thermal conditions of the waters in which they live. Warmer temperatures speed up fish metabolism which leads to increased oxygen demand. At higher temperatures oxygen is less soluble in water, compounding the problem of fish survival in low oxygen environments. A combination of high temperatures and low oxygen concentrations can result in fish kills.

The ability of fish to survive hypoxic conditions is therefore a function of the level and constancy of the supply of dissolved oxygen along with other environmental factors. Fish species, condition and life stage also play a part.

Experiments

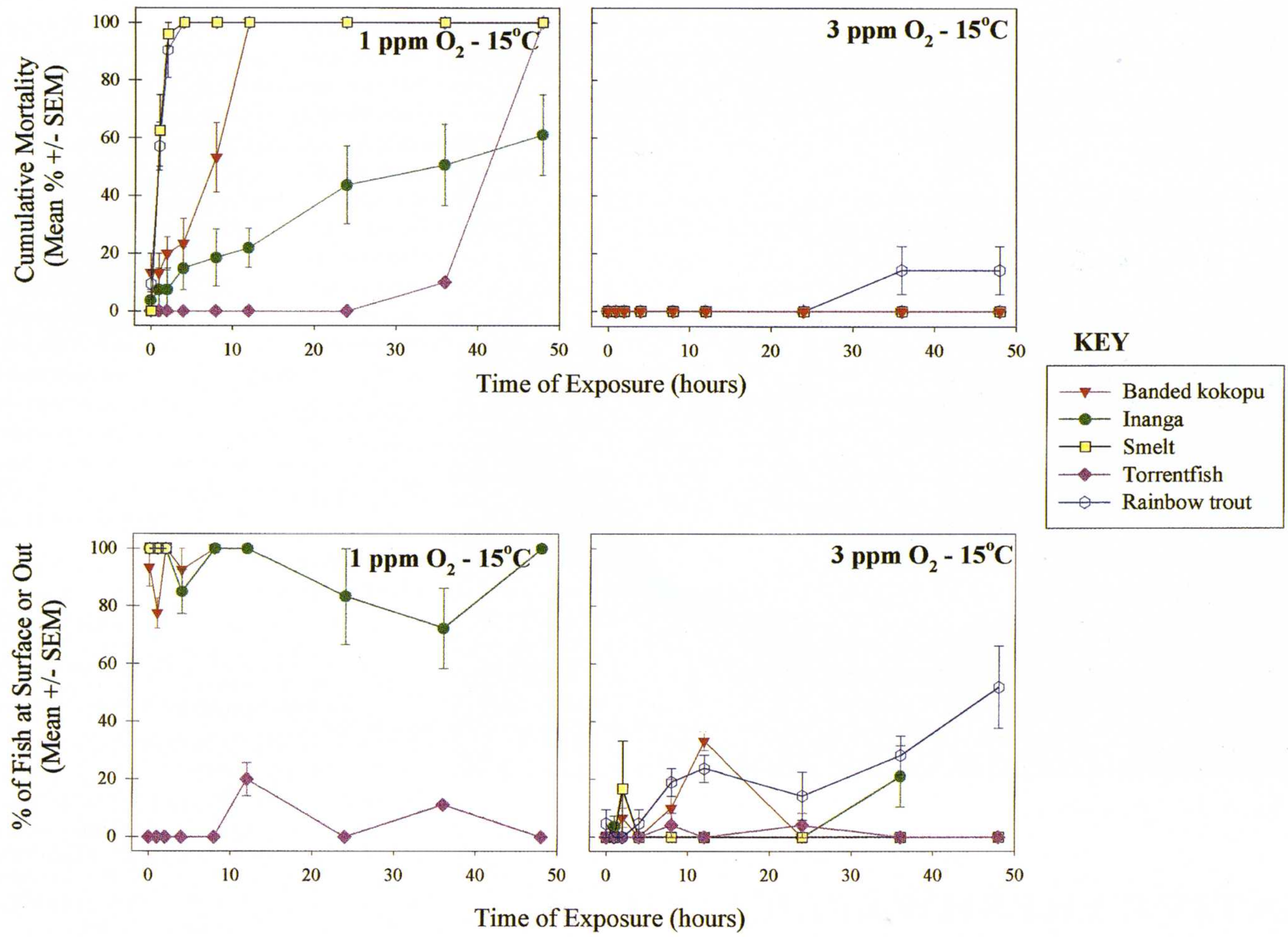
The survival of juvenile smelt, torrentfish, banded kokopu, inanga and rainbow trout was determined in oxygen concentrations of 1, 3 and 5 ppm, and temperatures of 15 and 20°C (see table, below left). The experiments were conducted in a 40-litre plastic tank containing 30 litres of water. Diffusers were positioned along both sides of the tank and fed with a supply of nitrogen and air. A small submersible pump was used to ensure mixing and to maintain water flow over an oxygen probe that constantly recorded dissolved oxygen levels.

Three bins with mesh sides, each containing between seven and ten fish, were placed in the apparatus to allow the fish to acclimatise before each experiment began. During this time oxygen saturation was maintained. After 12 hours, nitrogen was introduced, and oxygen levels within the tank fell to the desired levels over 2–3 hours, and were held there for 48 hours.

Fish mortalities and position within the water column were recorded after 1, 2, 4, 8, 12, 24, 36 and 48 hours of exposure to the selected oxygen level.

Fish species and oxygen concentrations included in the study so far

Species	Mean length (mm)	Experiments at 15°C			Experiments at 20°C		
		1 ppm	3 ppm	5 ppm	1 ppm	3 ppm	5 ppm
Smelt	56.1	x	x	x	x	x	
Torrentfish	41.0	x	x				
Banded kokopu	40.7	x	x	x	x	x	
Inanga	46.8	x	x	x	x	x	x
Rainbow trout	49.1	x	x	x			



above, upper: *Mean cumulative mortality of different fish species with time of exposure.*

above, lower: *Percentage of live fish at or above the water surface in response to experimental oxygen levels.*

Toxicity

The upper graphs show that juvenile smelt were the most sensitive of the native fish tested, followed by banded kokopu and inanga. Juvenile smelt and rainbow trout showed similar responses at dissolved oxygen levels of 1 ppm at 15°C. This is of particular interest as salmonids (trout, salmon and char) are generally considered to be the most sensitive group of freshwater fish (Alabaster and Lloyd 1980).

Only juvenile rainbow trout succumbed to oxygen levels of 3 ppm at 15°C, and only after 24–36 hours of exposure. Survivors breathed at the surface more than they did earlier in the experiment (see above, lower right graph).

There was no marked effect of temperature between 15 and 20°C for the three species tested so far. As expected, levels of 1 ppm resulted in more inanga deaths over 48 hours at 20°C than at 15°C. Banded kokopu, however, took longer to succumb to oxygen levels of 1 ppm at 20°C than at 15°C. This may be attributable to their surfacing and escape behaviour.

Behaviour

Dissolved oxygen concentrations of 1 ppm caused most of the fish to move towards the surface within the first few hours of exposure, except for torrentfish (see above, lower graphs).

All banded kokopu either moved to the surface or left the water completely. Those that left the water climbed the walls of the containers beyond the water surface, and only returned to the water after being exposed for some time. This behaviour is common amongst galaxiids, many of which can survive for considerable periods in moist habitats out of water and are known to be exceptional climbers.

At 20°C, the airspace of the experimental apparatus is likely to have been more humid, enabling banded kokopu to remain out of the water for longer periods.

Above 3 ppm, no native fish were recorded at the surface for any significant amount of time.

Breathing air is considered to be less costly to fish than aquatic respiration: air contains more oxygen per volume, and is less dense and viscous 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. ■

Tracie Dean and Jody Richardson are based at NIWA in Hamilton.

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.