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# ENVIRONMENTAL STUDIES PROGRAM
# PROJECT REPORT

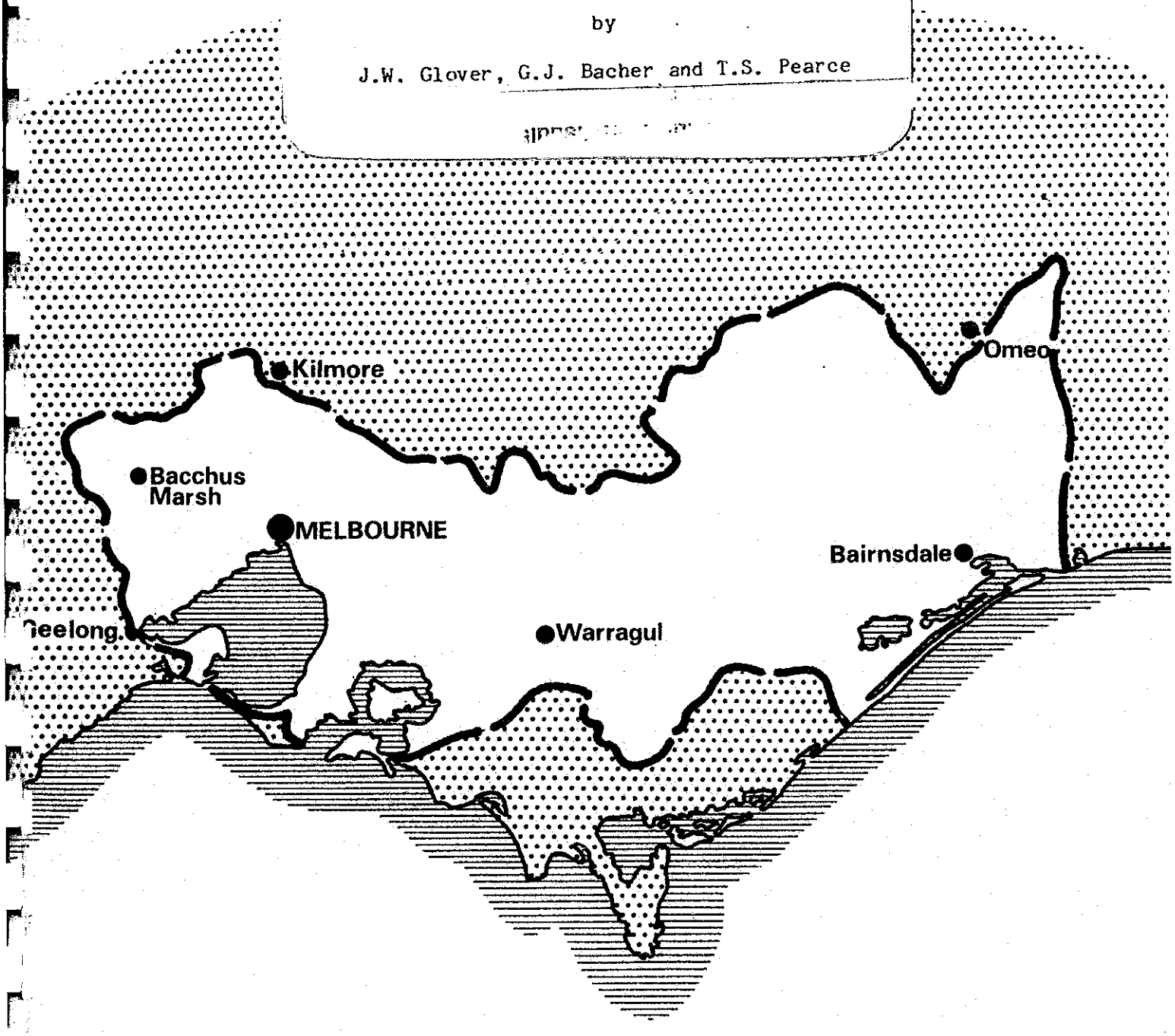


GIPPSLAND REGIONAL ENVIRONMENTAL STUDY

## HEAVY METALS IN BIOTA AND SEDIMENTS OF THE GIPPSLAND LAKES

by

J.W. Glover, G.J. Bacher and T.S. Pearce




MINISTRY FOR CONSERVATION - VICTORIA



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MINISTRY FOR CONSERVATION, VICTORIA

ENVIRONMENTAL STUDIES DIVISION



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FISHERIES AND WILDLIFE DIVISION

ENVIRONMENTAL STUDIES SECTION

ARTHUR RYLAH INSTITUTE FOR ENVIRONMENTAL RESEARCH

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# 1. INTRODUCTION

This is the final report of the project "Heavy Metals in Biota and Sediments of the Gippsland Lakes" (Task No 904-703) undertaken by the Fisheries and Wildlife Division on behalf of the Environmental Studies Section of the Ministry for Conservation. The project was commenced in January 1978 and completed in June 1979.

The objectives of this project were:

1. To collect existing information on past, present and future sources of metal inputs in the Gippsland Lakes Catchment.

2. To produce an inventory of the concentration of metals in the biota and sediments of the Gippsland Lakes, and to identify those species and tissues which may be suitable indicators of environmental contamination by metals.

Chemical analysis of fish, water and sediments from Lake Wellington for mercury (Smith 1976) and the analysis of small numbers of mussels from the eastern end of the Gippsland Lakes for 9 other metals, selenium and arsenic (Bacher unpublished data) indicate that all are present in the biota of the Gippsland Lakes. These data refer to samples from localised areas, and do not necessarily indicate the concentration of metals throughout the lakes. Similarly, the data do not indicate whether the sources are natural or due to man's activities in the catchment.

The metals* investigated in this project were zinc, cadmium, lead, chromium, copper, cobalt, nickel, iron, manganese, mercury, selenium and arsenic.

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* For convenience, selenium and arsenic will be included in the term metals.

## 2. THE STUDY AREA

The Gippsland Lakes, a group of lakes and coastal lagoons separated from Bass Strait by a series of broad sandy barriers, are situated in eastern Victoria, centred at 147° 30'E and 38°S.

The total area of the lakes is about 400 $km^2$, and the system receives runoff from seven river catchments, having a total area of about 21,000 $km^2$ (Gilmour et al. 1973).

Fresh water enters the lakes at two points; Lake Wellington, which receives water from the Latrobe, Avon and Perry Rivers and Lake King, which receives water from the Mitchell, Nicholson and Tambo Rivers. The Latrobe and Mitchell Rivers drain almost one-half of the total catchment, and account for more than one-half of the total input of fresh water into the lakes.

The Gippsland Lakes have undergone considerable physical and chemical change during the last 100 years. The transport of sediments, in the form of clay, silt and to a lesser extent sand, by the major rivers, has been a natural part of the evolution of the system. Soil eroded in the catchment, particularly during heavy summer rains contributes sediment to the rivers. Since European man's arrival in eastern Victoria this evolutionary process has been considerably accelerated by land clearing and agricultural development, particularly in the river valleys. Extensive grazing, particularly along the riverbanks, has accelerated erosion and increased sedimentation in the rivers. Gold mining in the catchment during the latter half of the 19th century, as well as the more recent practice of diverting water from several of the major rivers has changed the physico-chemical characteristics of the fresh water flowing into the lakes.

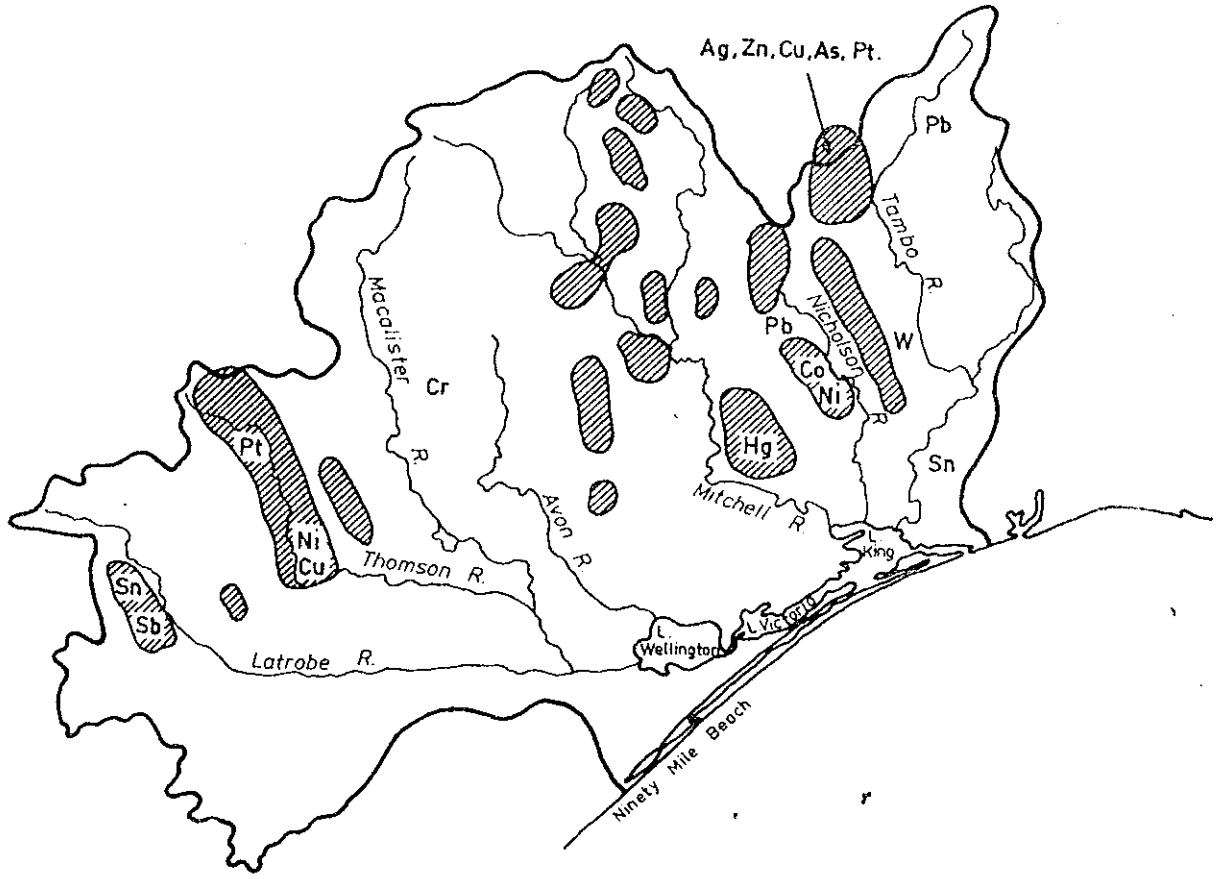


Figure 3.1 Mineral deposits in the Gippsland Lakes Catchment. Gold deposits are indicated by hatching, other elements by the appropriate symbol.

# 3. SOURCES OF METALS IN THE GIPPSLAND LAKES CATCHMENT

## 3.1 Minerals

Any investigation of the occurrence of heavy metals in the biota of the Gippsland Lakes catchment has to be concerned not only with man-made inputs of metals into the aquatic environment, but with the location and abundance of rocks which are also sources of metals (Figure 3.1). By processes of erosion, physical and chemical disintegration, and solution and transport, the metals can be redistributed into the alluvial deposits in the stream beds and from there to the river estuaries, the lake bed, and ultimately to the open sea.

The catchment contains the southern portions of the mineralized structures known as the Central Victorian, Eastern Victorian and Eastern Highlands Goldfields Provinces.

Mineral bearing rocks in the study area are usually of Ordovician and Silurian - Middle Devonian age, although gold and other metal ores are found in river gravels and the alluvium of streams of more recent origin. Disseminated metallic ores may also occur in small amounts in granites and granitic rocks of Paleozoic age.

### 3.1.1 Gold mining

The mining of gold, and the consequent release of heavy metals into the aquatic ecosystem occurred over a period extending from the 1850s to the 1930s.

#### 3.1.1.1 Thomson-Aberfeldy goldfield

The discovery of gold in the Jordan River area followed the exodus of miners from the Baw Baw diggings which had begun in November 1859 on the Tanjil River. Prospectors found alluvial gold near the headwaters of the

Thomson and Aberfeldy Rivers in 1861. Two years later, reef gold was found at Stringers Creek and the structure was later delineated as Cohens Reef. Subsequently numerous smaller reefs were found. The area, and the geological similar structures in the Upper Goulburn River Catchment were the source of the greater part of gold production in eastern Victoria.

3.1.1.2 Mitchell-Nicholson Goldfield.

Alluvial gold had been found in these streams as early as 1852, and reef mining was carried out in the period 1860-80. A relatively large alluvial field was discovered at Bullumwaal in 1893 and became very productive. Alluvial gold was found in Freestone and Gladstone Creeks in the 1860s and reef mining commenced in the 1870s.

3.1.1.3 Traralgon Goldfield.

Alluvial and reef mining was widespread in the Latrobe Valley - at Rosedale in 1859, and Haunted Hills, Morwell River, Narracan Creek, Mosquito Creek and the Moe River in the 1870s. Smaller alluvial deposits were worked in many streams in the area in the period 1877-86.

3.1.1.4 Tambo River Goldfield

Alluvial gold was found in Swifts Creek in 1854, at Tongio 1855-57, at Cassilis in 1858 and at Bruthen about a year later. There were many other minor discoveries of alluvial gold in the Tambo River valley at about the same time and hydraulic sluicing commenced on the Lower Tambo in the 1860s.

Reef mining began at Powers Creek in 1858, followed by many smaller reef workings during the 1860s. Because of heavy mineralization of the ore body, gold extraction was inefficient, and much gold and mercury was lost in the tailings.

In the 1880s and 1890s several reefs on Markeys Line were discovered, and some of these remained in production until the 1920s. Despite many technical innovations, which included roasting, flotation, chlorination and cyanide treatment, gold recoveries were incomplete.

3.1.1.5 Dargo, Crooked, Wongungurra River goldfields

The first major alluvial discoveries were made in the early 1860s, and reef mining began in 1864. Production from the Grant, Talbotville, Howittville and Tabletop areas continued until the early 1900s.

Several batteries were in operation on the Upper Dargo River from the mid 1860s to the early 1900s.

3.1.1.6 Gold production and estimated mercury lost

Because of the scarcity of reliable records, especially in the early years of alluvial mining, total gold production in the Gippsland Lakes Catchment cannot be accurately assessed. However, the major centres of production were the areas around the headwaters of the Thomson and Aberfeldy Rivers, and the upper part of the Tambo.

Mercury was used for the recovery of fine gold from alluvial deposits, but more importantly in the Patio process in the recovery of gold from the reef quartz matrix.

Several features of the operation of stamping batteries have facilitated the entry of mercury into streams.

During the crushing of the quartz, mercury was put into the stamping boxes in amounts estimated to be about twice the weight of gold contained in the ore. The stamping boxes were continuously flushed with water and the slurry of fine particles of quartz, amalgam and gold then passed over a copper plate covered with mercury. The tailings were then passed to a concentrator or to a Wifley table for further recovery of fine gold. After a period, the "clean-up" of the battery was made, and the amalgam was retorted to remove the mercury, which was then recycled.

Batteries were invariably located near streams for the provision of water for motive power and steam generation and to facilitate the hydraulic transport of the pulverized minerals.

Tailings, which contained mercury from the amalgamation process, and sulphide minerals of arsenic, lead, copper, zinc and other metals were discarded nearby into any convenient gully. Oxidation of these sulphides has allowed the leaching into the rivers of sulphates of copper and zinc; oxides of arsenic are also mobilized. The drainage from tailing dumps is highly acidic because of the sulphuric acid produced by oxidation of the sulphides.

Production figures for the major mines in the Thomson and Aberfeldy areas are summarised by Tomlin et al. (1979). More than 1,530,000 tonnes of ore was crushed for a yield of 1,613,185 troy ounces of gold. Mercury loss may be conservatively estimated by assuming that 15 grams of mercury were lost for each tonne of ore crushed (Hunt, personal communication). This calculation gives a figure of 23 tonnes of mercury. A more realistic rate of loss may be 0.75 troy ounces (about 23 grams) of mercury per tonne of ore crushed (Griffiths, personal communication), which yields a figure of 36 tonnes of mercury lost.

Other goldfields where reef mining was undertaken and stamping batteries and amalgamation processes operated were located in the Nicholson River, Upper Tambo and Crooked River areas. (Flett, 1970). Because of the difficulty of separating the gold from the heavily mineralized matrix in the Tongio

Cassilis area (Upper Tambo) losses of mercury were excessively high when compared with other fields (Fairweather, 1975). Griffiths (personal communication) has estimated that a minimum of 40 tonnes of mercury was lost from the goldfields of the Nicholson, Tambo and Mitchell river areas.

Loss of mercury due to goldmining into the catchment area of the Gippsland Lakes is therefore calculated as being between 63 and 76 tonnes. Bearing in mind the incomplete state of production records and the conservative nature of the calculations, considerably more mercury may have been lost to the environment. Even so this is small compared to estimated mercury losses due to gold mining in the Carson River system, Nevada, U.S.A. Losses during the period from 1865-1895 have been estimated as about 7,000 tonnes (Richins, R.T. and Risser, A.C., 1975).

### 3.1.2 Mining of other minerals*

#### 3.1.2.1 Antimony

Antimony as stibnite (antimony sulphide) and as bournonite (a sulphide of copper, lead and antimony) has been found in the gold-bearing quartz at Walhalla. Stibnite was also associated with gold in quartz veins in the Neerim-Noojee goldfields. Sulphides of antimony were also present in the highly mineralized ore bodies at Tongio and Cassilis on the upper reaches of the Tambo River.

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* Anon (1970).

3.1.2.2 Arsenic

Arsenic occurs chiefly as arsenopyrite in lode formations and is disseminated throughout sedimentary deposits. In the refractory, highly mineralized auriferous ores of the goldfield on the upper reaches of the Tambo River, the arsenopyrite made extraction of gold difficult. Consequently the gold-bearing ore was roasted, an operation which released large amounts of white arsenic (arsenic trioxide). Arsenopyrite is often found in tailings dumps, and during aerial oxidation yields sulphuric acid and arsenious oxide.

3.1.2.3 Cobalt

Small deposits of cobalt have been reported from the Eureka Dyke at Walhalla and in the auriferous reefs at Grant on the Crooked River. Cobalt was also found associated with nickel at Bulumwaal.

3.1.2.4 Copper

The earliest discoveries of copper in the catchment were at Coopers Creek where it occurs as elemental copper and chalcopyrite (iron copper sulphide), which is also present in most gold-bearing quartz. These deposits were mined intermittently for many years.

Recent geochemical surveys have indicated that deposits of copper are widely disseminated in the metamorphic rocks of the tablelands along the upper reaches of the Tambo River. Plans for development of the deposits are well advanced, and mining is expected to start shortly.

3.1.2.5 Chromium

Chromite (iron chromate) has been discovered north-east of Licola, and in sand from several streams in the catchment.

3.1.2.6 Iron

The main deposit of iron is at Nowa Nowa where the presence of relatively large quantities of haematite has been proved by survey. Iron occurs as pyrites (iron sulphide) in most auriferous reefs, as its oxides in many sandstones and in conglomerates as the cementing medium.
The Nowa Nowa deposit is not exploited at present, but has limited commercial potential because of the readily available deposits in S.A. and W.A.

3.1.2.7 Lead

Lead ores are widely distributed in Ordovician Silurian strata of the catchment. Where the ores are below the zone of surface decomposition the metal exists as galena in association with gold, pyrite, arsenopyrite, bornite and blende; in the weathered surface layers the lead occurs as cerussite, pyromorphite and other hydrated oxides and carbonates in association with malachite and azurite (hydrated copper carbonates) and limonite (hydrated iron oxide).

Lead sulphide occurs at Cassilis in association with the sulphides of other metals.

3.1.2.8 Manganese

Most of the manganese in the catchment is associated with the haematite deposits at Nowa Nowa, although as the oxide manganese occurs widely in small veins, films and coatings on quartz at Walhalla.

3.1.2.9 Mercury

No geochemical data support the often expressed belief that naturally occurring mercury is widespread in Victoria. All available evidence implicates traditional methods of treating gold ores as the source of mercury contamination of the catchment's streams and lakes.

Fragments of mercuric sulphide are said to have been found near a quartz reef at Bullumwaal, and mercury has been reported associated with gold at Gray's Creek, in the Upper Tambo area in 1892 (Fairweather, 1975).

3.1.2.10 Nickel

The presence of nickel in the Eureka Dyke near Coopers Creek, and at Grant, on the Crooked River, has been mentioned in the reference to cobalt.

3.1.2.11 Silver

Silver as an alloy with gold is found wherever gold occurs, as the chloride at Bullumwaal, and particularly in association with jamesonite (lead antimony sulphide) around Tongio, Cassilis and other goldfields on the Tambo River. As much as 150 troy ounces of silver per ton of ore were recovered (about 4.6 kg/Tonne).

3.1.2.12 Tungsten

The tungsten ores found in the catchment are associated with granite and granidorite. Wolfram (tungstate of iron and manganese) weathered from the granite, occurs widely in streams particularly in the Nicholson River and Boggy Creek, near Bairnsdale. There is a deposit of scheelite (calcium tungstate) in quartz at Boggy Creek.

3.1.2.13 Zinc

Zinc as sphalerite (zinc sulphide) has been found in the highly mineralized lodes in the Cassilis-Tongio area. Roasting and flotation used to treat these complex bodies of ore probably resulted in some contamination of the local environment (as it certainly did with arsenic).

3.1.3 Metals of less importance

3.1.3.1 Thorium has been located near Tabberabbera, but the deposit is not of commercial importance.

3.1.3.2 Platinum as an alluvial deposit, has been found in the Thomson River above Coopers Creek. In association with palladium it has been found in copper-bearing quartz from Coopers Creek and Frenchmans Gully, Aberfeldy.

3.2 Industrial and domestic wastes

Domestic sewage and industrial waste from many of the large towns in the Latrobe Valley (excepting Morwell, Traralgon, Sale, Churchill and Yallourn North) is discharged after treatment into the Latrobe River (Anon., 1978). Similar discharges from smaller towns in the catchment enter the Thomson, Macalister, Avon, Mitchell and Tambo Rivers.

Australian Paper Manufacturers at Maryvale are licensed by the Environment Protection Authority to discharge waste water into the Latrobe River. According to the licence up to 200 kg. of mercury, 10,000 kg of chromium and 2,000 kg of lead could be discharged per year. The State Electricity Commission of Victoria is also licensed to discharge liquid waste into the river. A maximum of 130 kg per year of chromium, copper and zinc could enter the river from this source.

Waste water from the A.P.M. chloralkali plant at Maryvale used to flow directly into the Latrobe River. The plant was built in 1956 and produces about 10 tonnes of chlorine per day (Norman, personal communication). Caustic soda is also produced.

Mercury losses from older mercury cathode chloralkali plants have been estimated at 200 grams per tonne of chlorine produced, but losses have been considerably reduced since the 1960's, when the problem of mercury contamination of aquatic animals was first recognised (Nobbs, 1972). The maximum contribution of mercury to the Latrobe River from A.P.M. may therefore be calculated as 14 tonnes, assuming continuous operation over 20 years.

However, after allowing for operation at less than full capacity, for the diversion of the waste water from the chloralkali plant to the sewer in recent years* and for some of the mercury loss being due to vapourisation and retention in the caustic soda, this estimate may be modified to about 10 tonnes.

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* The E.P.A. required A.P.M. to cease discharging waste water from the chloralkali plant into the Latrobe River on or before 1 October, 1974.

By contrast, Davidson and Stewardson (1974) quoting a Tasmanian Department of Environment report (Environmental Pollution in Tasmania, 1972) give a estimate of 3,300 lbs (1.5 tonnes) of mercury entering the environment from paper making operations, in that state, in each year.

As far as is known, phenyl mercuric acetate, often used as a slimicide in paper manufacture, was not used extensively at A.P.M. Maryvale, and in any case, would have been discharged to the sewer and would probably remain in the sedimenting basins known as "cardboard ponds".

## 3.3 Airborne Sources

### 3.3.1 Atmospheric fall-out of heavy metals from thermal power stations

Almost 90% of Victoria's electricity generation capacity is located in the Latrobe Valley. With the construction of Loy Yang station the proportion will be increased, with only a small part of the total being located outside the valley.

Coal consumption which averaged about 12 million tonnes in the late 50's has now more than doubled, and will double again in the next 10-15 years.

The heavy metal content of fossil fuels is generally low, but consumption of brown coal in the Latrobe Valley is so large that the release of heavy metals may contribute significant amounts of pollutants into the atmosphere.

Steam for electricity generation is raised in boilers fired by pulverised brown coal. About 26 million tonnes of coal are consumed per annum.

When the coal is burnt, some heavy metals are concentrated in the fly-ash and some in the vapour (Klein et al. 1975). Equipment to trap 95-99% of the fly-ash is now installed in most of the power stations in the Latrobe Valley. However, it is probable that the greater proportions of very volatile elements, such as mercury and selenium, are lost to the atmosphere, either as vapour or adsorbed onto fine fly-ash particles (Swaine, 1978). Klein et al (1975) have shown in a study of a cyclone-fed coal burning power plant that up to 90% of the mercury and 20% of the selenium in the coal may be lost to the atmosphere as vapour. In addition, they state that other relatively volatile elements such as arsenic, cadmium, copper, lead and zinc are not retained as efficiently by the precipitation equipment as the less volatile elements due to preferential adsorption on very fine fly-ash particles. This latter point is significant for pulverised-coal fired power stations, because about 90% of the total ash is fly-ash (Klein et al. 1975). Calculations of the rate of discharge of various elements based on an annual combustion of 26 million tonnes of brown coal, the average concentrations of trace elements in Australian bituminous coal (Swaine 1977), in the absence of any figures for brown coal, and the percentage losses to the atmosphere found by Klein et al. (1975) are summarised in Table 3.1.

Table 3.1 Estimated rates of discharge of heavy metals to the atmosphere from the power stations in the Latrobe Valley.

| Metal | Concentration in coal (ug/g) * | Loss to atmosphere (%)# | Discharge to atmosphere (tonnes/year) |
|---|---|---|---|
| Arsenic | 3 | 2 | 1.5 |
| Cadmium | 0.1 | 2 | 0.05 |
| Copper | 15 | 2 | 7.5 |
| Lead | 10 | 2 | 5 |
| Mercury | 0.1 | 90 | 2.3 |
| Selenium | 0.8 | 20 | 4 |
| Zinc | <100 | 2 | <50 |

* Swaine (1977). # Klein et al (1975)

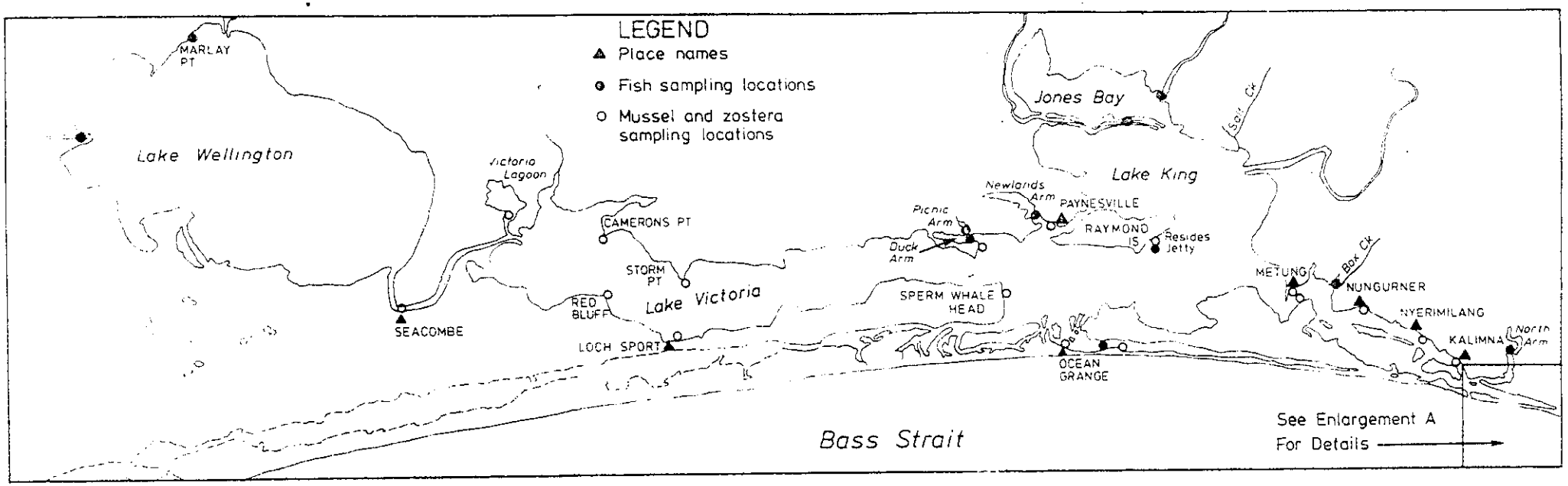
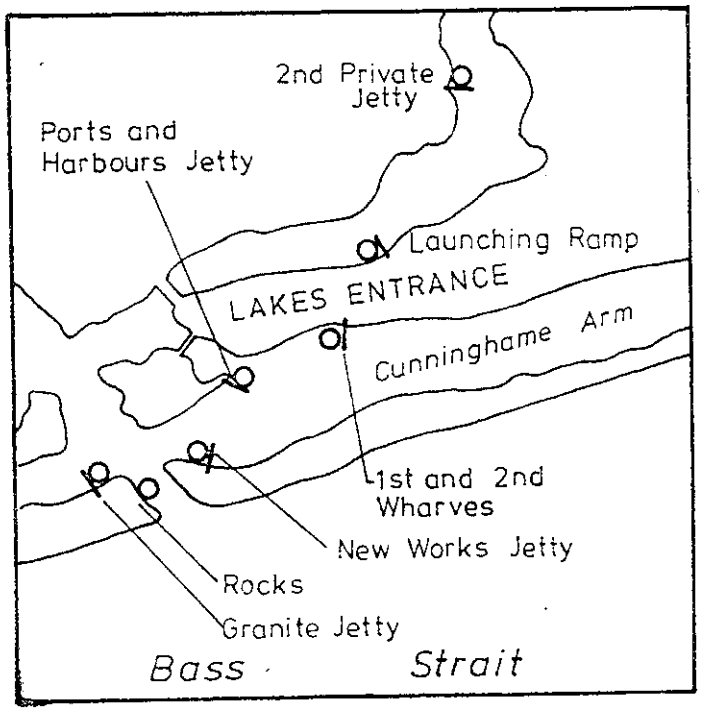



Figure 4.1 Fish, mussel and Zostera sampling stations.

Enlargement A



# 4. RESULTS AND DISCUSSION

## 4.1 Fish

Nineteen species of fish were caught in the lakes (Fig. 4.1) although only three or fewer specimens were obtained for six species. Three species, blackfish, carp and trout were obtained from other areas for comparison. Liver and gill, or viscera if the fish were small, were analysed for the 11 metals, but muscle was analysed only for mercury. Preliminary experiments showed that the concentrations of metals were higher in liver than in muscle. The results of analyses of all fish are given in Appendix XII.

Concentrations of mercury in fish (Table 4.1) were very variable, 0.01-3.7 ug/g, dry wt in muscle and 0.14-8.8 ug/g, dry wt in liver. The concentration of mercury was usually higher in the liver than in the muscle of dusky flathead, luderick, yellow-eye mullet, sand mullet and sea mullet; the converse was true for estuary perch, tailor, bream and carp. The concentration of mercury in gills was usually about one-half or one-quarter of that in liver.

Of the 23 dusky flathead analysed, 9 had a mercury concentration in muscle tissue of 2.5 ug/g, dry weight, or higher. Of the species analysed, flathead was the only species in which some specimens exceeded the Victorian Health Department statutory limit of 0.5 ug/g, wet weight, or 2.5 ug/g, dry weight. One bream also exceeded the statutory limit, but was the only example from 102 specimens analysed.

Linear regressions of mercury concentration against total length were calculated for all species. Significant correlations were obtained for muscle tissue of bream, tailor, dusky flathead and estuary perch. No correlations were obtained for liver tissues (Table 4.2).

Table 4.1(a) Mercury concentration in fish tissues in the Gippsland Lakes (ug/g, dry weight).

| Species | No. of fish | Length (cm) | | Concentration of mercury (ug/g. dry weight) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Muscle | | | Liver | | | Gills | | |
| | | Mean | Range | No. analysed | Mean | Range | No. analysed | Mean | Range | No. analysed | Mean | Range |
| Flathead | 23 | 62.1 | 43.0-78.5 | 23 | 2.19 | 0.52-3.7 | 17 | 3.78 | 0.52-8.8 | 2 | 0.19 | 0.19-0.19 |
| Estuary Perch | 21 | 24.3 | 15.8-31.8 | 21 | 1.05 | 0.52-2.0 | 15* | 0.81 | 0.28-1.9 | 5 | 0.31 | 0.16-0.39 |
| Tailor | 16 | 23.1 | 13.3-32.9 | 16 | 1.09 | 0.49-1.8 | 6* | 0.84 | 0.32-1.8 | 1 | 0.46 | |
| Scad | 3 | 24.3 | 22.9-25.6 | 3 | 0.76 | 0.51-0.93 | 1* | 0.77 | | 1 | 0.27 | |
| Trevally | 8 | 20.7 | 12.9-29.5 | 7 | 0.61 | 0.20-1.5 | 2 | 1.5 | 1.4-1.5 | 1 | 0.12 | |
| Bream | 100 | 20.4 | 10.1-37.1 | 100 | 0.54 | 0.15-2.2 | 41 | 0.59 | 0.17-1.5 | 7 | 0.19 | 0.08-0.35 |
| Carp | 19 | 39.4 | 30.0-52.5 | 19 | 0.52 | 0.30-0.85 | 5 | 0.35 | 0.25-0.47 | 3 | 0.16 | 0.13-0.19 |
| Luderick | 14 | 29.? | 17.5-44.5 | 14 | 0.38 | 0.05-1.05 | 7 | 0.56 | 0.40-0.85 | 2 | 0.13 | 0.06-0.19 |
| Yellow-eye Mullet | 43 | 24.0 | 12.6-34.1 | 43 | 0.33 | 0.10-0.81 | 23 | 1.31 | 0.54-3.2 | 4 | 0.20 | 0.05-0.31 |
| Sand Mullet | 9 | 26.3 | 23.9-34.0 | 9 | 0.23 | 0.15-0.40 | 7 | 1.46 | 0.45-3.0 | 2 | 0.20 | 0.20-0.20 |
| Sea Mullet | 45 | 39.0 | 22.9-51.8 | 45 | 0.08 | 0.01-0.58 | 42 | 0.72 | 0.14-4.5 | 2 | 0.13 | 0.07-0.18 |
| Eels | 11 | | 36.5-119 | 11 | 1.09 | 0.58-1.79 | 3 | 0.52 | 0.45-0.60 | ns | | |
| Sole | 3 | 17.4 | 16.5-18.5 | 3 | 0.05 | 0.01-0.10 | ns | | | ns | | |
| Tupong | 1 | 18.2 | | 1 | 0.64 | | ns | | | ns | | |

ns = not sampled

* Including one bulked sample.

Table 4.1(b) Mercury concentrations in whole fish in the Gippsland Lakes.

| Species | No. of fish | Length (cm) | | Concentration of mercury (ug/g, dry weight) | |
|---|---|---|---|---|---|
| | | Mean | Range | Mean | Range |
| Bullhead Gudgeon | 1 | 8.1 | | 0.14 | |
| Flounder | 2 | 3.9 | 3.5-4.3 | 0.08* | |
| Salmon | 2 | 8.2 | 8.2-8.2 | 0.42 | 0.39-0.45 |
| Bream | 2 | 8.5 | 7.9-9.1 | 0.19 | 0.12-0.25 |
| Yellow-eye Mullet | 3 | 9.7 | 9.0-10.3 | 0.27 | 0.17-0.44 |
| Hardyhead | 5* | 5.1 | 3.8-6.3 | 0.76 | 0.66-0.88 |
| Anchovy | 1* | 6.5 | | 1.02 | |
| Shrimp | 1* | 3.8 | | 1.64 | |
| Tupong | 1 | 14.1 | | 0.42 | |

* bulked samples

Table 4.2 Linear regression of mercury concentration in muscle and liver tissue against length of fish.

| Species | Muscle | | Liver | |
|---|---|---|---|---|
| | No. analysed | Correlation coefficient | No. analysed | Correlation coefficient |
| Tailor | 16 | 0.819 * | 5 | 0.54 |
| Estuary Perch | 21 | 0.460 # | 14 | -0.43 |
| Bream | 100 | 0.783 * | 40 | 0.17 |
| Flathead | 23 | 0.410 # | 17 | 0.446 |

* Significant at the 0.1% level

# Significant at the 5% level

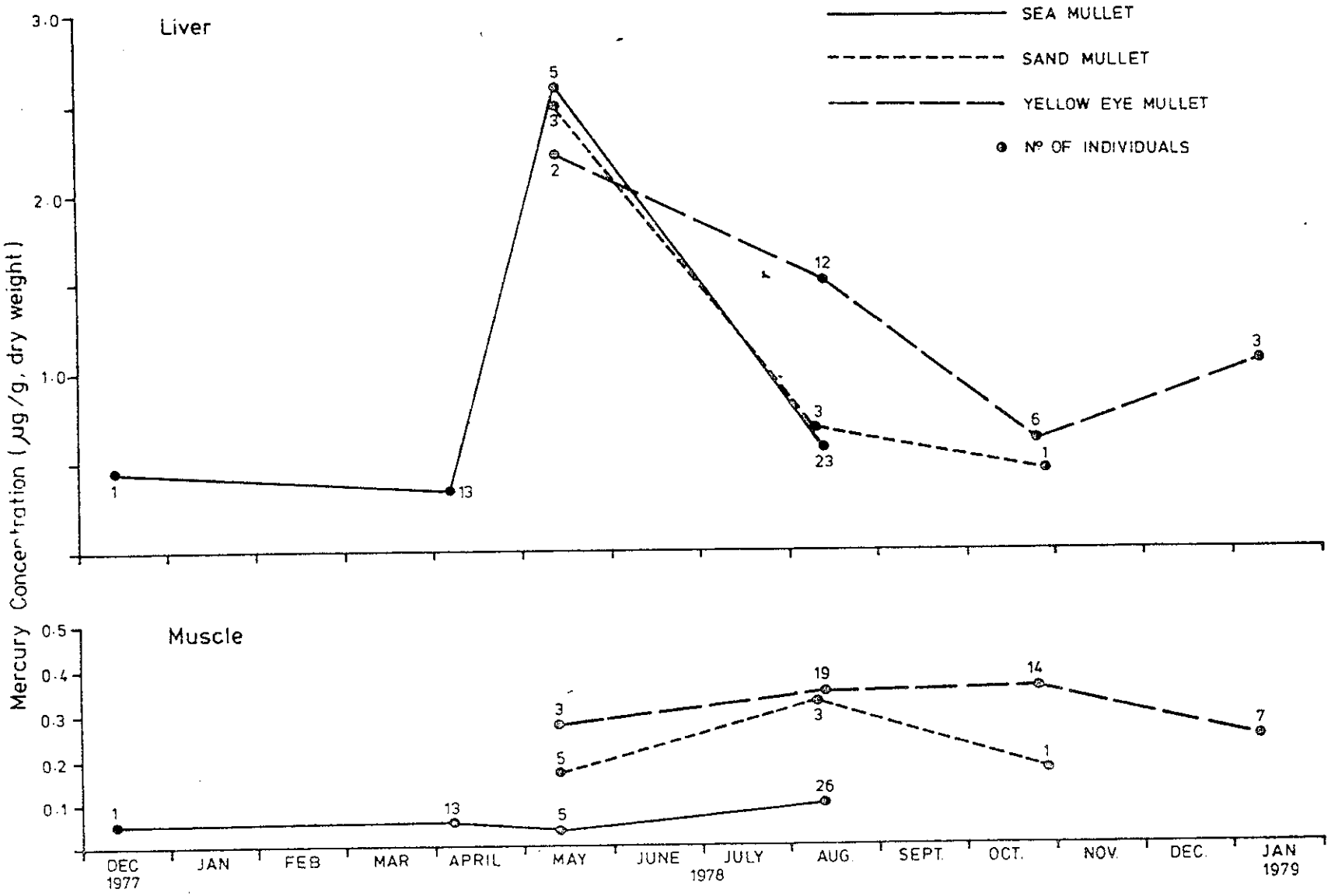



Figure 4.2 Concentrations of mercury in mullet.

Analysis of mullet for mercury (Fig. 4.2) clearly shows, despite the few samples analysed, that mercury concentration in the liver rises just after the first freshwater flush (3 April 1978). There is a more gradual and much smaller rise in mercury concentration in the muscle.

Other species of fish which were sampled before and after the freshwater flush in April 1978, such as dusky flathead and bream, do not show a marked rise in the concentration of mercury in the liver as observed in mullet.

Cobalt, chromium, lead and nickel were detected in the livers of only two sand mullet and two sea mullet, and even in these the values obtained were very close to the limit of detection (see Table 7.1 for limits of detection for all elements).

Cadmium was detected in about 22% of liver samples (Table 4.3). The livers of one bream, one tailor, six luderick, four silver trevally, and three yellow-eye mullet had more than 1.0 ug/g, dry weight, of cadmium. One luderick had 15 ug/g and one silver trevally had 16 ug/g.

Table 4.3 Cadmium concentration in liver of fish from the Gippsland Lakes greater than the limit of detection of about 0.5 ug/g, dry weight.

| Species | Number analysed | No. over detn. limit | Concentration over detn. limit | | |
|---|---|---|---|---|---|
| | | | Range | Mode | Mean |
| Bream | 35 | 15 | 0.45-1.9 | 0.70 | 0.81 |
| Carp | 5 | 1 | 0.58 | 0.58 | 0.58 |
| Tailor | 9 | 3 | 0.55-6.4 | 0.68 | 2.54 |
| Dusky Flathead | 9 | 1 | 0.94 | 0.94 | 0.94 |
| Luderick | 9 | 6 | 1.5-14.9 | 4.9 | 5.1 |
| Silver Trevally | 7 | 4 | 1.0-16 | 4.3 | 6.4 |
| Yellow-eye Mullet | 31 | 5 | 0.6-3.9 | 1.1 | 1.5 |
| Sea Mullet | 31 | 4 | 0.5-0.8 | 0.60 | 0.61 |

Table 4.4 Mean and standard deviation of concentrations of metals other than mercury in fish liver.

| Species | No. of livers analysed | Concentration and standard deviation in liver (ug/g, dry weight) | | | | | |
|---|---|---|---|---|---|---|---|
| | | As | Cu | Fe | Mn | Se | Zn |
| Bream | 31 | 3.2 ± 2.1 | 83 ± 58 | 1321±1144 | 4.5 ± 1.8 | 7.8 ± 3.8 | 323 ± 136 |
| Carp | 5 | 0.52 ± 0.17 | 97 ± 35 | 357± 210 | 2.6 ± 1.0 | 3.9 ± 1.2 | 383 ± 67 |
| Tailor | 9 | 1.6 ± 0.6 | 9.8 ± 2.1 | 747± 333 | 2.4 ± 1.7 | 6.4 ± 2.4 | 80 ± 21 |
| Estuary Perch | 17 | 4.0 ± 2.3 | 18 ± 9 | 317± 156 | 6.4 ± 2.3 | 8.9 ± 2.8 | 82 ± 31 |
| Dusky Flathead | 9 | 0.35 ± 0.16 | 9.2 ± 4.3 | 1090± 600 | 1.1 ± 0.6 | 4.6 ± 1.9 | 87 ± 32 |
| Luderick | 9 | 1.8 ± 0.9 | 137 ± 77 | 689± 395 | 3.9 ± 1.1 | 8.3 ± 2.0 | 250 ± 132 |
| Silver Trevally | 7 | 8.0 ± 3.6 | 24 ± 9 | 573± 150 | 7.1 ± 2.0 | 9.3 ± 2.3 | 183 ± 35 |
| Sand mullet | 9 | 3.8 ± 2.0 | 89 ± 61 | 848± 631 | 2.6 ± 1.6 | 5.5 ± 1.6 | 174 ± 67 |
| Yellow eye mullet | 31 | 3.6 ± 2.5 | 20 ± 10 | 1530±1160 | 5.3 ± 3.6 | 10.5 ± 4.3 | 119 ± 32 |
| Sea mullet | 31 | 3.9 ± 2.2 | 570 ± 480 | 995± 358 | 2.7 ± 0.9 | 16.4 ±12.4 | 176 ± 92 |

The concentrations of arsenic, copper, iron, manganese, selenium and zinc in fish livers are summarised in Table 4.4. Arsenic in flathead and carp is about one-tenth that in other species, as is copper in flathead, tailor, yellow-eye mullet and silver trevally. The mean concentrations of manganese, selenium, iron and zinc for all species are more uniform and the lowest and highest concentrations differ by only a factor of five. Variation between individuals within a species is statistically significant. In most cases the standard deviation for the concentration of one metal in a species is of the same order, and sometimes more than half of the mean. The concentration of iron in bream liver for instance varies between 159 and 11,570 ug/g although most values are betwen 400 and 2000 ug/g. In all species the concentration of manganese is greater in gills than in liver, whereas the concentrations of iron, arsenic, copper, zinc and selenium are always greater in liver than in gills.

The concentrations of mercury in mullet indicate a high mercury concentration in the diet of mullet (and therefore in the water) at the time of high river flow into the lakes. The mercury, whether dissolved in the water, or adsorbed onto fine particulate matter, could be absorbed quickly by the relatively small organisms which comprise the diet of mullet (Scott et al. 1974).

The fact that dusky flathead and bream do not give similar results to mullet may be because these fish, which accumulate mercury in their flesh to a greater extent than mullet, normally feed on organisms with higher mercury concentrations than those which comprise the diet of mullet. This could cause daily fluctuations of mercury concentration in liver comparable to that observed for mullet over a much longer period. In addition, a temporary rise in mercury concentration in the water takes some time to manifest itself in fish muscle as has been shown for mullet. Any sustained rise in mercury concentration of liver for a predatory fish, such as flathead, which feeds on other fish, will occur later still.

Table 4.5 Mean and range of concentrations of metals in different tissues of a sample of nine common mussels from the Gippsland Lakes.

| Organ | Concentration (ug/g, wet weight) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Cd | Co | Cu | Fe | Mn | Ni | Pb | Zn |
| Byssus | | | | | | | | |
| mean | 0.44 | 3.1 | 10 | 310 | 77 | | 4.2 | 51 |
| range | 0.14–0.82 | 1.7–6.2 | 4.9–20 | 160–520 | 6.6–140 | 3.4–30.0 | 1.2–14 | 7.6–110 |
| Muscle | | | | | | | | |
| mean | 0.26 | 0.45 | 0.70 | | 1.4 | 0.88 | 0.24 | 30 |
| range | 0.13–0.54 | 0.08–1.2 | 0.24–1.4 | 6.6–7.0 | 0.75–4.8 | 0.12–3.4 | <0.02–1.1 | 17.48 |
| Gill | | | | | | | | |
| mean | 0.36 | 0.85 | 1.4 | 64 | 2.8 | 2.3 | 0.86 | 31 |
| range | 0.14–0.92 | 0.05–1.3 | 1.2–1.7 | 22–210 | 1.2–3.7 | 0.35–9.5 | <0.02–5.0 | 12–75 |
| Foot | | | | | | | | |
| mean | 0.66 | 3.3 | 1.6 | 48 | 5.0 | 12.3 | 0.57 | 12 |
| range | <0.02–1.9 | 1.3–7.8 | 0.93–2.5 | 25–110 | 1.3–23 | <0.1–67 | <0.1–2.0 | 7.7–19 |
| Mantle | | | | | | | | |
| mean | 0.13 | 0.15 | 1.1 | 19 | 1.3 | 0.99 | 0.10 | 9.5 |
| range | 0.04–0.25 | 0.09–2.0 | 0.53–2.0 | 7.8–47 | 0.59–3.1 | 0.12–2.2 | <0.02–0.47 | 0.9–16 |
| Viscera | | | | | | | | |
| mean | 2.9 | 0.74 | 15 | 49 | 6.0 | 3.3 | 0.37 | 170 |
| range | 0.38–19 | 0.14–1.4 | 1.7–107 | 35–93 | 1.9–30 | 0.59–15 | <0.02–1.8 | 16–>1000 |

Table 4.6 Different tissues of common mussel, ranked in order of decreasing metal concentration, from mussels of nine different localities in the Gippsland Lakes.

| Rank | Tissues in which each metal was found | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Cd | Co | Cu | Fe | Mn | Ni | Pb | Zn |
| 1 | viscera | foot | byssus | byssus | byssus | byssus | byssus | byssus |
| 2 | byssus, foot | byssus | viscera | viscera | foot | foot | gills | viscera |

## 4.2 Mussels

Common mussels (Mytilus edulis planulatus, (Linne, 1758) were collected in March 1978, from locations near Lakes Entrance, and up as far as Nungurner (Figure 4.1). These samples were dissected before analysis to determine the relative concentrations of each metal in the different tissues. The results are given in Appendix VI and the mean and range of concentrations for mussel tissues over all locations are presented in Table 4.5. The data indicate that the viscera concentrates cadmium, copper and zinc, the byssal threads concentrate every metal and the feet concentrate cobalt and nickel. However, the mean values calculated are greatly affected by the sample from Nungurner, which has very high concentrations of cadmium, copper, manganese and zinc.

If the concentrations of each metal in each tissue from the nine samples are ranked from highest to lowest (Table 4.6) copper, iron, manganese, nickel, lead and zinc in a mussel are most often concentrated in the byssus, cadmium in the viscera and cobalt in the foot. An exception is the sample from Nungurner in which copper and zinc are concentrated in the viscera rather than the byssus; the relatively excessive concentrations of metals present may be the reason.

Extensive flooding in mid 1978 flushed the whole lakes system with fresh water, including areas near the entrance, such as Cunningham Arm and North Arm. Consequently, during sampling in August 1978, the common mussel was found only on the rocks and granite jetty immediately inside the entrance. Mussels were collected from these two sites in August and October. The common mussel had recolonised Kalimna jetty by March 1979, and some small mussels were collected and analysed as one sample. The results of analyses of these common mussels are presented in Appendix VII, and summarised in Table 4.7.

Table 4.7 Mean and standard deviation of concentrations of metals in common mussels from various locations in the Gippsland Lakes.

| Location | Date | No. of samples | Mean length (mm) | Mean concentration ± standard deviation (ug/g, dry weight) of: | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | As | Cd | Cu | Fe | Hg | Mn | Se | Zn |
| Granite jetty | 9.8.78 | 10 | 58 | 2.6±1.3 | 3.2±1.2 | 3.7±0.9 | 105±42 | 3.8±2.6 | 4.1±0.8 | 4.6±0.8 | 67±37 |
| Granite jetty | 25.10.78 | 4 | 48 | 1.9±1.6 | 4.2±1.5 | 4.0±4.8 | 83±13 | | 4.9±1.5 | 4.3±1.1 | 86±48 |
| Rocks | 9.8.78 | 19* | 50 | 6.4±2.3 | 2.9±1.1 | 4.6±1.1 | 114±49 | | 7.9±2.5 | 4.3±1.3 | 129±48 |
| Rocks | 25.10.78 | 11# | 48 | 13.4±3.1 | 2.3±1.1 | 4.8±2.0 | 81±42 | 0.13±0.06 | 12.1±3.9 | 3.3±1.3 | 51±18 |
| Kalimna | 1.3.79 | 11 | 16 | 11.0 | 1.0 | 4.5 | 167 | <0.05 | 21 | 6.4 | 53 |

* including 3 beaked mussels

\# including 2 beaked mussels

Table 4.8 Mean and range of concentration of metals in common mussels from various Victorian waters.

| Water body | Sampling date | No. of localities sampled | No. of individuals | Concentration (ug/g, dry weight) and range of: | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Cd | Cu | Fe | Mn | Pb | Zn |
| Western Port* | 23.4.74 to 12.2.76 | 16 | 400+ | 1.0<br>0.11-4.41 | 4.7<br>1.7-10.3 | 522<br>244-888 | 6.1<br>3.5-11.4 | 1.8<br>0.3-11.6 | 202<br>128-331 |
| Port Phillip Bay* | 14.10.75 to 9.4.76 | 26 | 570 | 3.4<br>1.1-5.9 | 5.5<br>3.9-12.3 | 302<br>70-601 | 9.4<br>4.7-33.3 | 8.4<br>0.6-39 | 173<br>77-345 |
| Gippsland Lakes (At entrance to sea only) | 9.8.78 to 1.3.79 | 3 | 51 | 2.7<br>1.0-4.2 | 4.3<br>3.7-4.8 | 110<br>83-167 | 9.8<br>4.1-21 | | 79<br>51-138 |

* Fabris et al. (1976a).

Although not all common mussels were analysed for mercury, the results show that the mercury content of mussels collected during August was thirty times that of mussels collected in October; similarly that in October was twice that in March. The other metals vary less markedly.

The results obtained for the common mussel in this study and those obtained for the same species in Port Phillip Bay and Western Port are given in Table 4.8. Unfortunately, figures for mercury are not available for comparison. The higher cadmium concentrations and the lower iron and zinc concentrations of mussels from the Gippsland Lakes compared to those from Western Port and the similarity in copper concentration for all mussels are noteworthy.

A small mussel, the Little Black Horse mussel (Modiolus pulex Lamark, 1819) was found on piles and attached to Zostera roots in the sediment of the littoral zone. This species was found as close to the sea as Kalimna and as far away as Resides Jetty and Loch Sport. As the largest individuals were only 37 mm long, and most were between 20 and 25 mm long, 10-20 individuals were necessary to obtain a sample of acceptable size for chemical analysis.

The analytical results for all horse mussels are given in Appendix VIII. Table 4.9 summarises the results for each sampling date. Figure 4.3 illustrates the information contained in Table 4.9.

The mercury concentration in mussels from the first sampling was ten times that from the second sampling, whose mercury concentration was twice that of the third sampling. Manganese and arsenic increase by a factor of four from the first to the third sampling and selenium and cadmium by a factor of two over the same period. Iron and zinc show a maximum concentration in the second sampling. The concentration of copper remains relatively constant throughout.

Table 4.9 Mean and standard deviation of concentrations of metals in Little Black Horse mussels collected from piles and sediments in the Gippsland Lakes, according to sampling date.

| Date of sampling | No. of samples | Mean no. of mussels per sample | No. of locations | Mean mussel length | Mean ± standard deviation (ug/g, dry weight) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | As | Cd | Cu | Fe | Hg | Mn | Se | Zn |
| From piles | | | | | | | | | | | | |
| 9.8.78 | 4 | 10 | 1 | 23 | 2.3±1.3 | 1.2±0.3 | 10.7±1.6 | 170±34 | 5.7±2.0 | 7.5±0.9 | 2.8±0.2 | 46.5±1.9 |
| 25.10.78 | 11 | 15 | 6 | 23 | 7±3 | 1.2±0.5 | 11.5±0.7 | 241±76 | 0.29±0.14 | 20±13 | 4.2±0.4 | 59±5 |
| 1.3.79 | 11 | 14 | 9 | 23 | 11±1 | 2.0±0.9 | 11.0±1.9 | 111±33 | 0.13±0.08 | 30±18 | 5.4±2.5 | 44±4 |
| From sediments | | | | | | | | | | | | |
| 8.8.78 | 2 | 8 | 2 | 19 | 3.3 | 1.7 | 17 | 256 | N.A | 10 | 4.1 | 58 |
| 24,25.10.78 | 4 | 15 | 3 | 19 | 10.1 | 1.0 | 15 | 465 | 0.46 | 24 | 3.8 | 64 |
| 1.3.79 | 1 | 11 | 1 | 19 | 8.4 | <0.7 | 17 | 258 | 0.46 | 21 | 3.4 | 49 |

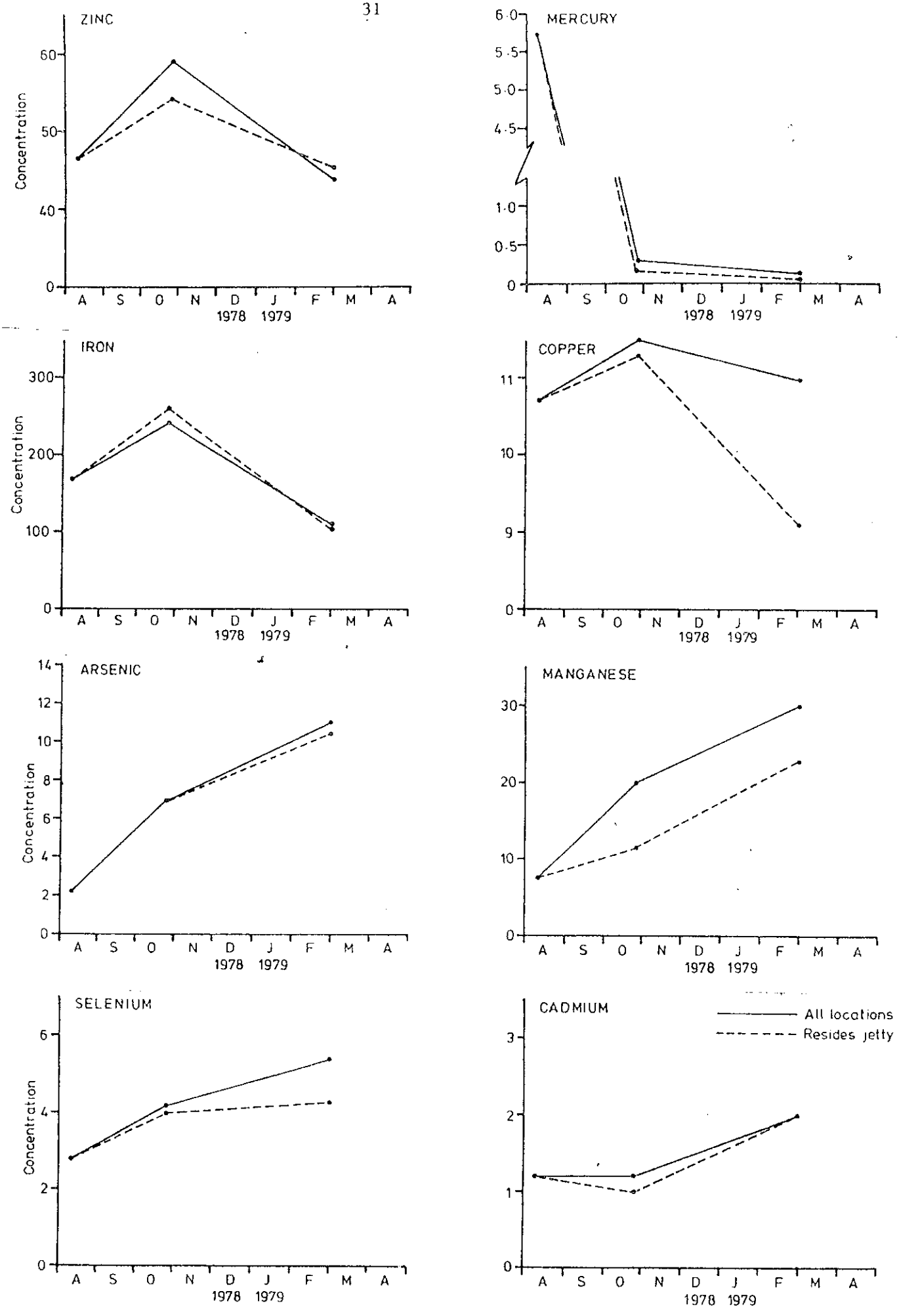



Figure 4.3 Concentrations of heavy metals (ug/g, dry weight) in Little Black Horse mussels

The Modiolus pulex found in the sediment attached to Zostera roots had concentrations of metals, other than iron and copper, markedly similar (Table 4.9) to those of mussels found on piles although they were about 20% smaller. Insufficient samples prevent firm conclusions being made about seasonal variations of metals in these mussels but the data suggest that the concentrations of iron and zinc decrease from winter to summer, and that those of copper, manganese and selenium remain constant.

Analyses of both species of mussel indicate that the concentration of mercury in the water or suspended solids during August is relatively high and then decreases rapidly during the next two months, and more gradually thereafter. Some of the mercury, whether dissolved in the water or adsorbed on fine suspended solids, is apparently swept out to sea, as common mussels in the entrance channel had a mean mercury concentration two-thirds that of Little Black Horse mussels in Lake King, on the same date. Nevertheless, some mercury does settle in the lakes, and was detected in the sediment (Section 4.4).

15% of the common mussels from Western Port had more than 1.5 ug/g of cadmium, compared to 95% of those from the Gippsland Lakes. Cadmium concentration in mussels from the entrance to the lakes is similar to that found in mussels from Princes Pier, Duncan's Road (Werribee), Portarlington, St. Leonards, Frankston and Mornington in Port Phillip Bay and in those from San Remo and Tooradin in Western Port (Fabris et al. 1976a).

The concentration of some metals in common mussels can be effected by the size of the mussel (Fabris et al. 1976a). In particular cadmium increases and iron and manganese decrease markedly with increasing size. This could explain the observed differences in cadmium, iron and manganese concentrations between the small mussels from Kalimna and the larger ones from other locations nearby.

Table 4.10 Concentrations of metals in Zostera muelleri from the Gippsland Lakes, according to sampling date.

| Sampling dates | No. of locations sampled | Mean concentration ± standard deviation (ug/g, dry weight) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | As | Cd | Co | Cu | Fe | Hg | Mn | Ni | Pb | Se | Zn |
| 7-9 March 1978 | 15 | N.A. | 1.1±1.5 | 5.0±3.2 | 9.0±4.1 | 540±99 | 0.23±0.14 | 344±235 | 15±6 | 8±7 | N.A. | 112±45 |
| 8-9 Aug. 1978 | 2 | 1.5±0.2 | 0.6±0.6 | 24±9 | 7.0±2.6 | 973±124 | 0.82±0.28 | 6465±2128 | 6.2±3.8 | <4 | <0.3 | 109±44 |
| 25 Oct. 1978 | 10 | 2.0±1.1 | 0.4±0.2 | 3.6±2.6 | 11.5±6.0 | 2160±1480 | 0.13±0.13 | 1275±610 | 4.0±2.4 | 0.6±0.6 | <0.5 | 62±45 |
| 10 Jan. 1979 | 1 | 0.8 | <0.5 | N.A. | 4.6 | 83 | 0.13 | 1130 | N.A. | <10 | 0.3 | 9.7 |

N.A., Not analysed

Location also affects the concentrations of metals in mussels. Mussels collected on the same day from the Granite Jetty had lower concentrations of arsenic and manganese than those from the Rocks. The concentrations of zinc from mussels at these two sites overlap a great deal because although the means are different, the range of values as indicated by the standard deviations is very wide.

The copper concentrations show remarkable consistency for all sizes, locations and sampling dates.

## 4.3 Sea Grass and other aquatic plants

Sea grass Zostera muelleri was collected in shallow water at 24 locations (Figure 4.1). Fifteen locations were sampled when water-levels were low on 3 days, 7-9 March 1978, and nine locations when the lakes were flooded on 25 October 1978 (see Appendix I for river heights and discharges). A few samples were also collected on 8-9 August 1978 (during flood) and 10 January 1979. Concentrations of metals in samples of sea grass are presented in Appendices III and IV, and those in samples of algae in Appendix V.

The mean concentrations of all metals, for four groups of samples, are given in Table 4.10. Since the first group of samples was analysed without drying, the results for this group have been converted to dry weight assuming a moisture content (based on experiment) of 80%.

The mean concentrations of arsenic, cadmium, copper and zinc varied within a factor of only two during the 10 months; those of cobalt, mercury and manganese during August were four or more times that at other times. Concentrations of iron were highest during October, and those of nickel and lead were highest during March.

Zostera from several locations shows high concentrations of some metals. At Metung, samples collected in October had concentrations of zinc, copper and lead higher than at any other location. At Newlands Arm on 9 August 1978 concentrations of cadmium, nickel, zinc and manganese were higher than those at other locations.

Zostera at Storm Point and Newlands Arm both had relatively high cadmium concentrations on 7 March 1978 and that at Launching Ramp, North Arm and Seacomb's Landing had relatively high lead concentrations.

Interpretation of these data is complicated by two factors. Firstly, the lakes were flooded with fresh water between the first and second samplings when extensive flood occurred in early April, from late May to early June, and in mid June. Secondly, Zostera may take up metal salts from the sediment (via the roots), from the water (via the leaves), or by adsorption on the surface of leaves. Absorption of metals from the water would be evident sooner than uptake from the sediment which takes some time to settle.

High concentrations of cobalt, mercury and manganese when river flow is high suggest that the salts of these metals are adsorbed onto or absorbed into the leaves. The absence of high concentrations of iron during floods suggests that the roots of Zostera absorb iron from the sediments rich in iron. Lead would tend to accumulate during low river flow, in areas of boating activity. The decrease in lead concentration later in the year may be explained as "washing" of the Zostera leaves by the freshwater flush in winter.

A refuelling, boat building and maintenance area is located at Metung, and could be the reason for the high concentrations of zinc, copper and lead found there. The high lead concentrations in Zostera from Launching Ramp, North Arm and Seacomb's Landing are probably also due to boating activity.

The elevated cadmium concentrations found at Storm Point and Newlands Arm on 7th March 1978 are not easily explained. Further sampling and analysis is required in these areas to determine the reason for the high concentrations.

Comparison of the concentrations of metals obtained in Zostera from the Gippsland Lakes with those reported for Western Port and Port Phillip Bay, (Table 4.11) shows that the concentrations of iron and manganese have a much broader range in the Gippsland Lakes samples. Samples of Zostera from the Gippsland Lakes have concentrations of copper, lead and zinc similar to those in Western Port whereas Zostera from Corio Bay shows much higher concentration of these metals.

Table 4.11 Concentrations of metals in Zostera muelleri from different Victorian waters.

| Location | Range of concentration (ug/g, dry weight) | | | | | |
|---|---|---|---|---|---|---|
| | Cd | Cu | Fe | Mn | Pb | Zn |
| Corio Bay* | 4.3-61 | 9.0-50 | 250-1070 | 185-960 | 5.0-25 | 39-270 |
| Western Port* | 0.2-1.5 | 3.0-27 | 100-3600 | 30-400 | 0.1-6.0 | 25-95 |
| Gippsland Lakes# | <0.3-6.0 | 4.1-24 | 83-4660 | 65-7970 | <0.5-4.8 | 9.7-170 |

*Samples taken and analaysed 1975-76 (Fabris et al. 1976b).

#Samples taken in this study, 1978-79.