How marine life copes with a lead smelter

Since 1889, the smelters at Port Pirie on South Australia's Spencer Gulf have been producing lead from Broken Hill's rich ore. Over the years millions of tonnes of lead and zinc have been produced from what has become the world's largest lead smelter.

In the process, metal-bearing dusts and liquids have been discharged to the surrounding environment. For example, in recent years 100 tonnes or more of lead, zinc, and cadmium, at the parts per million level, have flowed annually into Spencer Gulf in the smelter's liquid effluent stream.

In addition, the smelter's smokestacks may have contributed substantial quantities of metals to the Gulf. A survey of the soils around Port Pirie conducted by the CSIRO Division of Soils (see *Ecos* 7 and 28) showed elevated levels of these elements, and similar levels of metal fall-out presumably occurred over the water.

Run-off, or wind-blown dust, from the metal-contaminated land could also add to the metal burden of the Gulf sediments.

The company operating the smelter, Broken Hill Associated Smelters, has made considerable efforts to reduce the emission of pollutants. Total emission levels are now at least ten times lower than in earlier years. To achieve this, the company has constructed settling ponds, erected a 205-m-high chimney, and installed efficient filters and electrostatic precipitators. Unfortunately, the long-lived nature of the effluents means that metals discharged in past years still exert some influence today.

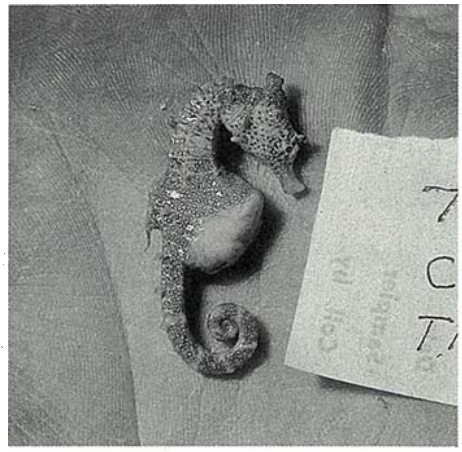
Upper Spencer Gulf is somewhat like a lake. Its highly saline waters mix very little with the open sea, and river flow into it is, for most of the time, negligible. As a result, metals accumulate in the Gulf environment.

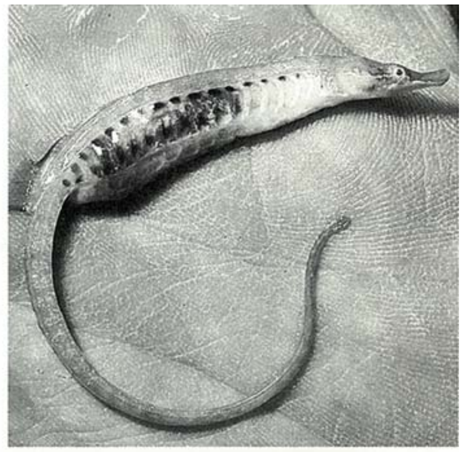
1. The bad old days. A picture of the smelter taken in about 1903. Most of the pollutants found in Spencer Gulf today were emitted in these early years.

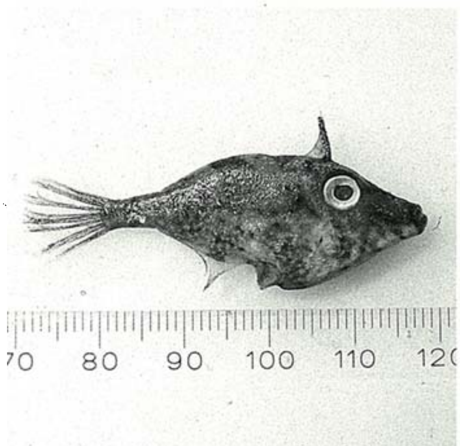
2. The smelter today. It incorporates much pollution-abating equipment and a 205-m-high chimney.

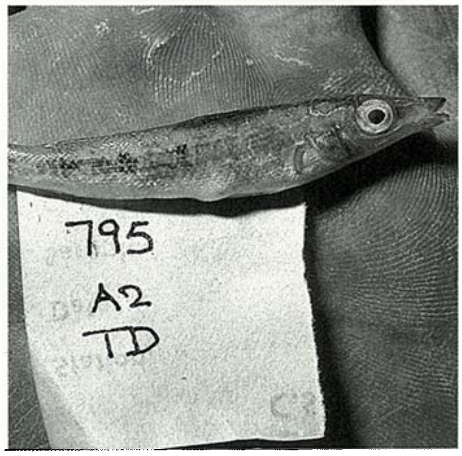
3. A razorfish — disguised by the many creatures that live on its shell.

> *The long-lived nature of the effluents means that metals discharged in past years still exert some influence today.*









Some of the many animals that live among the seagrass.

The question then naturally arises: what effects have the smelter's output of metals — some of which are toxic at low concentrations — had on marine fauna and flora? As the smelter is the only significant source of these metals for hundreds of kilometres, it should be possible to identify its impact.

Finding the answer has occupied Dr Trevor Ward, a marine biologist with the CSIRO Division of Fisheries Research, for the past 4 years. Investigations into the geochemistry of sediments were carried out by Dr Len Warren of the Division of Mineral Chemistry and by Dr Kevin Tiller and Dr Keith Norrish, of the Division of Soils. Also involved was Dr Peter Young of the Division of Fisheries Research. The study was commissioned by the International Lead Zinc Research Organization (a consortium of metal-producers set up to initiate research relevant to the industry) and co-ordinated by Dr Dal Swaine of the CSIRO Division of Fossil Fuels.

The study has now been completed, and its findings included the following highlights.

- Sediments within about 30 km of the smelter (encompassing about 600 sq. km of the Gulf) contain elevated levels of metals derived from the smelter.
- Some 20% of this area (about 100 sq. km) is significantly contaminated with concentrations of cadmium, lead, and zinc greater than ten times background level.
- Almost all organisms, plant and animal, living in the 100 sq. km contaminated area showed elevated concentrations of lead, zinc, and cadmium.
- Human health is unlikely to be affected by consumption of seafood caught in that area. With the exception of cadmium in one crustacean, the levels of metals in the parts normally eaten did not exceed recognized health limits.
- Metal concentrations were not magnified in the seagrass food chain. Although seagrass, and the small organisms that live on it, contained high metal concentrations, levels were much lower in the small fish that lived in the seagrass beds. However, top-level carnivores — sharks, sea-birds, large fish, and the like — were not sampled.
- The most obvious effects on the fauna were observed near the point of liquid effluent discharge (First Creek), but effects probably extended over about 100 sq. km of seagrass beds.
- Seagrass growing in the contaminated area was less productive, but appeared healthy, despite high metal concentrations.
- Metals reduced or eliminated 20 of the most common species (mostly small non-commercial fish) that live among the seagrass in the contaminated area.
- Suspended sediment plays an important role in determining the ecological balance. In some areas, reduced seagrass growth was probably caused by sediment stirred up by shipping, tidal currents, and waves. Suspended clay and silt reduced or eliminated about 15 species, mainly small crustaceans.
- The distribution pattern of cadmium was unexpected in that concentrations of the metal were, in some cases, higher in molluscs some distance from the smelter than in those closer to it.

Metal build-up

Although the metals in the vicinity of Port Pirie obviously originated from the smelter, it is difficult to pin down what proportion found their way to the sediments by sea and what proportion by air.

The liquid effluent from the smelter has, for the last decade or more, been ponded before it flows into the Gulf. This allows most of the particulate material to settle out. Most of the metals that now enter First Creek are therefore in soluble form.

Sampling of soils and sediments in the area by Dr Tiller and his co-workers suggests a substantial input of metals to Spencer Gulf in past years from aerial emissions. The pattern of fall-out on land indicates that metals have been deposited directly into the Gulf, generally only between the north and north-west of the smelter, and sediment sampling tends to confirm this.

Another source of metals, already mentioned, is run-off from land. Others are spillage of ore and concentrates during handling and shipping, especially in earlier days, and dust blown from the works area.

The relative magnitudes of each of these sources have not been determined, but

Species richness and distance from the smelter

site in Gulf	average number of species living on the shell of the razorfish winter	summer
4 km off First Creek (4 km from effluent outfall)	4·3	9·3
6 km off Fifth Creek (10 km from effluent outfall)	15·0	15·7
7 km off Port Davis Creek (20 km from effluent outfall)	19·0	21·3

Close to the smelter, few species live on the razorfish's shell. Many more do so further away. The number of species is a very good indicator of contamination levels.

evidence from Dr Tiller's soil-sampling work indicates that particulates from the atmosphere may have made the largest single contribution of metal to the sediment in past years. However, the high concentrations of metals in sediments near First Creek indicate that the current effluent's contribution is now a more significant source.

Sediment analysis

The major contaminants of the sediments were found to be lead, zinc, and cadmium. Minor contaminants detected were arsenic, copper, manganese, and antimony.

Sampling showed that about 600 sq. km of the Gulf is contaminated to a measurable extent. About 100 sq. km is contaminated to about ten times the background level for lead (100 p.p.m.), zinc (200 p.p.m.), and cadmium (1 p.p.m.). Near First Creek about 25 sq. km is contaminated with levels 200–300 times the background for lead and zinc, and about 1000 times for cadmium.

Dr Ward notes that the degree of contamination near First Creek is severe by world standards.

Dr Warren developed a method of sediment analysis that made it possible to determine the metal concentrations in the most common particle sizes and mineral components. About 80% of the total metal was found to occur in the silt- and sand-size particles, those 10–1000 μm in size. Significantly, shell fragments comprised the largest component of the sediment and also carried the largest proportion of metal. Within seagrass beds, plant debris was found to be an additional significant reservoir of metals.

Edible portions of seafoods were always below recognized health limits.

Dr Norrish examined particles in an electron microprobe and found most of the metals present as sulfides. In shell fragments, the way the metal sulfides are dispersed suggests that they are incorporated by direct chemical processes rather than by metabolism of the shellfish.

Nevertheless, the substantial amount of metal sulfides found in the sediment — in a form different from that of the smelter's emissions — suggests that a considerable amount of metal recycling occurs.

Despite their occurrence as metal sulfides, which are usually regarded as able to 'lock up' metals, most of the metals in the sediments were in a form that could be made available to plants and animals. Many animals' food-assimilation processes are based on acid digestion, and Dr Warren found that about 80% of the lead, zinc, and cadmium in shell could be extracted with dilute acid. So could

Most of the metals in the sediments were in a form that could be made available to plants and animals.

some 80% of the lead and zinc from organic debris, and about half of the cadmium.

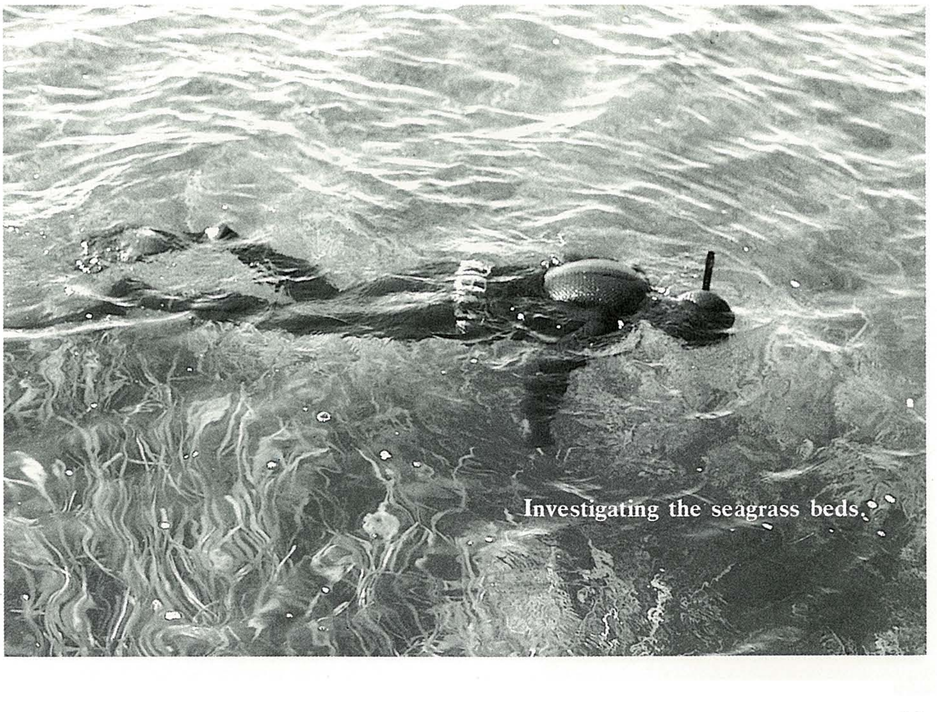
With the financial support of BHAS, some detailed studies of the availability of sediment metals to flora and fauna are continuing.

Sediment toxicity

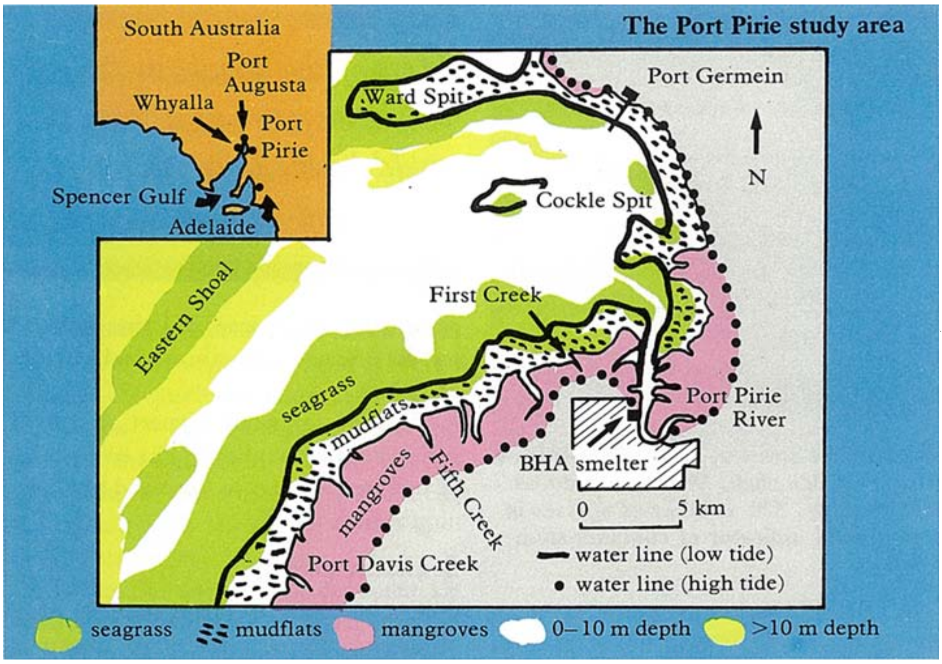
One of the more surprising findings of the study was the adverse effect that suspended sediment, even if it is not contaminated by toxic metals, has on a considerable number of organisms.

Seagrasses are particularly sensitive to high concentrations of suspended solids, since this reduces the amount of light available for photosynthesis. Near Port Pirie, seagrasses largely appear at depths less than 3 m, whereas in much of Spencer Gulf they grow in water as much as 10 m deep.

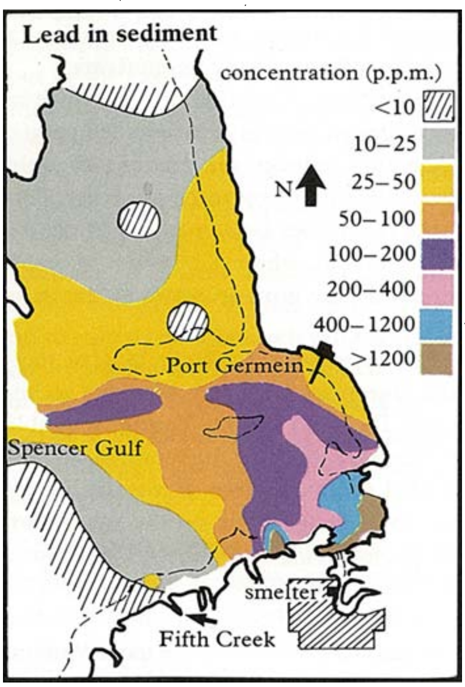
By transplanting a large bivalve mollusc (the razorfish) from one spot to another, Dr Ward and Dr Young were able to separate out the influences of suspended sediment (free of metals) and of dissolved metal alone on the more than 70 species living on its shell. They found that about one-fifth of the common species were directly affected by metals at the concentrations found in the most contam-



Investigating the seagrass beds.



Liquid effluent from the BHAS smelter, which contains dissolved metals, flows into Spencer Gulf through First Creek. The scientists looked for the effect on marine life in this area.



The highest concentrations of lead in sediment were found near the mouths of First Creek and Port Pirie River. The distributions of other metals were similar.

inated areas, and some others were affected by the stirred up uncontaminated sediment. The combination of the two factors makes a particularly inhospitable environment for many living creatures.

Unfortunately, this combination is widespread near Port Pirie. To begin with, fine sediment is rich in metals. It was found that the fine fraction had metal levels one-third to three times higher than the bulk of the sediment. This means that filter feeders, and other species that ingest sediment while feeding, can be exposed to high concentrations of metals.

The other aggravating factor is that Spencer Gulf is generally shallow, facilitating the re-suspension of sediment. Much of the Gulf is less than 10 m deep, and it contains extensive intertidal areas. Near Port Pirie, a tidal range of 3·5 metres gives rise to mudflats and mangrove swamps about 6 km wide.

Any water movement easily re-suspends sediment. Tidal currents commonly run at 1–2 knots, and can carry metal-rich sediments large distances. Even waves, whipped up by the wind, can cloud the waters.

But another considerable influence is the dredging of shipping channels and the movements of ships along them. At Port Pirie itself, the river has been extensively dredged. In the late 1800s, only a few centimetres of water remained at low tide. Now a set of wharves lines the river for several kilometres, and can accommodate vessels of up to 20 000 tonnes. A shipping channel has been dredged to give a free draught of 7 m at low tide, and this extends some 16 km into open waters.

Dr Ward thinks that little can be done to diminish the size of the accumulated submarine deposit of toxic metals, but it may be possible to reduce its effects on the fauna by restricting dredging, and by restoration of seagrass beds to bind sediments.

The food web

At the bottom of the food web in Spencer Gulf are seagrasses and algae — they are the major 'primary producers'. Upon their health and integrity depends the viability of commercial and recreational fishing, which harvests fish at the top of the food web.

The Gulf supports a multi-million-dollar king prawn industry, together with a lesser garfish and whiting fishery. Also, flathead, leatherjacket, blue swimming crab, scallops, and the razorfish mollusc are caught by recreational fishermen.

Dr Ward's study focused mainly on the so-called cryptic fauna: the animals that fill the gap in the food chain between the seagrass and the large fish, squid, sea birds, and dolphins. In terms of numbers, these small species are the most abundant.

Cryptic fauna — crustaceans, molluscs, sponges, bryozoa, worms, and others — don't feed directly on the seagrass; rather they are detrivores. The leaves of the seagrass die, break up, and are slowly decomposed by bacteria and marine fungi. The intermediate-level fauna then eat the resulting detritus.

From his sample analyses Dr Ward estimated that seagrass leaves in an area 1·5 km square near First Creek contained, at the end of winter, about 73

Suspended sediment, even if not contaminated by toxic metals, has an adverse effect on a considerable number of organisms.

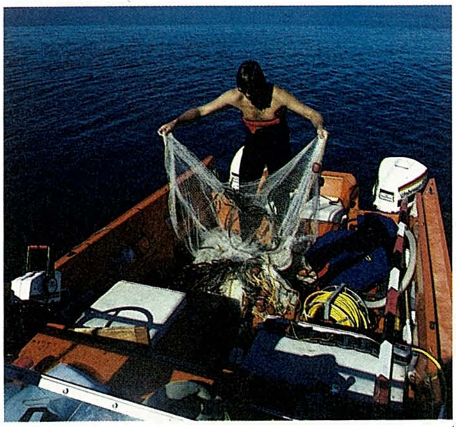
tonnes of cadmium, 51 tonnes of lead, and 571 tonnes of zinc. This is a larger amount than the dissolved metals emitted in a year by the smelter (approximately 5, 50, and 150 tonnes of cadmium, lead, and zinc respectively at the time of the study).

Since the leaves regrow at least annually, the seagrass is an important recycler of metals. It absorbs them either directly from solution or through the sediment. Considerable cycling of the metals between sediment components and between sediments and living organisms occurs, and in the process the metals exert their toxic effects.

Metal concentrations

Careful analysis of tissues by atomic absorption spectrophotometry showed that just about all the organisms in the contaminated area had elevated levels of cadmium, lead, and zinc.

The muscle of razorfish is known as a seafood delicacy. Fortunately, sampling showed that consumption of this shellfish



Emptying the sampling net.

should not present a health risk. Neither cadmium nor lead exceeded the National Health and Medical Research Council's maximum recommended concentrations. Levels of zinc exceeded the recommended level for molluscs (750 p.p.m.); but if the standard for oysters (5000 p.p.m.) was applied, then the razorfish samples would be well within that constraint.

Most of the other seafoods sampled in the study contained elevated levels of metals, but the edible portions were always below recognized health limits.

No biomagnification was observed. The sampling nets used were unsuited to catching large fish, but on occasions did capture some. None had excessive metal concentrations in their edible parts. However, further study of the larger fish would seem worth while, to be sure on this aspect.

Ecological effects

Of course, measurements of metal concentrations alone in flora and fauna tell us nothing about how the smelter's emissions have affected animal and plant populations. To gather information on ecological effects, Dr Ward studied two main habitats: the shallow-water seagrass communities and the sponge and razorfish communities on the sand and mud of deeper waters. He compared the populations of uncontaminated areas with those in areas with different levels of metal contamination.

Blue swimming crabs were found in greater abundance in contaminated areas.

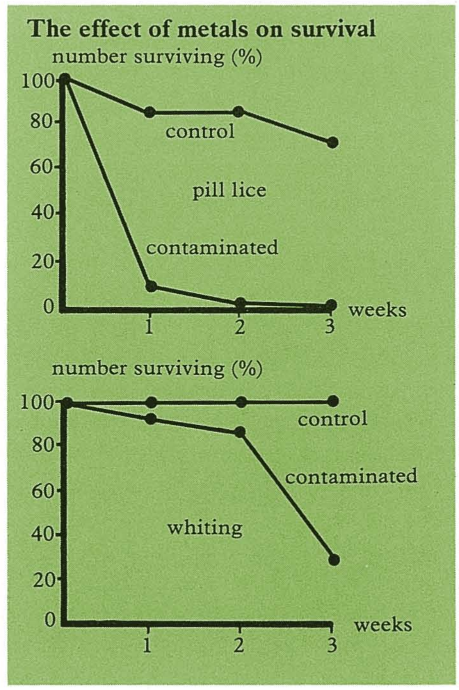
He examined the diversity and abundance of species in each locality, and looked out for species that were especially sensitive to metals — the so-called indicator species — and for species that reflected in their tissues the concentration of metal in their surroundings — the 'sentinel accumulators'.

However, the specific effects of trace metals are very hard to unravel. Marine communities are closely interrelated, and so effects of metals on one species may spread throughout the system.

Metals in relatively low concentrations can kill some species. Dr Ward did do some experiments to determine short-term toxicity, but he makes the point that it is difficult to relate this to how the ecological balance of a community will be affected in the long term.

Sublethal effects are just as important, but much more subtle and difficult to assess. They can take the form of altered behaviour (feeding, mating, moulting, and the like), slower growth rates, and changes in number of offspring. Some species are more susceptible than others, and the egg, larvae, and embryo stages are more sensitive than the adult. Of course, some species may adapt to the new stress, and become tolerant of the metals.

Seagrasses are at the bottom of the food web.



Fish (whiting) and crustaceans (pill lice) were held captive for 3 weeks at the mouths of First Creek (contaminated) and Fifth Creek (control). More animals in the uncontaminated location survived.

How did the aquatic life near Port Pirie fare? Things could be much worse. The metals seem to have little effect on the seagrasses, for example. The distribution of seagrasses near First Creek is near normal, even though the sediments there contain the highest concentrations of metals. Their productivity is reduced, but this may be caused by the effects of increased suspended solids.

However, the study of seagrass fauna — a total of 106 different species — showed that the metals reduced or eliminated 20

A device for sampling suspended sediment.

of the most common ones, mainly non-commercial fish. Clay and silt in the sediments affected about 15 others, mainly small, less common crustaceans.

Most of the commercial and recreational fish are migratory, so they are not likely to be directly affected by metals or by reduced numbers of prey animals in the contaminated area. However, the numbers of two species resident in the seagrasses and taken by recreational fishermen (leatherjacket and weedy whiting) are reduced by the metals.

Prawn numbers were unaffected by the metals, and blue swimming crabs actually were more plentiful in the most contaminated area!

Away from the seagrass beds, in the deeper waters, the most conspicuous creature is the razorfish, which lives in the soft sediment. It grows to about 30 cm in length, and projects about 200 sq. cm of its shell above the mud (its edge is sharp like a razor).

The exposed surface is encrusted and overgrown with a wide variety of animals and algae. It is the only widespread hard surface in the Gulf on which these life forms (epifauna) can grow. Dr Ward counted 72 separate species of animals: 33 molluscs, 16 sponges, 10 bryozoans, 3 barnacles, and 10 others.

He found that the number of species the mollusc carries is a very good indicator of contamination levels. The epifauna increased in richness as contamination levels dropped. As mentioned earlier, both metals and sediment have an effect.

Pollution resulting from metals with a long residence time is obviously difficult to rectify. Even if the smelter stopped discharging metals, some effects would continue. Dr Ward believes that further studies are required to determine the outer boundaries of the effects and to find out how to ameliorate the effects he has observed.

Andrew Bell

More about the topic

The distribution and effects of metals in the marine environment near a lead–zinc smelter, South Australia. T. J. Ward, L. J. Warren, and K. G. Tiller. In 'Contamination of Ecosystems around Smelters', ed. J. O. Nriagu. (Wiley & Sons: New York 1983.)

Heavy metals in the environs of a smelter. D. J. Swaine, T. J. Ward, and L. J. Warren. In 'Trace Substances in Environmental Health — XV', ed. D. D. Hemphill. (University of Missouri: Columbia 1982.)