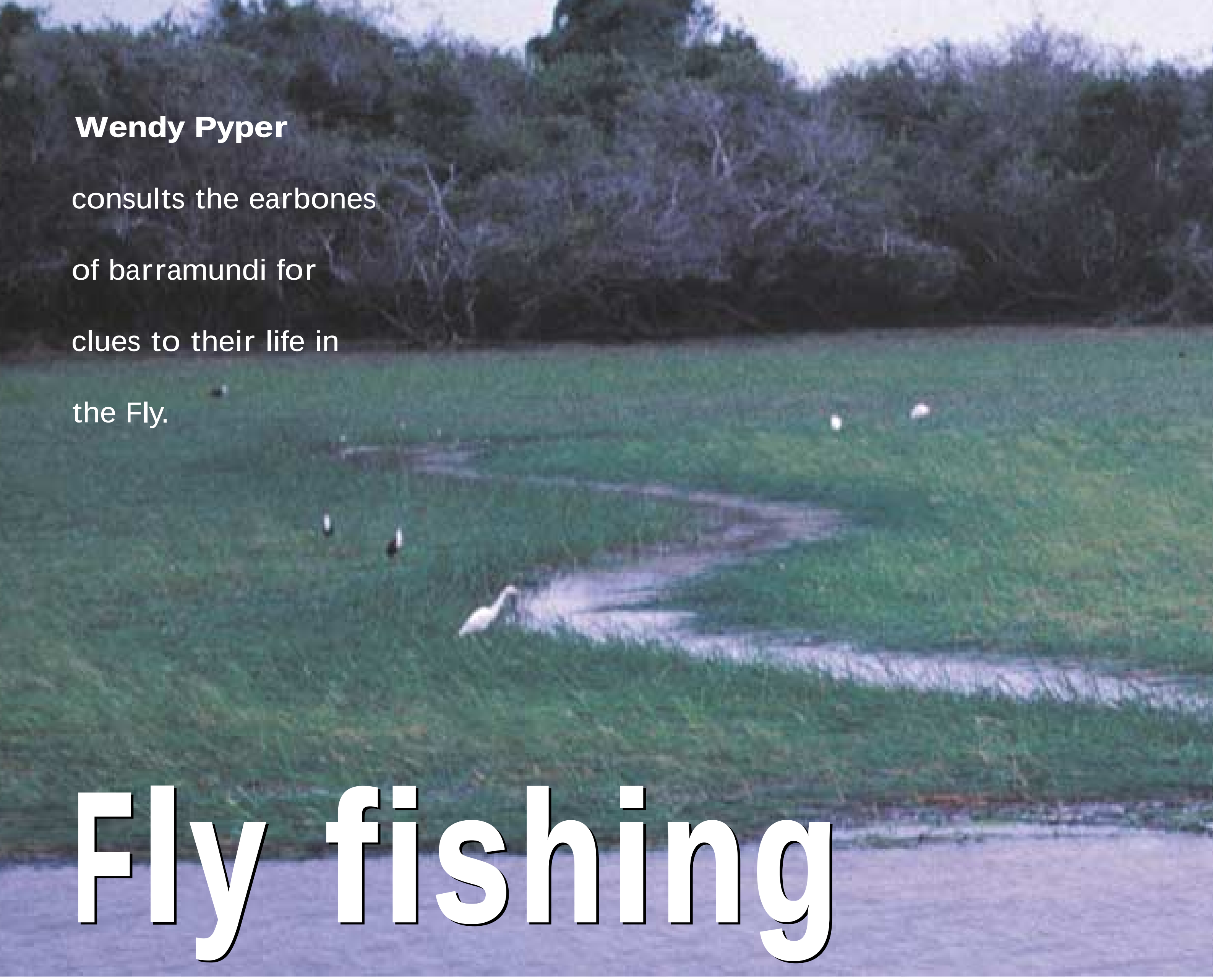


Wendy Pyper consults the earbones of barramundi for clues to their life in the Fly.

Fly fishing

On its way to the Gulf of Papua, the mighty Fly River traverses some 1400 km from its source in the Western Highlands of Papua New Guinea (PNG), through virgin rainforest, tropical swamp forest, open savanna and grasslands.

The river and its delta provide habitat for an abundance of waterbirds, frogs and fish. But the Fly and its largest tributary, the Ok Tedi River, are also dumping grounds for the by-products of the Ok Tedi gold and copper mine.

Since operations commenced in 1984, the mine has discharged up to 80 000 tonnes of waste rock and 120 000 tonnes of tailings, per day, directly into the Ok Tedi / Fly River system.

Because of the high rainfall and geological instability of the region, construction of a tailing dam has not been feasible. As a result, sediment build-up in the rivers has changed the way they flood and raised the height of the Ok Tedi River by up to four metres.

This has led to die-back of floodplain forest over large areas, due to the increased frequency and duration of floodplain inundation.

Scientific staff from the Environment Department of Ok Tedi Mining Ltd have been monitoring the hydrological, chemical and biological impacts of mining activities on the Fly River since 1983.

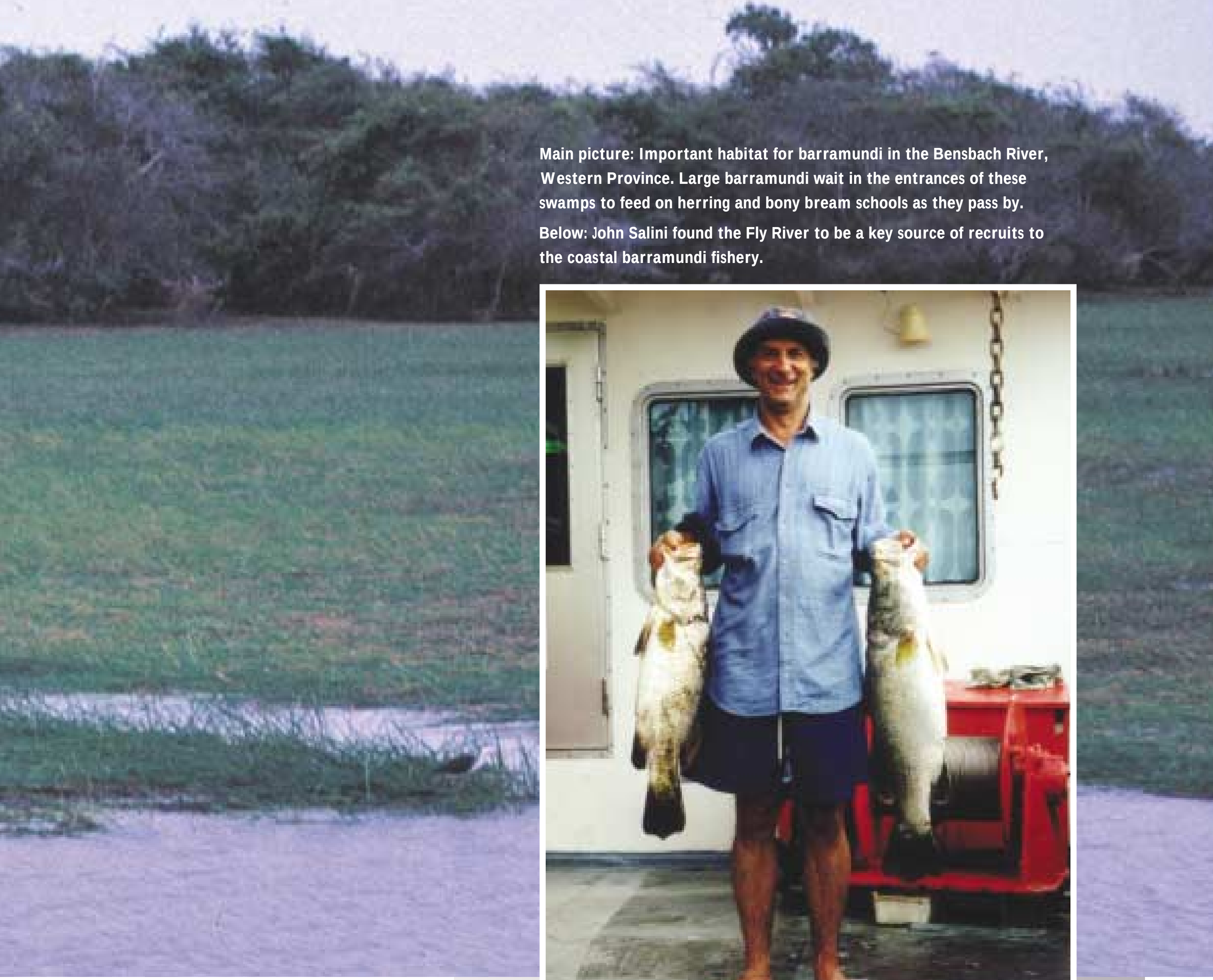
In the early 1990s the scientists recorded a dramatic decline in the number and abundance of freshwater fish species – including the economically important barramundi – in the Ok Tedi and upper and mid Fly. Barramundi are the most commercially-valuable fish species in Western Province and are especially important to villages along the middle Fly River which do not have direct access to markets for most of their garden produce.

To see if the mine was having an effect on barramundi behaviour, CSIRO Marine Research fisheries ecologist Dr David Milton looked at the 'otoliths' of barramundi collected at the junction of the Ok Tedi and Fly rivers.

Otoliths are small calcium carbonate structures within fishes' ear canals. When fish move through contaminated water, trace metals, such as copper and zinc, can replace the calcium in the otolith, providing a record of the fishes' movement or behaviour.

'I wanted to see if the otoliths would show whether the fish were moving into contaminated water or avoiding it,' Dr Milton says.

Using an 'inductively coupled plasma mass spectrometer' (ICPMS), Milton and his geochemist colleague, Dr Simon Chenery, from the British Geological Survey in the UK, looked for changes in concentrations of copper, lead and zinc –



Main picture: Important habitat for barramundi in the Bensbach River, Western Province. Large barramundi wait in the entrances of these swamps to feed on herring and bony bream schools as they pass by.

Below: John Salini found the Fly River to be a key source of recruits to the coastal barramundi fishery.

the main by-products of the Ok Tedi mine – in the otoliths. But their results were inconclusive.

'There appeared to be no clear relationship between the concentration of trace metals in the water and concentrations in the otoliths,' Milton says.

As there were conflicting views on the relationship between otoliths and trace metal concentrations in water, Milton set up a laboratory experiment to test the relationship.

To do this he placed barramundi in freshwater containing copper, lead or strontium. He also fed groups of barramundi diets enhanced with one of each of these metals. The absolute trace metal concentrations chosen were similar to the maximum recorded in the Fly River.

'We wanted to test the hypothesis that otolith concentrations of metals are related to environmental concentrations, and identify the major source of the metals in

Genetics link river and fishery

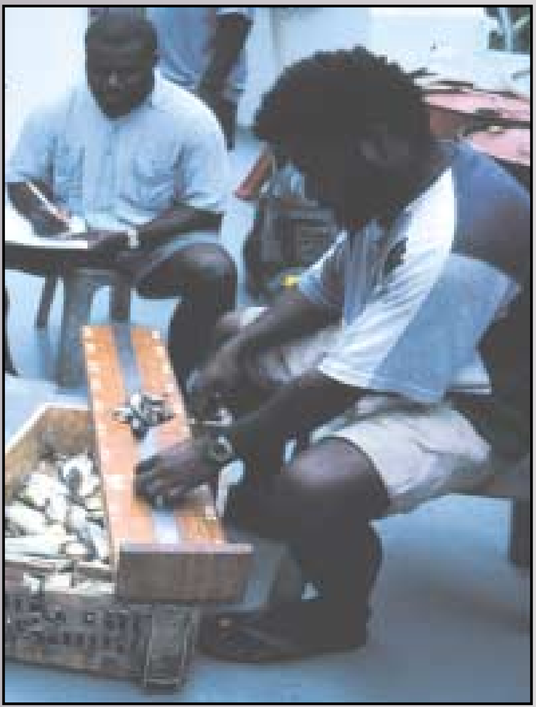
A GENETIC study of barramundi (*Lates calcarifer*) in Papua New Guinea has shown that the Fly River is an essential source of recruits to the adult population that breeds in coastal waters west of the river mouth.

Using mitochondrial DNA, CSIRO Marine Research fisheries ecologist John Salini looked at the genetic profiles of juvenile fish taken from the coast near the Fly River mouth, and tried to identify their origin as either West Papua (Irian Jaya), the eastern Gulf of Papua, or the mid-Fly.

He found that 50% of the fish appeared to have come from the mid-Fly and about 3% appeared to have come from West Papua. The remainder, however, could not be assigned to a particular area.

Salini says the results indicate there is a lot of mixing of barramundi populations along the southern coast of Papua New Guinea, but that the Fly River is the most important source of fish in the area.

He says provided coastal and inland fishing is properly managed, there should always be a supply of barramundi to repopulate coastal areas.



Left: The Environment Department of Ok Tedi Mining Ltd has been monitoring the impacts of mining activities on the Fly River since 1983.

Below: Copper is one of the main by-products of the Ok Tedi mine. The absence of elevated copper concentrations in fish taken from the confluence of the Ok Tedi and Fly rivers suggests that much of the copper is not bio-available, and therefore not toxic to fish.

Bottom: Barramundi are born male and take three to four years to reach maturity and breed. They become females at six or seven years of age. At this stage of their life they weigh about five kilograms and are the size most targeted by fishers.

otoliths that result from small changes in environmental concentrations,' Milton says. 'So we looked at the importance of water and diet as sources of copper, strontium and lead.'

After 22 days, Milton and Chenery examined the otoliths for daily changes in each of the trace metals added to the water. They found that barramundi kept in water containing copper, strontium or lead had significantly more of these metals in their otoliths, while fish fed diets containing these metals had no detectable increases in their otoliths.

Two control groups of fish transferred between freshwater and seawater also showed changes in the concentrations of naturally occurring lithium, strontium and barium in their otoliths. There were no changes in copper or lead concentrations however.

'Our results show that there is a relationship between water and otolith concentrations of the five metals we examined, but the relationship differs for each metal,' Milton says.

Milton says the inconsistencies between the results of experimental and field studies indicate that much more work needs to be done before scientists have a good understanding of all the mechanisms involved in otolith formation and trace metal incorporation.

However the absence of elevated copper concentrations in fish taken from the confluence of the Ok Tedi and Fly rivers suggests that much of the copper is not bio-available. Studies in other countries have shown that much of the copper in the rivers is complexed with dissolved organic matter and is not expected to be toxic to aquatic life.

Tracing fish movements

Milton and Chenery have also used otoliths to study the movement of barramundi in the Fly River and coastal breeding grounds of Papua New Guinea, in an attempt to understand why an important coastal barramundi fishery has declined.

'The coastal barramundi fishery relies on the annual spawning migration of fish from the Fly River to the coastal breeding ground,' Milton says. 'In the early 1990s the fishery collapsed. We thought the decline may have been due to overfishing, but we were still seeing plenty of fish in the river.'

The village of Bossett on the middle Fly has relied on barramundi as a major source of income in the past. Problems with declining catches and the operation of a freezer plant, however, caused the fishery in this community to close in 1996.

To explore this discrepancy, Milton collected fish from different riverine and coastal areas and examined their otoliths for the presence of strontium and barium.

'Strontium and barium are naturally occurring elements in water that come from dissolved rock in the headwaters,' Milton says.

'Strontium concentrations are about 50 times higher in seawater than in freshwater, while barium concentrations are two to three times higher in freshwater than in seawater. Both strontium and barium can replace calcium in the otolith, and so reflect the movement of fish between seawater and freshwater.'

Laboratory experiments have shown that fish kept in freshwater for 80 days, for example, experience a decline in the concentration of strontium in their otoliths. If the fish are then placed in seawater, the otoliths record an immediate increase in strontium.

A line of tiny holes were drilled in the surface of each otolith, from its inner core to outer edge. As each hole was made (using the ICPMS's laser), the material in the otolith atomised and the concentrations of elements were measured.

'Each hole is equivalent to about one month of growth, so we can measure the intervals and look at the uptake of each element as the fish grows,' Milton says.

The study showed that the majority of breeding barramundi caught in the coastal breeding grounds in the Gulf of Papua had remained in the coastal waters, rather than migrating up the Fly River. Most fish caught in the Fly River, in contrast, had migrated from coastal nurseries into the river, where they remained.

'It appears that fish caught around the coast have never migrated to freshwater, and fish caught in the Fly have migrated to the coast once, or not at all,' Milton says.

So why was this happening? Why were the barramundi that once supported a thriving migratory fishery, suddenly staying put?

An ACIAR-funded study has recently identified the most likely cause of the decline. When Milton looked at barramundi monitoring data collected by the Ok Tedi mine, he saw the drop in barramundi catches correlated with an El Niño drought period.

'Low catch rates in the mid-1990s appears to be due to consistently poor breeding success and migration in consecutive years,' Milton says.

'This may have been due to the El Niño in the late 1980s and early 1990s, which could have dried out the swampy coastal habitat essential for the survival of larval and juvenile barramundi.'

Milton says that with increased rainfall in recent years, breeding has been more successful. Populations of barramundi have since bounced back and strong migrations are evident.

More about barramundi

Milton DA Chenery SR (2001) Sources and uptake of trace metals in otoliths of juvenile barramundi (*Lates calcarifer*). *Journal of Experimental Marine Biology and Ecology* 264:47–65.

Milton DA Yarrao M Fry GC and Tenakanai C (submitted). The relative importance of environmental factors, mining and fishing on trends in the distribution and abundance of barramundi *Lates calcarifer* in the Fly River, Papua New Guinea.

Abstract: In the early 1990s, the Environment Department of Ok Tedi Mining Ltd recorded a dramatic decline in freshwater fish species – including the economically important barramundi – in the Ok Tedi and upper and mid Fly rivers. The otoliths, or earbones, of barramundi were examined to see if the Ok Tedi gold and copper mine was having an effect on barramundi behaviour. When fish move through contaminated water, trace metals such as copper and zinc, can replace the calcium in the otolith, providing a record of the fishes' movement or behaviour. The results were inconclusive, but subsequent laboratory studies suggested that much of the copper at the confluence of the Ok Tedi and Fly rivers is not bio-available, and probably not toxic to aquatic life. Otolith and genetic analysis has also been used to study migration of barramundi between the Fly River and coastal fisheries.

Keywords: barramundi, fish, population dynamics, otoliths, fish migration, trace metals, Ok Tedi Mine, PNG, Fly River, PNG.