Spectrum

Metals in the wilderness

Tasmania's south-west is famous for its wilderness, beautiful rivers and rugged coastline. But all is not quite as pristine as these images suggest.

The central west coast's Macquarie Harbour, and the lower part of the King River that drains into it, have higher than normal levels of heavy metals and petroleum-derived hydrocarbons, according to recent research by scientists at CSIRO and the University of Tasmania.

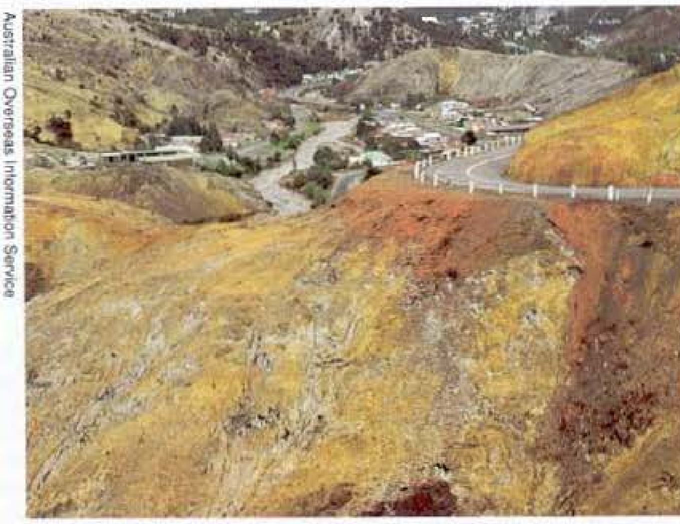
Dr Denis Mackey, Dr Ed Butler, Mr Harry Higgins and Dr Peter Nichols, of the CSIRO Division of Oceanography, in collaboration with Dr Peter Carpenter of the Department of Chemistry at the University, measured the concentrations of five heavy metals, as well as iron, iodine, hydrocarbons and other indicators of water quality, at sites in the Harbour and in both the Gordon and King Rivers. (The heavy metals measured were manganese, copper, cadmium, nickel and zinc.) The study was the first of its kind in that region, and provided baseline values for heavy metals and organic material.

Sampling for trace metals in the upper...

... and lower King River

Edward Butler

Australian Overseas Information Service



The denuded hills around Queenstown — the result of mining and smelting in the region.

The area also interested oceanographers because it offers a natural laboratory for the study of water-mixing and estuaries, with rivers draining into a large body of water that has only a small outlet to the sea (see the map on page 32). Many of the chemical processes that occur at the boundary between rivers and oceans are still poorly understood. Field studies taking into account several pollutants and their possible interactions in estuarine systems are lacking.

What sorts of problems does Macquarie Harbour face? To determine that, we need to recognise that heavy metals in water differ in their absolute toxicities, as do living things in their abilities to tolerate them. More importantly still, the toxicity of individual metals varies according to their chemical state. Moreover, various organic compounds in water — referred to as humic substances — can attach to heavy metals to form complexes, which render the metals far less toxic to living things.

The scientists therefore measured the complexing capacity of the water at each of their sampling sites, by seeing how readily copper was bound. Copper forms complexes with the organic material more readily than the other metals, and is also the most toxic to marine life. The copper-complexing capacity of sea water gives an indication of the water's ability to cope with the other metals.

Metals from mines

Results of the analyses clearly showed that the King River is the conduit by which the heavy metals enter Macquarie Harbour. The sampling showed very high levels of heavy metals in this river, which carries discharged water from the Mt Lyell copper mine near Queenstown. In its lower reaches, the scientists found metal concentrations up to 1000 times greater than the background sea-water values — and for iron and manganese (less toxic than the others) the values were up to 10 000 times the background. Most of the heavy metals in the river exist as small particles, which are deposited just inside the mouth of the river.

The other river that flows into the harbour — the Gordon — drains undeveloped World Heritage wilderness areas and national parks, consisting of forests and button grass plains. These contribute the useful humic substances carried into the harbour in such quantity. Apart from iron and manganese, which are naturally in much higher concentrations in fresh water than in sea water, the measured heavy metals occurred at much lower levels in this river, showing that it was clearly not the source of the metals in the harbour.

Measurements of sea water near the entrance to the harbour, at Cape Sorell, also formed a control, and confirmed that all the metals occurred in low concentrations in open sea water. And around the harbour itself, the only possible source of pollution is the small settlement of Strahan, with a population of about 400. It seems clear that the principal source of the heavy metals is the mine.

However, all is not gloom. Iron and manganese are not considered toxic at observed levels in natural waters. The harbour contains concentrations of cadmium, nickel and zinc that, although higher than background, are still within the proposed national water-quality guidelines for Australia and New Zealand. This is just as well, as it also contains enclosures used for farming the gourmet-beloved Atlantic salmon.

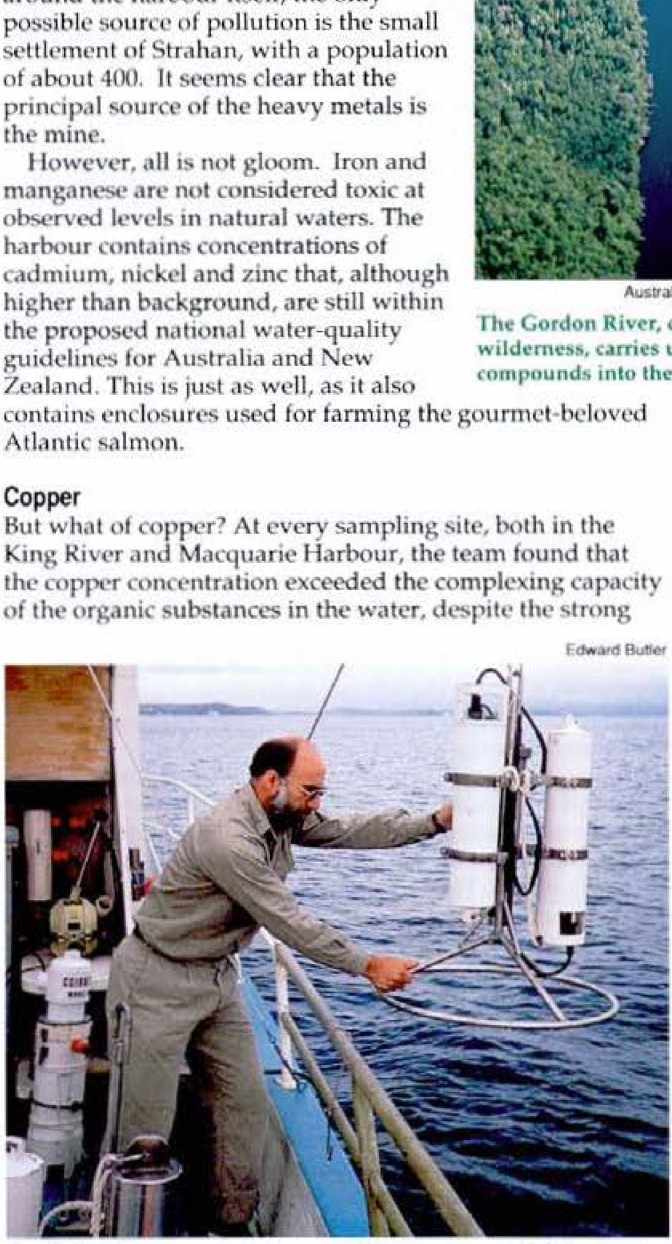
Australian Overseas Information Service

The Gordon River, draining undeveloped wilderness, carries useful complexing compounds into the harbour.

Copper

But what of copper? At every sampling site, both in the King River and Macquarie Harbour, the team found that the copper concentration exceeded the complexing capacity of the organic substances in the water, despite the strong contribution to that capacity made by the humic substances coming down the Gordon River. The most difficult questions to answer are whether, and to what degree, the copper is likely to create a problem in waters used for aquaculture, where fish are artificially fed.

Edward Butler



Deploying instruments for trace metal measurement in Macquarie Harbour.

According to guidelines from the United States Environmental Protection Agency, the answer to the first question would be yes. The American standard for such waters decrees that the copper concentration should not exceed 46 nanomoles per litre (2·9 µg per litre) more than once every 3 years. In fact, the copper concentration in surface waters of the harbour ranged from 68 to 175 nanomoles per litre. The scientists concede that their sampling took place on only one occasion, and thus can only really offer us a 'snapshot' of the situation — but, as far as is known, it did not follow any recognisable events that could have raised the heavy metal concentration in the water.

The Western Australian State government has set the maximum median concentration for copper over 6 months at 79 nanomoles per litre in waters used for fish-farming; again, Macquarie Harbour would be considered too polluted. But the Tasmanian Department of the Environment has set a standard for such waters of 315 nanomoles of copper per litre and therefore, according to the State's own criteria, Macquarie Harbour is certainly not seriously polluted.

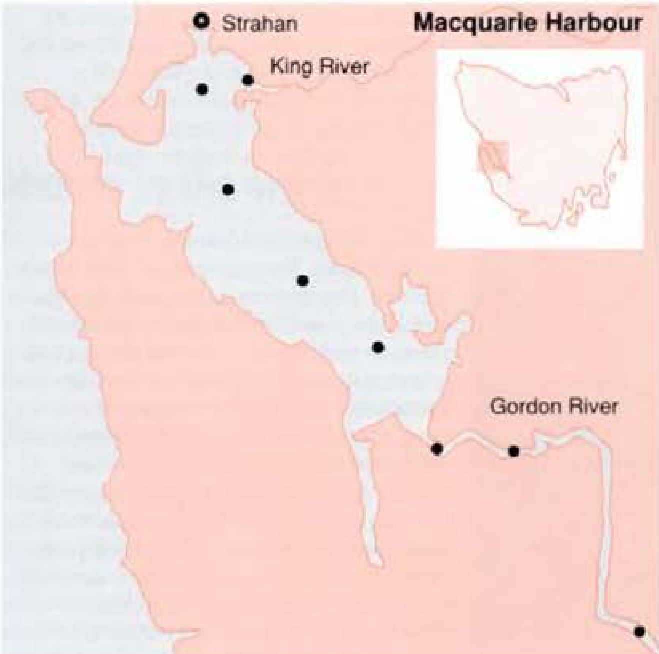
Heavy metals don't account for all the worry. A limited survey showed that sediment near the mouth of the King River was contaminated with hydrocarbons — organic compounds that can come from oil or plants. Analysis of the compounds showed that they were derived from petroleum; elsewhere, such as in the lower Gordon River, the hydrocarbon type indicated a plant origin. Where the petroleum-derived hydrocarbons came from is not yet clear.

In the past few years, two well-documented fish kills have occurred in the fish farms of Macquarie Harbour. Nobody knows whether the deaths resulted from a sudden flush of heavy metals or other, quite natural, events.

One possibility is the sudden appearance at the surface of low-oxygen waters from the depths brought up by strong winds and changes in water stratification. Another is the re-suspension of sediment accumulated at the bottom; this could kill simply by clogging the fishes' gills or, if the sediment was rich in heavy metals as is likely, by sudden poisoning. Post-mortem studies of some of the fish by the Department of the Environment suggested that the gills were choked with 'particulate material', but whether the fish ingested metals from the sediment in sufficient quantity to have a lethal effect remains undecided.

Marine life

However, on the basis of present knowledge, consumers should not worry unduly. If acute poisoning occurred, the major organs would contain high concentrations of heavy



The dots show the sites where the scientists sampled water.

metals, but the flesh and bone would be spared — and anyway, dead fish are not for human consumption. Also, as the fish are artificially fed and their food does not come from Macquarie Harbour, they do not form part of the natural food chain there and so would not normally take in metals in any significant quantity. Hence, the fact that the water in the area exceeds guidelines for fish-farming from elsewhere may be a worry for the farmers but not for the consumers.

Perhaps a bigger concern is the area's natural marine life. Nobody has yet carried out a detailed survey, but we do know that the region is less productive than it was at the beginning of this century, when several species of fish in the harbour supported a score of trawlers. Clearly, all is not well in those waters; further research is needed to clarify the extent of the problems.

Roger Beckmann

Chemistry of trace elements, humic substances, and sedimentary organic matter in Macquarie Harbour, Tasmania. P.D. Carpenter, E.C.V. Butler, H. W. Higgins, D.J. Mackey and P.D. Nichols. *Australian Journal of Marine and Freshwater Research*, 1991, **43** (in press).

Monitoring environmental stress

Scientists estimate that more than 60% of Australia's plants and animals have yet to be described. Among the invertebrates, another 100 000 species may be awaiting discovery.

In such a dimly perceived environment, it hardly seems credible to attempt to determine the biological impact of human activities, and make predictions about what consequences will follow.

In toxicology, for example, Australia depends heavily on overseas research findings — often derived from acute toxicity tests using animals alien to this continent — to establish safe levels of exposure to toxic chemicals. A veterinary pathologist in Victoria found in 1989 that an endangered and rapidly dwindling marsupial species, the eastern barred bandicoot, appears to have been poisoned by farm chemicals such as DDT. The researcher despaired, however, that he knew far more about safe levels for DDT in sheep than in any native species.

According to a 1990 report by the Australian Science and Technology Council (ASTEC), ecological research here is fragmented, *ad hoc* and immature. Ecologists cannot agree on how best to study ecosystems, and much of the research that does occur is narrow in scope and difficult to apply in making management decisions.

The environmental impact statement — now a common feature in the developmental stages of major mining or industrial projects — has had a chequered record, with some studies amounting to little more than market strategy documents for the proponent. Even the most genuine studies typically base their recommendations on short-term investigations using one or two species, gross changes in biodiversity or overseas toxicity tests.

Into this neglected patch of scientific expertise comes a sweeping innovation. Called Biotest, the new and powerful system measures environmental stress in organisms. Better still, it has been refined here, using Australian species.

It works like this: any organism, whether plant, insect, bird, fish or mammal, under stress from, say, heavy metal pollution begins to lose homeostasis — that is, the ability to maintain its physical development at an optimal level. A decline in homeostatic efficiency may result in changes to the organism's biochemical functions, chromosomes, physical appearance or ability to defend itself against infection and parasites. In short, it may lose fitness. These homeostatic changes provide the foundation for what promises to be a reliable, cheap and universal method of environmental assessment.

Left and right

Dr Geoff Clarke, a researcher at the CSIRO Division of Entomology, and colleagues at the University of Melbourne and Marine Science Laboratories in Victoria have found that the well-known biological concept of fluctuating asymmetry provides an effective means of assessing homeostasis (see *Ecos* 51, Autumn 1987). By simply noting differences between the left and right sides of a normally symmetrical organism, a scientist can gain a measure of the environmental or genetic stress the organism has experienced during its early stages of development. In many cases, the work may require nothing more sophisticated than measuring the shape of the left and right wings on an insect or the length of the legs on a marine microcrustacean. The greater the stress becomes, the higher the asymmetry.

Research overseas has established links between fluctuating asymmetry and a wide range of stress factors, including DDT and dioxin levels in fish, sound stress in rats and heavy metal contamination in shrews.

A number of Australian studies using flies have shown that fluctuating asymmetry will reveal environmental stress at much lower levels than traditional indicators such as body weight, and with greater reliability. The technique can also detect genetic stresses caused by inbreeding or changes in the structure of a population.

In their latest work, Dr Clarke and Mrs Leslie McKenzie, a technician in the Division, have investigated stresses that occur during the mass rearing of insects in the laboratory.

Dan Bedo

The face of a Biotest indicator: much magnified, the larval head of a midge, *Chironomous salinarius*, collected from water at a chemical plant near Odessa on the Black Sea.

Insects, such as the sheep blowfly, are commonly reared by CSIRO scientists for subsequent release in biological control programs in which the laboratory-bred insect has to successfully infiltrate a target population or ecosystem. Success depends on the number of insects reared and their level of fitness, hence the need to minimise stress.

The two researchers used such a mass rearing facility to rate existing methods of measuring stress against fluctuating asymmetry. They reared a laboratory strain of the sheep blowfly (*Lucilia cuprina*) at different densities to assess the stress caused by larval crowding. After the larvae had pupated, they weighed these and later counted the emerging adults to provide an estimate of survival. They analysed 50 adult males for fluctuating asymmetry by counting bristles on each insect's head, on the outer wing and along a wing vein. Mean values were calculated by adding the absolute differences between the left and right sides of each individual and dividing by the number of individuals. The experiment was duplicated using a different strain. In another experiment, the fly larvae were reared on trays maintained at temperatures ranging from 15° to 35°C to assess heat stress.

In the larval-crowding experiments, the level of fluctuating asymmetry proved to be proportional to the density of the larvae on the rearing trays. In the heat experiments, the level of asymmetry was lowest at 27°C, the temperature at which the laboratory insects are normally maintained, and highest at 15°C.

Most sensitive

Compared with the results obtained from the pupal weight and survival calculations, fluctuating asymmetry was the most consistent and sensitive stress indicator. While pupal weight proved a good indicator of stress caused by larval crowding, it did not reliably indicate stress due to cold. The survival data proved unreliable for both temperature and crowding stress.

Apart from being more reliable and sensitive, fluctuating asymmetry has other advantages: it can be applied to many species, it can be used both in the laboratory and in the field and, if the researchers are right, it may provide the basis of a universal early-warning system for environmental damage.

Dr Clarke belongs to an international committee of scientists trying to develop a range of environmental early-warning indicators under the aegis of Biotest, and based on different ways of measuring homeostatic change. The Biotest indicators currently being used by committee members include tests for immunological efficiency, enzyme levels, patterns of oxygen consumption and host–parasite relationships.

The Chief of the Division of Entomology, Dr Max Whitten, says fluctuating asymmetry will be an important element in Biotest. 'This method is the most sensitive approach I know for showing something is having a biological impact. If there is no increase in asymmetry, you can be quite confident in saying there is no impact', he said. Dr Whitten believes a Biotest system could significantly change the face of environmental assessment, shifting the emphasis away from a technology-driven preoccupation with chemical parameters to direct measurement of biological stress on a wide front.

Black Sea

Already the Soviet Union, through its Academy of Sciences, is investing heavily in Biotest. Dr Clarke and a group of American and European scientists spent 10 days last July conducting environmental impact tests on a urea plant near Odessa on the Black Sea.

In this first major field trial of Biotest, the research team collected plants, marine and fresh-water animals and small mammal species near the facility and at several 'control' sites up to 20 km away. Preliminary results, based on tests for fluctuating asymmetry, show significant levels of environmental stress close to the plant, gradually decreasing further away.

'We're convinced the plant is nowhere near as clean as they (the plant managers) say it is. We know already that it's having an environmental impact up to 3 or 4 km from the plant', Dr Clarke said.

He says samples of shrimp he collected from an estuary near the plant had antennae significantly more asymmetrical than those on shrimp collected at two control sites. Other scientists in the group found that more than 10% of the samples of one fish species, collected at a pond containing treated waste water from the plant, had deformed jaws. All samples of the same fish collected at the control sites had normal jaws. It is believed the treatment pond water, which is used to irrigate crops, contains the lethal chemical, methanol.

Dr Clarke hopes the Biotest committee will evolve into a research foundation offering environmental impact services to industry and government. He believes the system may be especially valuable in monitoring how well ecosystems respond to climate change due to global warming. The Soviet authorities, he says, are highly enthusiastic, and plan to build three permanent Biotest laboratories for further studies.

Investment by Australian industry and governments is proving much harder — a number of requests to public and private bodies have gone unheeded. Without modest financial support, Biotest research in Australia will wither, and a commercial opportunity may be lost.

Brett Wright

'Environmental Research in Australia.' (Australian Science and Technology Council: Canberra, 1990.)

Fluctuating asymmetry as a quality control indicator for insect mass rearing colonies. G. M. Clarke and L. J. McKenzie. *Journal of Economic Entomology*, 1991, **84** (in press).

The effect of avermectin B_1 on developmental stability in the bush fly, *Musca vetustissima*, as measured by fluctuating asymmetry. G.M. Clarke and T.J. Ridsdill-Smith. *Entomoloqia Experimentalis et Applicata*, 1990, **54**, 265–9.

Developmental stability of insecticide-resistant phenotypes in blowfly; a result of canalizing natural selection. G.M. Clarke and J.A. McKenzie. *Nature*, 1987, **325** (6102), 345–6.

Fishing in paradise

Life on tropical ocean islands, surrounded by coconut palms and coral lagoons, sounds idyllic. But for many in this situation earning a living is difficult. Countries like the Solomon Islands, Kiribati or, in the Indian Ocean, the Maldives have little with which to earn foreign currency other than tourism and fish.

The fishing industry that interests the islands' economists catches tuna in the open ocean, by a simple pole-and-line method, and exports the catch throughout the world. On the other hand, many of the local villagers seek the reef fish that inhabit the lagoons, which traditionally provide an important part of their diet or, in the case of the Maldives where the locals ignore reef fish, the food for the tourist beachfront bures.

The two types of fishing are not entirely separate, for to catch tuna you need live fish as bait. The obvious sources of these bait-fish are the coral lagoons surrounding the islands. So the tuna industry wants a lot of fish from the lagoon; the villagers may do too. Do we have the beginnings of a resource-use conflict?

Helping to answer this question is a team of scientists led by CSIRO biologist Dr Stephen Blaber from the Division of Fisheries' Brisbane laboratories. Villagers in the Solomon Islands were reporting lowered catches of some reef fish and wondered whether the tuna industry was to blame. Accordingly Dr Blaber, in collaboration with staff of the Fisheries Division, Solomon Islands, and funded by the Australian Centre for International Agricultural Research (ACIAR), carried out a detailed study of how bait-fishing affects the reef fishery.

Stephen Blaber

Gill-netting to catch baitfish-predators in the Solomon Islands.

Weighing the catch after one of the bait-fish-catching competitions.

Now, the species caught as bait are not those that the islanders use for food, so direct competition does not exist. But many people thought that the bait-fish provided the main food source for the sought-after types (such as coral trout and snapper) and that their large-scale harvesting — about 2000 tonnes a year in the Solomon Islands — was affecting the food supply of many of the species that make up the reef (or subsistence) fishery.

So Dr Blaber and his team set to work in the Solomons to determine the place of bait-fish in the ecology of the lagoons, together with their importance to the subsistence fishery. Firstly, the scientists needed to know more accurately just what reef species the islanders liked to catch for food. So they organised fishing competitions. In two parts of the Solomons, islanders were encouraged to catch as many of their preferred fish as possible, using their traditional methods, with various prizes on offer for the largest hauls. The scientists then sorted through the catches, identifying the species and weighing the fish.

As you might expect, biological diversity is clearly a feature of the coral lagoons. The many thousands of fish caught came from 183 different species, comprising 31 fish families. The team took more than 1800 individual fish representing 122 species for sampling, and studied the stomach contents for information on diet.

They found that individuals from 45 species had consumed baitfish, but in only 28 of these did this comprise more than 10% of the diet. (They classified these species as 'major' bait-fish predators.)

A particular style of fishing was responsible for the catch of many of the bait-fish predators. Called 'trolling', it involves towing an artificial lure from a boat. Although important at a few places, it is neither widely nor frequently used in the Solomons; rather, the islanders prefer drop-lining, a method that catches few of these major predators.

Various species already known to be important predators of baitfish were not caught in the competitions. All in all, therefore, the scientists concluded that the subsistence fishery has little to do with fish that rely strongly on bait-fish for their food. So, unless trolling suddenly becomes 'all the rage', bait-fish harvests should not

Catching tuna off the Maldives — with pole and line in a 'dhoni', or local boat.

directly affect the food chain supplying the villagers.

In the Indian Ocean atoll chain of the Maldives, the scientists caught reef fish by gill-netting. They did not attempt to organise competitions this time, as the locals rarely use lagoon fish for food, eating tuna almost exclusively. (Indeed, by the end of their field work the scientists became a little tired of curried tuna!)

Gill-netting caught a total of 1818 fish of 118 species. Dietary analyses showed that only 10 species ate bait-fish, although these species made up 22% of the weight of the catch. That last figure suggests that the bait harvest may have an effect on the lagoon fish in the Maldives.

However, as these predators are not important in the islanders' food, there's no problem at present. But the reef fishery has the potential to expand to feed tourists, and supply the recreational needs of those who like to try their hand at catching coral trout or parrotfish. The Maldivian authorities will need to keep a careful watch on this developing demand and the extent of the bait-fishery.

For environmental reasons pressure is increasing to move away from gill-net fishing (the so-called 'wall of death') and purse-seining in the South Pacific, which means that the simpler pole-and-line method of tuna-fishing is likely to come into greater use in many of the island nations.

Inevitably, this involves bait-fish, so Dr Blaber's work has wide application. He is continuing with ACIAR-funded studies in Kiribati and Fiji in collaboration with local scientists there. But the knowledge gleaned also helps in Australia, as knowing which species eats which is fundamental to understanding the ecology of our extensive coral reefs.

Roger Beckmann

Diet and prey selection of six species of tuna baitfish in three coral reef lagoons in the Solomon Islands. D.A. Milton, S.J.M. Blaber and N.J.F. Rawlinson. *Journal of Fish Biology*, 1990, **37**, 205–24.

Diets of lagoon fishes of the Solomon Islands: predators of tuna baitfish and trophic effects of bait-fishing on the subsistence fishery. S.J.M Blaber, D.A. Milton and N.J.F. Rawlinson. *Fisheries Research*, 1990, **8**, 263–86.

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