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REPORTS

Mortality, Growth and Fecundity of Transplanted Mussel and Barnacle Populations near a Pulp Mill Outfall

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The mortality, growth and fecundity of transplanted adult mussel *(Mytilus edulis)* and barnacle *(Balanus glandula)* populations near a kraft pulp mill outfall at Port Mellon, British Columbia, were determined. The results indicated that adults of both species were tolerant of bleached kraft pulp mill effluent and survived near the pulp mill outfall. However, the growth rates of both species were retarded when compared with those at the control station. The reproductive activities of the transplanted barnacles were also impaired.

Effluent discharged from bleached kraft pulp mills is a common pollutant in the coastal waters of Canada (Davis & Mason, 1973) and the south-eastern United States (Livingston, 1975). The toxicity usually stems from effluent components such as mercaptan, lignin derivatives (Pearson, 1972) and resin acids (Howard & Walden, 1965). The high level of discharged particulate matter also increases the water turbidity and modifies the nature of the bottom substratum, thus affecting the feeding and the settling of a variety of benthic species. Many laboratory studies have been performed to determine the deleterious effects of bleached kraft pulp mill effluent on the physiology and mortality of a variety of marine species, for example, on fish (Sprague & McLeese, 1968a,b; Davis & Mason, 1973), lobster larvae (Sprague & McLeese, 1968a,b; Scaratt, 1969), shore crabs (Hardon, 1970) and oysters (Pedlow, 1974).

Studies have also been carried out in the field to relate the effects of bleached kraft pulp mill effluent to the population or community ecology of organisms. Kraft mill effluents (KMEs) have been shown to cause a significant decrease in species diversity in intertidal communities (Nassichuck, 1972; Harger *et al.*, 1973), fresh water invertebrates (Ito & Kuwada, 1964), marsh fish assemblages (Livingston, 1975), benthic macrophytes (Zimmerman & Livingston, 1976) and zooplankton communities (Copeland, 1966). Conversely, Pearson (1970, 1971) and Wildish *et al.* (1972) found little effect of KMEs on the macrobenthic communities which they studied. Such differences may be due to the properties of the effluent considered, which is usually highly variable and dependant upon the manufacturing processes (Davis & Mason, 1973).

Chemical and physical monitoring of KMEs are difficult because KME is a complicated mixture and a variety of chemical (e.g. organic acid, lignin, sulphides, sulphites, mercaptan) and physical (e.g. turbidity, dissolved oxygen, biochemical oxygen demand) parameters have to be measured. Similarly, biological monitoring at the community level requires detailed studies; and the results of laboratory toxicity testing may not be directly applicable to natural field conditions. The use of biological indicator species appears to be particularly suitable in monitoring KME pollution. However, very few data are available concerning this aspect.

Harger *et al.* (1973) reported that all barnacles (*Balanus glandula*) and mussels (*Mytilus edulis*) transplanted at a site some 3.3 km from the KME outfall at Port Alberni (British Columbia, Canada) died after 3 weeks. Interestingly, these two intertidal species are commonly found within 1 km of the KME outfall at Port Mellon, B.C. (Nassichuck, 1972; Levings & McDaniel, 1976), although they appear to be generally smaller (personal observation). This suggests that these two animals may tolerate KMEs of low toxicity but not those of high toxicity. Because of their small size, ubiquity, and ease of handling, these organisms may serve as ideal candidates for monitoring the biological effects of KME discharge. The present work was therefore carried out to determine the growth, fecundity and mortality of transplanted barnacles and mussels near the pulp mill outfall at Port Mellon. The feasibility of using these 2 species in future pulp mill monitoring was the aim.

Study Area

Port Mellon is a large bleach kraft pulp mill in Howe Sound, British Columbia, Canada (Fig. 1) producing up to 540 air-dry tons of bleached kraft pulp per day. The unneutralized pulp waste is discharged by separate acid and alkaline outfalls at approximately mid-tide level and forms one of the major contaminants in Howe Sound (Nassichuck, 1972; Levings & McDaniel, 1976). The detailed composition of the KME produced by the Port Mellon mill has been elucidated elsewhere (Davis, 1973; Davis & Mason, 1973). Field surveys have shown that organisms of all taxa were virtually absent from the lime mud near the alkaline outfall. Only the barnacle (*Balanus glandula*) and the mussel (*Mytilus edulis*) were commonly found on hard substrates (e.g. on boulders and pilings) near the mill (Nassichuck, 1972; Levings & McDaniel, 1976).

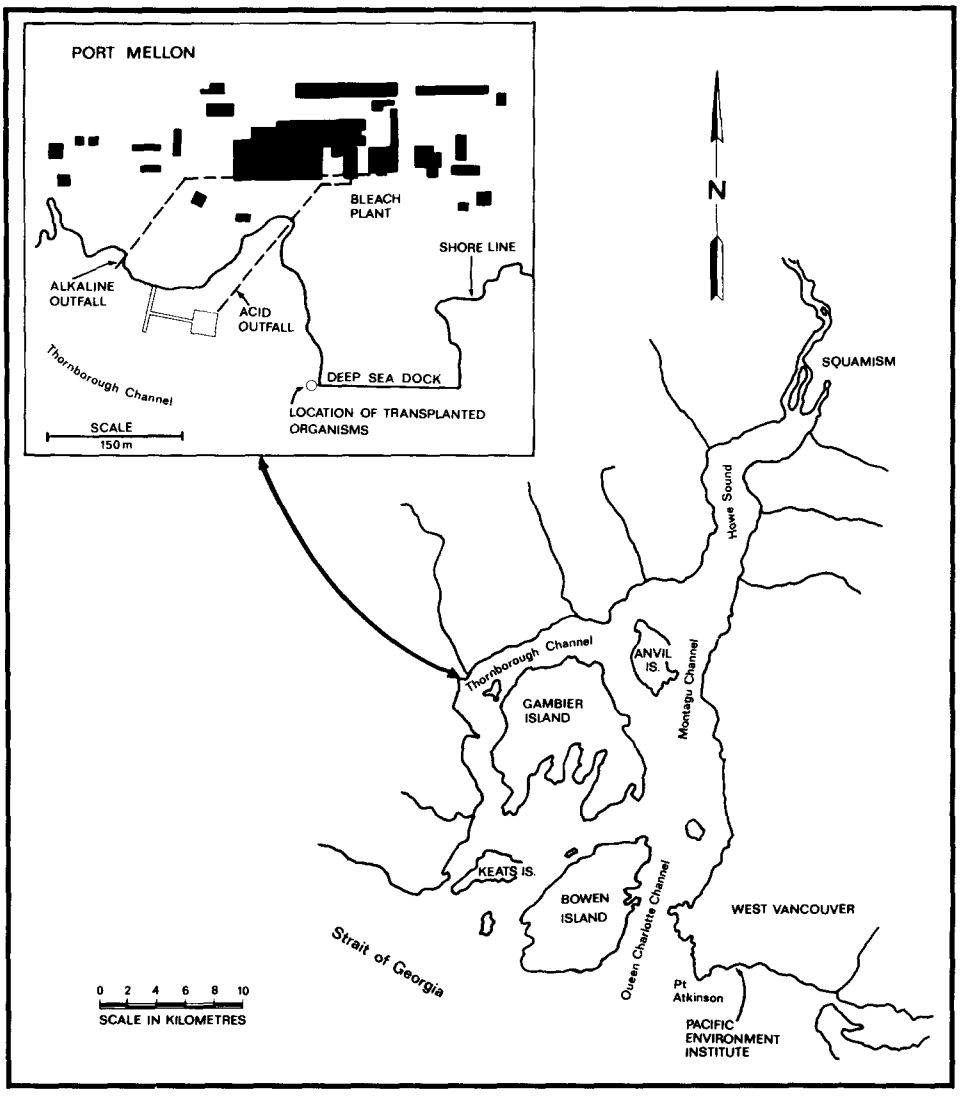

Fig. 1 Chart of Howe Sound, showing the location of the two stations, and the location of the transplanted barnacles and mussels at Port Mellon in relation to the pulp mill outfalls.

Materials and Methods

Experiments were designed to compare the mortality, growth and fecundity of mussels and barnacles at a control station established at the Pacific Environment Institute, West Vancouver, B.C. (123° 15′ W; 49° 20′ N), with that near the pulp mill outfall at Port Mellon (123° 29′ W; 49° 31′ N) (Fig. 1). The water quality parameters (e.g. salinity, temperature) were very similar at these two stations. Experiments commenced in September 1976 and terminated in January 1977.

Mussels

In September 1976, mussels (*Mytilus edulis* L.) were collected at low tides near the Pacific Environment Institute. 360 individuals with a body length of 3.5 ± 0.2 cm ($\bar{x} \pm$ S.E.) were selected for study. Ten randomly-selected mussels were shucked and tissue dry weight was determined by drying in an oven at 100°C for 48 h. One hundred individuals were placed in a cage (mesh size = 3 cm²) and located at +3 m tidal level (total tidal range = 0–12 m) on a piling at the Pacific Environment Institute, West Vancouver. The remaining 250 mussels were put in a similar cage and located at the same tidal level on a piling of the wharf at Port Mellon, which is located about 50 m from the acid outfall (Fig. 1). Eight individuals were sampled at monthly intervals from each site and their mean tissue dry weight was determined as above after measuring their length with a caliper. The dry weight of the mussel gonad was not determined separately because it was not feasible to isolate the gonad from the rest of the tissue. The number of survivors at both sites was counted with each sampling. Individuals still gaping when physically stimulated were considered dead and discarded.

Barnacles

Since crowding exerts a significant effect upon growth and egg production of barnacles (Wu *et al.*, 1977), experiments were designed to allow for this and permit comparison of mortality, growth and fecundity of isolated barnacle individuals near the pulp mill outfall at Port Mellon with those at the control station at the Pacific Environment Institute.

In August 1976, 1000 barnacles were allowed to settle at a distance 1.75 cm apart on a 0.61 m² plexiglass panel secured at the +3 m tidal level on a piling at the Pacific Environment Institute, using the techniques described by Wu *et al.* (1977). In September 1976, the panel was taken out of water and cut into halves. One half was replaced on the piling at the Pacific

Environment Institute, and the other half was transplanted on the same day to the same tidal level on the piling at Port Mellon.

Fifteen barnacles were sampled monthly from the panels at both stations. The body tissue and eggs of each individual was dissected and dry weight determined separately after drying in an oven at 100°C for 48 h. The number of survivors on the panels at both sites was also determined on each sampling trip.

Results

Mussels

The percentage survival of mussels at Port Mellon and the Pacific Environment Institute from September 1976 to January 1977 is shown in Fig. 2. The transplanted mussel population at Port Mellon suffered a slightly higher mortality compared with that at the Pacific Environment Institute.

The mean length and tissue dry weights of mussels sampled during the study period are shown in Figs 3 and 4, respectively. A student *t*-test showed that both the mean length and the mean dry weight of the mussels at Port Mellon were significantly lower ($P < 0.05$) than at the Pacific Environment Institute for every month following transplantation.

Barnacles

The percentage survival of barnacles at Port Mellon and the Pacific Environment Institute is shown in Fig. 2. Mortality was very low at both sites, although the mortality of the barnacles at Port Mellon was slightly higher than at the Pacific Environment Institute.

The monthly mean dry weight of the body tissues and eggs of the barnacles sampled at Port Mellon and the Pacific Environment Institute are shown in Figs 5 and 6, respectively. A student *t*-test showed that the mean dry weight of both the body tissue and the eggs of the individuals at Port Mellon was significantly lower than those of individuals at the Pacific Environment Institute ($P < 0.05$) for every month after transplantation. Moreover, no naupliar embryos could be found in the mantle cavity of the barnacles at Port Mellon in November and December, whilst the majority of the barnacles at the Pacific Environment Institute were incubating naupliar embryos.

A light barnacle settlement (1140 m^{-2}) occurred on the transplanted panel at Port Mellon in October 1976, at which time an intensive settlement (22 000 m^{-2}) was noted on the control panel at the Pacific Environment Institute.

Discussion

The significantly higher mortalities and lower growth rate of the Port Mellon mussel transplants compared to those at the Pacific Environment Institute may be ascribed to the effects of the KME, as other water quality parameters are similar at the two sites. Pedlow (1974) found no growth or gonad formation in the oyster *Crassostrea gigas* when transplaned at 1.1 km distance from the outfall at Port Mellon, and oyster mortality was directly related to the distance from the outfall. The present findings indicate that *M. edulis* is similarly affected but more tolerant than *C. gigas* to KME pollution.

Adult barnacles were also highly tolerant of kraft pulp mill effluent at Port Mellon. The mortality of the transplanted barnacles at Port Mellon was only slightly higher than that of the control animals; 98% of all experimental barnacles survived to the end of the study. These results contradict those of Harger *et al.* (1973) who found 100% mortality in barnacles transplanted some 3.3 km from a KME pulp mill outfall at Port Alberni, B.C. This may be due to differences in the toxicity of the effluents at the two pulp mills, as suggested by Davis and Mason (1973). Sulphite pulp mill effluents are much more toxic than are effluents from kraft mills: Bagge (1969) reported high mortality of the barnacle *B. improvisus* near a sulphite mill in Sweden.

The dry weights of body tissues and of the barnacles at Port Mellon were much lower than those of barnacles at the

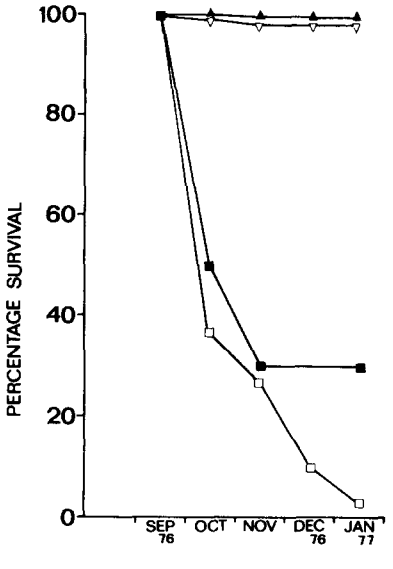

Fig. 2 Survival of the mussel and barnacle populations at Port Mellon (PM) and the Pacific Environment Institute (PEI). □ mussels at Port Mellon; ■ mussels at the Pacific Environment Institute; ▽ barnacles at Port Mellon; ▲ barnacles at the Pacific Environment Institute.

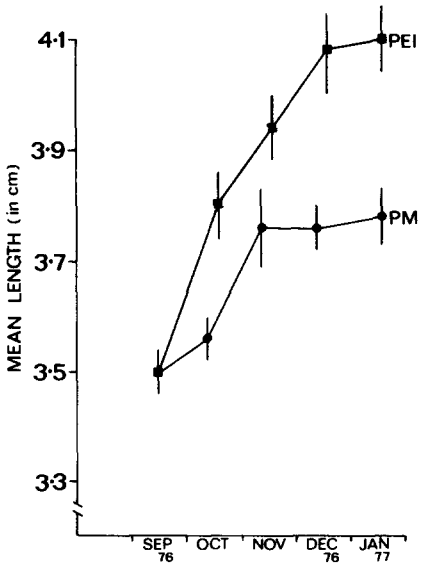

Fig. 3 Comparison between the mean length of mussels at Port Mellon (PM) and the Pacific Environment Institute (PEI) ($\bar{x} \pm$ S.D.).

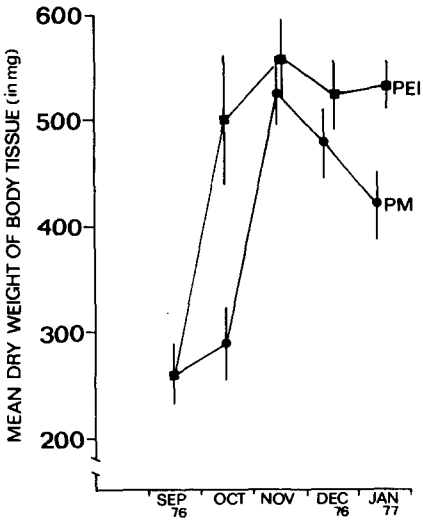

Fig. 4 Comparison between the mean dry weight of body tissue of mussels at Port Mellon (PM) and the Pacific Environment Institute (PEI) ($\bar{x} \pm$ S.D.).

Pacific Environment Institute, suggesting that the pulp mill effluent significantly retarded the growth of the barnacles. Stockner & Cliff (1976) found that the bleached kraft pulp mill effluent reduced primary production at Port Mellon. The low availability of planktonic food, together with other environmental stresses exerted by the bleached kraft pulp mill effluent (e.g. low dissolved oxygen and salinity, high suspended solids and resin acids) may, therefore, be responsible for the poor growth of the mussels and barnacles at Port Mellon.

The absence of viable nauplii at Port Mellon, together with an extremely low egg production, indicated that the reproductive activities of the transplanted barnacles at this site were impaired. The small settlement observed in October on the settling plate at Port Mellon indicated that at least some of the barnacle cyprids could survive and settle normally near the outfall. The result of the present study correlates well with the natural occurrence of barnacles and mussels at Port Mellon (Levings & McDaniel, 1976), where low density and reduced size of both species were found around the KME outfall.

Since both the growth and fecundity of the barnacles and mussels were found to be sensitive to bleached kraft pulp mill effluent, these ubiquitous animals may serve as potential candidates in future pulp mill pollution monitoring.

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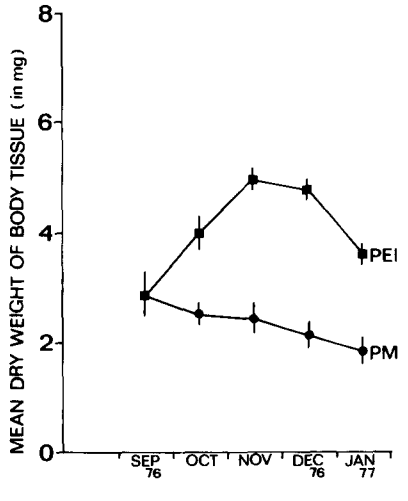

Fig. 5 Comparison between the mean dry weight of body tissue of barnacles at Port Mellon (PM) and the Pacific Environment Institute (PEI) ($\bar{x} \pm$ S.D.).

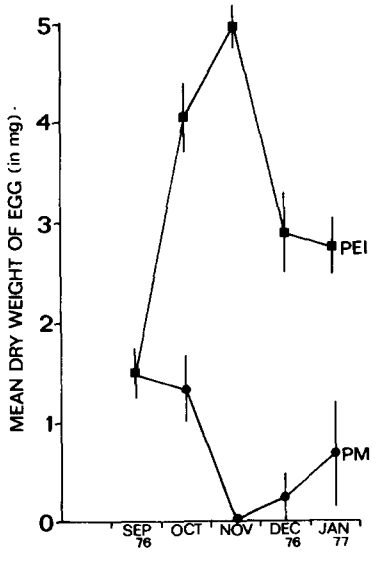

Fig. 6 Comparison between the mean dry weight of eggs produced by barnacles at Port Mellon (PM) and the Pacific Environment Institute (PEI) ($\bar{x} \pm$ S.D.).

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Chlorinated Hydrocarbons in Fish-eating Birds from the Gdańsk Bay, Baltic Sea

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Chlorinated hydrocarbons in industrial and agricultural use are found at significant concentrations in coastal regions. This paper reveals concentrations of HCB, DDT and PCB in tissues of the fish-eating birds staying at their winter quarters in the South Baltic.

It is well known that synthetic chlorinated hydrocarbon residues are of widespread occurrence throughout the marine ecosystem (Risebrough *et al.*, 1968; Jensen *et al.*, 1969). Measurable levels of organochlorines were found in aquatic birds from highly polluted areas in North America and in areas remote from continents (Ohlendorf *et al.*, 1974; Bourne & Bogan, 1972). Such pollutants as DDE and polychlorinated biphenyls (PCB) are most often associated with eggshell changes and bird population decreases (Peakall, 1970; Ratcliffe, 1970; Koeman, 1973). Under controlled experiments it has been shown that chlorinated hydrocarbons are responsible for birds death during starvation periods (Stickel, 1973). High concentrations found in brains of birds and neurotoxic symptoms of poisoning suggested that chlorinated hydrocarbons were the cause of bird deaths (Bourne, 1972; Koeman *et al.*, 1973; Young & Heesen, 1977; Clark, 1978). The aim of this work is to present the results of analyses for chlorinated hydrocarbon residues in the fish-eating birds staying during the winter in the Gdańsk Bay area.

Materials and Methods

The specimens examined were gathered on the beaches of Gdańsk Bay and were taken from fishing nets. The birds were collected during the seasons: autumn–winter–early spring and were without signs of the tissue decay. The material was thawed and ground with anhydrous sodium sulphate to remove moisture. The resultant mixture was transferred to a paper thimble and extracted with petroleum ether on a Soxhlet apparatus for approximately 8 h. After solvent evaporation at the room temperature, the extractable fat content of the sample was determined. The extractable material was subjected to cleanup with mixture of concentrated and fuming sulphuric acid, in a similar manner as described by Jensen (Jensen *et al.*, 1972). The sample was firstly analysed for polychlorinated terphenyls (PCT) and secondly, after aliquot dilution, for hexachlorobenzene (HCB), ΣDDT and PCB residues.

Samples were analysed by gas chromatography, on a column of 3% OV-1 on 100–200 mesh Gas Chrom Q (PCT), and 67 parts of QF-1 (8%) and 33 parts of SF-96 (4%) on 100–120 mesh Gas Chrom Q (for remainder organochlorines), fitted with ^{63}Ni electron capture detector.

The samples contained a PCB mixture which most closely corresponds to Clophen A 60 (Fig. 1). So this PCB mixture was used as a standard to quantify the amount of PCB present. The PCB peaks appearing after *p,p'*-DDE on the gas chromatogram were used in the quantification. While DDE, which was the commonest of the organochlorines present, was calculated from the total height of the peak with retention time equal to that of *p,p'*-DDE. Verification of the presence of DDT and DDD was by dehydrochlorination with alcoholic potassium hydroxide.

Results and Discussion

The results of analysis of the birds for organochlorine pollutants presented in Table 1, are given for extractable fat and for fresh tissue. All birds analysed are more or less migratory, and those spending the winter at the Gdańsk Bay most probably came from the Northern regions. The