Bull. Environ. Contam. Toxicol. (1996) 57:589-596

Bulletin of Environmental Contamination and Toxicology

Heavy Metals in Blue Mussels (*Mytilus edulis*) in the Bergen Harbor Area, Western Norway

V. Andersen,[1] A. Maage,[2] P. J. Johannessen[1]

[1]Department of Fisheries and Marine Biology, University of Bergen, N-5020 Bergen, Norway
[2]Institute of Nutrition, Directorate of Fisheries, Box 185, N-5002 Bergen, Norway

Received: 25 September 1995/Accepted: 12 April 1996

Heavy metal discharges to the marine environment are of great concern all over the world. Both essential (e.g., Fe, Zn, Cu) and non essential (e.g., Hg, Cd, Pb) metals are toxic to living organisms when subjected to high concentrations (Underwood and Mertz 1987). Many heavy metals accumulate in organisms and some also accumulate in the food chain (Ruiter 1995). The anthropogenic heavy metal outlets can in this way both reduce marine species diversity and ecosystems. Further, by consuming seafood, humans will be exposed to the metals with a potential danger to human health.

Goldberg (1975) proposed to use marine mussels to monitor contamination levels of coastal waters. Since then marine mussels, especially the blue mussel (*Mytilus edulis),* has been used widely as a surveillance organism (Claisse 1989; Cossa 1988). The blue mussel is regarded a suitable species for this purpose because it accumulates metals, is sessile, has a relatively long life span, is large enough for individual analysis, can tolerate a relatively wide range of temperature and salinity regimes (Phillips 1977), and can also synthesize the metal-binding protein, metallothionein, for metal detoxification (Köhler and Riisgård 1982). Furthermore, the blue mussel is a popular and tasteful food source and is suitable for culturing. The world-wide annual yield of mussels during the period 1988 to 1992 was about 1.3 million tons, of which about 0.5 million tons was *Mytulis edulis.* In Norway, the annual production was 77 tons in 1990 (FAO 1994). The interest of culturing mussels has increased in recent years, but the consumption of mussels has been hampered both by toxic algae and high levels of heavy metals. The latter is of special concern to those close to urban or industrial areas.

The Bergen Harbor area (Byfjorden, Western Norway) is highly urbanized and has several industrial plants that discharge waste directly to the fjord. There is also heavy loading of municipal and industrial sewage to this area. It has been estimated that 9 tons of the heavy metals Zn, Cu, Pb, Hg and Cd were discharged from several small outlets to the southern part of Byfjord in 1992 Investigations have revealed that the sediments in the area are loaded with very high metal

Correspondence to: A. Maage

levels (Skei et al. 1994). Even though the fjord is deep (350 m) it is a rather closed water system with limited water exchange, connected to the coastal water by several narrow sounds.

The present study was conducted to investigate whether blue mussels in the Bergen Harbor area were contaminated with the heavy metals Zn, Cu, Pb, Cd and Hg, thereby evaluating whether the mussels could be used for human consumption.

MATERIALS AND METHODS

Blue mussels were collected the 8th, 9th, and 16th of March 1993 from 19 stations in the inner Byfjorden (Fig. l), and one station in Galteneset (Station 20), an assumed less affected area in Herdlefjorden. About 100 mussels were collected approximately 50 cm below sea level during low tide at each station. After sampling, the mussels were put into plastic bags and transferred to the laboratory where they were stored at - 20 °C until dissection. Three pooled samples of 17 mussels each were prepared from each station. The mussels, ranging from 40 - 55 cm, were picked out randomly from the total. Soft tissues were removed from the shells, washed in distilled deionized water, and dried in air for about one hour and pooled. The pooled samples were oven dried (Termax) at 90 °C to constant weight and homogenized to a powder. The mean weight and dry matter percentage for each sample were calculated.

Two ml HNO_3 and 0.5 ml H_2O_2 were added each to 0.2 g dry sample. This mixture was then digested in a microwave oven (Milestone mls 1200) for 20 min. The samples were diluted with nanopure water to 25 ml. Standard Reference Materials (SRMs) and blanks were also prepared for analysis. The 25 ml were divided in three parts: 10 ml for Cu and Zn analysis, 5 ml for Pb and Cd analysis and 10 ml for Hg analysis, to which 10 ml $KMnO_4$.was added. Zinc and Cu concentrations were measured by flame atomic absorption (Perkin Elmer 3300) Hg by cold vapour atomic absorption (Perkin Elmer Mercury Analysis System) and Pb and Cd by ICP/MS (Perkin Elmer Elan 5000A). For analytical quality control the following SRMs were used: Oyster Tissue from National Bureau of Standards and Technology (Gaithersburg, MD, USA), Mussel Tissue from the Community Bureau of Reference (Brussels, Belgium) and Dogfish Muscle Tissue (DORM-l) from the National Research Council (Canada). The results from the analysis of SRM were all within the 95 % confidence limit of the SRMs. The detection limits for the methods were (µg/L); Cd: 0.036, Cu: 5, Hg: 0.01, Pb: 0.41, Zn: 10.

Comparisons according to individual shell length and wet weight between the three samples at each station were performed by analysis of variance (ANOVA). Prior to the ANOVA, individual wet weights and shell lengths were tested by Kolomogorov-Smirnov's test of normality (Zar 1984) and Levene's test of equal

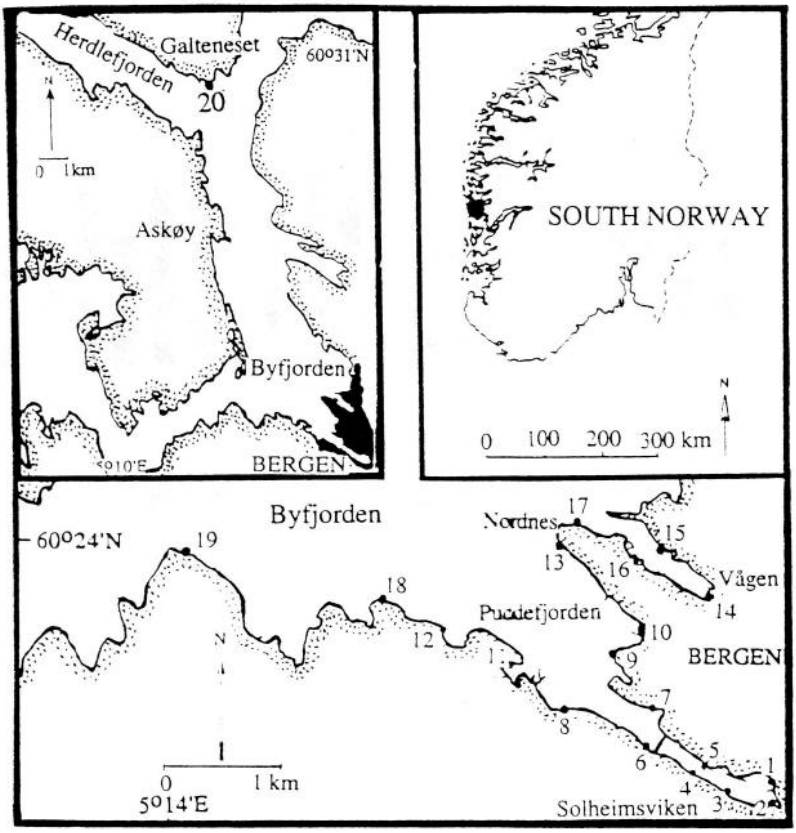

Figure 1. Map showing sampling stations (1-20) in the Bergen Harbor area, Western Norway.

variance (Brown and Forsythe 1974). Shell length, wet weight, percent dry matter and metal concentration comparisons between sampling stations were also subjected to ANOVA. If the results were significantly different ($p < 0,05$) the data were tested by Tukey' s HSD test of multiple comparisons (Zar 1984). Mean values and 95 % confidence intervals of the three samples were calculated for each station.

RESULTS AND DISCUSSION

The mean lengths of the mussels used for analysis from the 20 sampling sites were from 41 to 51 mm. Shells from stations 3, 4, 9, 10, 19, and 20 were significantly longer than those from the other stations. Comparisons of soft tissue wet weight between stations showed that they varied from 5.4 g at Station 3 to 1.7 g at Station 17. Comparing percent dry matter between the 20 sampling stations showed that there was a variation from 11.5 % (Station 18) to 16.8 % (Station 3). Some investigations have shown that the accumulation of heavy metals is dependent of size (Boyden 1977; Latouche and Mix 1982). However, there is no general agreement on how the metal concentration is affected by size. Knutzen and Skei (1990) defined "high background levels" for the heavy metals in sediments and

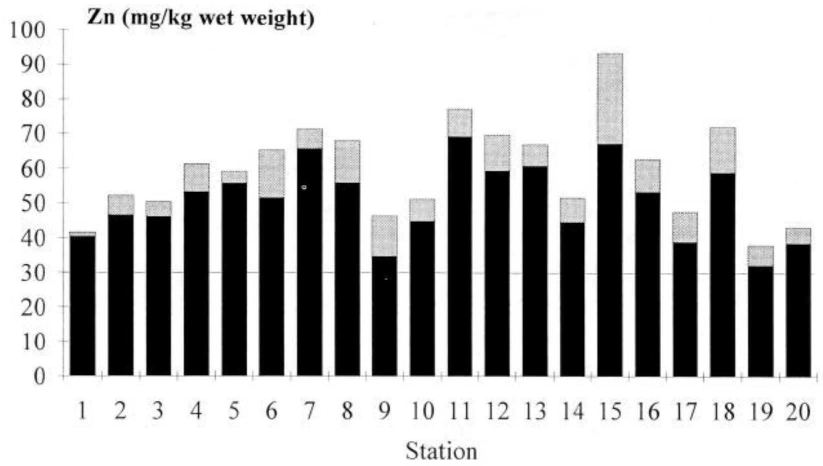

Figure 2. The concentration of Zn in soft tissue of blue mussels from different sampling stations in the harbor area of Bergen, Norway. The gray shadows represent the 95 % confidence interval. The line represents a limit value for polluted areas called “high background levels” (see text).

biota to indicate areas affected by heavy metal pollution.

The Zn concentrations in the mussels sampled ranged from 69.3 mg/kg (wet weight) at Station 11 to 32.2 mg/kg (wet weight) at Station 19 (Fig. 2). At all stations the Zn concentrations were higher than “high background values” of Zn in mussels from unpolluted areas according to Knutzen and Skei (1990). The observed values were, in fact, typical for Zn-polluted areas such as in Sørfjorden, Western Norway and in Cork Harbor, Ireland (Berrow 1991; Julshamn et al. 1985). With respect to use for human consumption, however, the values are of no concern as even a 150 g meal only will contribute about 10.5 mg Zn. In fact, Zn content in most Western diets is too low rather than too high.

Mussels showed decreasing concentrations of Cu from the inner area and outwards (Fig. 3), especially Stations 2, 5, and 6 with 3.8, 3.8, and 3.7 mg/kg wet weight, respectively, were high compared to “high background values” of Cu in mussels (Knutzen and Skei 1990). Also, Station 15 showed an elevated Cu level (3.2 mg/kg), but the high variation at this station made it difficult to draw conclusions about why this was found. The blue mussel has not been regarded as a good surveillance organism for Cu pollution because it has the ability to regulate Cu levels in the soft tissue even when exposed to high levels of the metal (Amiard-Triquet et al. 1986; Phillips 1976). The high concentrations observed in the mussels from the inner harbor area are therefore of great concern with regard to the environment. This may reveal a marked source of Cu pollution. In Great Britain there is a recommendation for a limit of 20 mg/kg for Cu levels in food. There is no such recommendation in Norway, but even in highly polluted areas the Cu levels in mussels are of no concern with regard to human consumption.

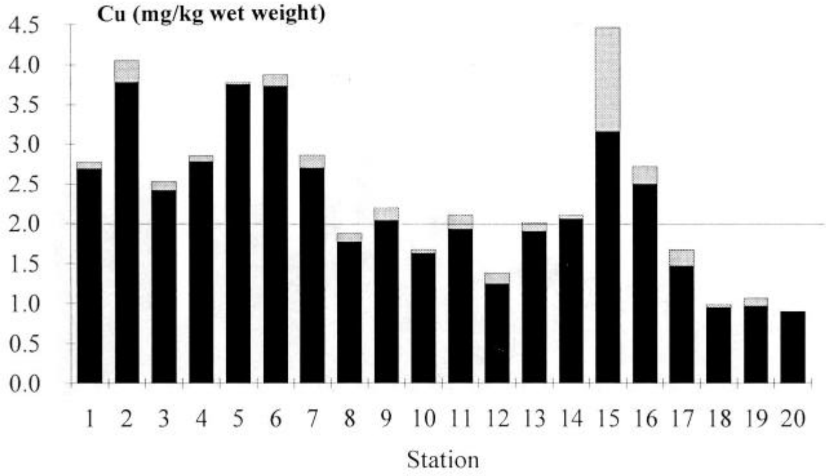

Figure 3. The concentrations of Cu in soft tissue of blue mussels from different sampling stations in the harbor area of Bergen, Norway. The gray shadows represent the 95 % confidence interval. The line represents a limit value for polluted areas called “high background values” (see text).

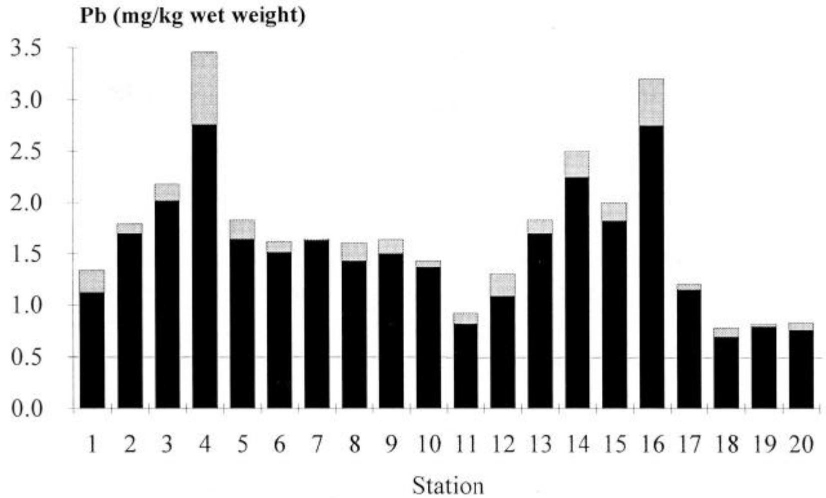

Figure 4. The concentrations of Pb in soft tissue of blue mussels from different sampling stations in the harbor area of Bergen, Norway. The gray shadows represent the 95 % confidence interval. The line represents a limit value for polluted areas called “high background levels” (see text).

Mussels from stations 4 and 16 had mean Pb values greater than 2.5 mg/kg wet weight and had significantly higher Pb concentrations in their tissues than mussels from the other stations (Fig. 4). At all stations the concentrations of Pb were above “high background values” (Knutzen) and Skei 1990). The rather high concentrations of Pb in the blue mussels in this area confirmed that the Bergen Harbor area is highly affected by urbanization. The sources of Pb are

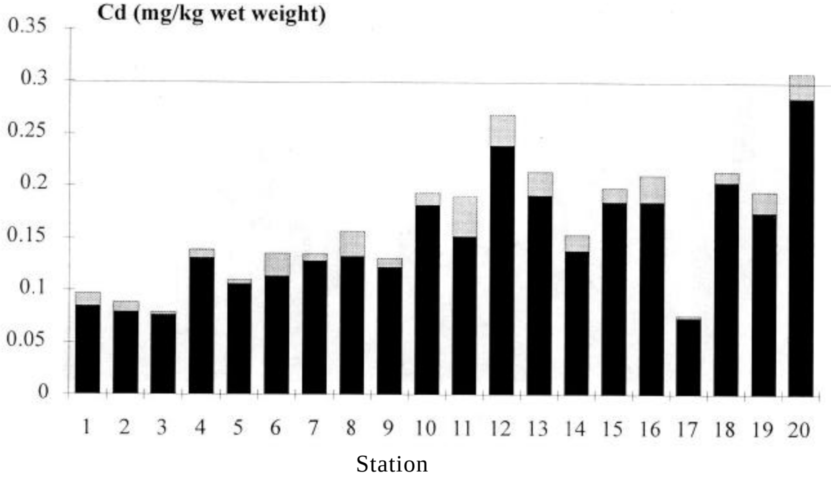

Figure 5. The concentrations of Cd in soft tissue of blue mussels from different sampling stations in the harbor area of Bergen, Norway. The gray shadows represent the 95 % confidence interval. The line represents a limit value for polluted areas called "high background values" (see text).

probably from leaded petrol from cars and boats and some local industrial plants. The concentrations of Pb in mussels from this study are comparable to the values from the slightly polluted areas in the outer part of the Hardangerfjord, Western Norway (Julshamn et al. 1985). However, the concentrations are lower than those in mussels from Cork Harbor, Ireland and the inner part of the Hardangerfjord, Western Norway, which have been regarded as Pb-polluted areas (Julshamn et al. 1985; Berrow 1991). Since Pb is a toxic non-essential metal, this metal is of some concern. Lead can biomagnify in the food chain and accumulate in bone and teeth. Following the recommendation from several countries about not eating molluscs containing more than 1 mg Pb/kg, the mussels from the Bergen inner harbor area should be regarded as Pb-polluted and should not be exported (FAO 1989).

Cadmium concentrations in the mussels deviated from the expected results when it was shown that the reference station (20) had the highest value (0.29 mg/kg wet weight) and the stations in the inner harbor area the lowest values of Cd (Fig. 5). All observed Cd concentrations were lower than "high background values" (Knutzen and Skei 1990). The values from Byfjorden seem to be typical for unpolluted areas (Richardson et al. 1994). From a nutritional point of view there is no concern about eating mussels with such low concentrations of cadmium even though Cd is a very toxic metal (FAO 1989).

Mercury analyses showed trends similar to Cu; the highest concentrations of Hg were found in mussels from the inner harbor area, especially Station 4 with a concentration of 0.06 mg/kg wet weight (Fig. 6). The lowest value was at Station 18 (0.01 mg/kg wet weight). In the inner harbor area the observed values were

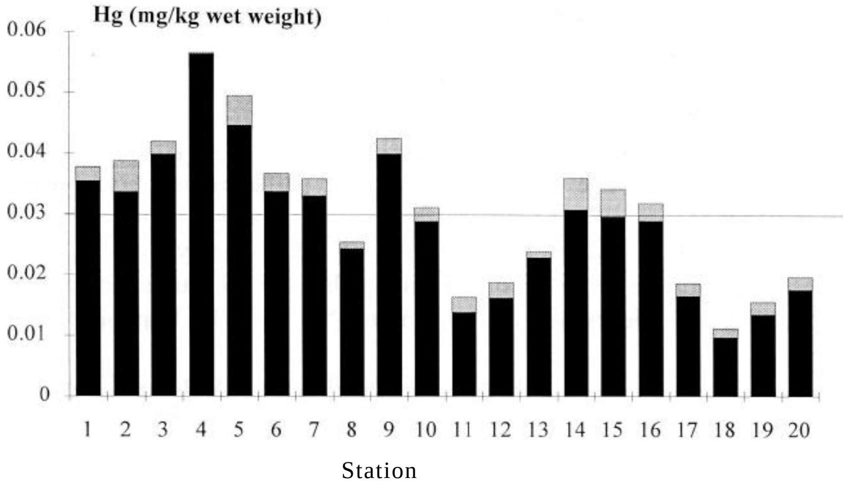

Figure 6. The concentrations of Hg in soft tissue of blue mussels from different sampling stations in the harbor area of Bergen, Norway. The gray shadows represent the 95 % confidence interval. The line represents a limit value for polluted areas called “high background values” (see text).

higher than “high background values” (Knutzen and Skei 1990). The results from this study showed lower Hg concentrations than typical polluted areas (De Wolf 1975; Julshamn et al. 1985). Despite the fact that Hg is a very toxic metal, there is no danger of eating mussels from the Bergen Harbor area with regard to this metal (FAO 1989).

In conclusion, the levels of metals in blue mussels from the Bergen Harbor area showed that the area is contaminated with Zn, Cu and Pb. However, with regard to human consumption only Pb gives rise to worry, and in terms of keeping with the JECFA recommendations on Pb intake, an intake of up to 800 g/week would not in itself make a person exceed the PTWI-level.

REFERENCES

Amiard-Triquet C, Berhet B, Metayer C, Amiard JC (1986) Contribution to the ecotoxicological study of cadmium, copper and zinc in the mussel *Mytilus edulis* II. Experimental study. Mar Biol 92:7-13

Berrow SD (1991) Heavy metals in sediments and shellfish from Cork Harbour, Ireland. Mar Pollut Bull 22:467-469

Boyden CR (1977) Effect of size upon metal content of shellfish.. J Mar Biol Assoc UK 57:675-714

Brown MB, Forsythe AB (1974) Robust tests for equality of variances. J Amer Stat Assoc 69:364-367

Claisse D (1989) Chemical contamination of French coasts. The results of a ten years mussel watch. Mar Pollut Bull 20:523-528

Cossa D (1988) Cadmium in *Mytilus* spp.: worldwide survey and relationship between seawater and mussel content. Mar Environ Res 26:265-284

De Wolf P (1975) Mercury content of mussels from West European coasts. Mar Pollut Bull 6:61-63

FAO (1989) Food safety regulations applied to fish by major importing countries. Fisheries Circular no. 825. FAO, Rome

FAO (1994) FAO Yearbook. Fisheries Statistics, 1992 (Vol. 74). FAO, Rome

Goldberg ED (1975) The mussel watch - A first step in global marine monitoring. Mar Pollut Bull 6: 111

Julshamn K, Slinning KE, Haaland H, Bøe B, Føyn L (1985) Analyse av sporelementer og klorerte hydrokarboner i fisk og blåskjell fra Hardangerfjorden og tilstøtende fjordområder høsten 1983 og våren 1984. Fisk Dir, Rapporter og Meldinger, pp 55

Knutzen J, Skei J (1990) Quality criteria for micropollutants in water, sediments and organisms and preliminary proposals for classification af environmental quality. NIVA-report, l.nr. 2540, NIVA, Oslo, Norway, pp 139

Köhler K, Riisgård HU (1982) Formation of metallothioneins in relation to accumulation of cadmium in the common mussel *Mytilus edulis*. Mar Biol 66:53-58

Latouche YD, Mix MC (1982) The effect of depuration, size, and sex on trace metal levels in bay mussels. Mar Pollut Bull 13 :27-29

Phillips DJH (1976) The common mussel *Mytulis edulis* as an indicator of pollution by zinc, cadmium, lead and copper. I. Effects of environmental variables on uptake of metals. Mar Biol 38: 59-69

Phillips DJH (1977) The use of biological indicator organisms to monitor trace metal pollution in marine environments - a review. Environ Pollut 13:281-317

Richardson BJ, Garnham JS, Fabris JG (1994) Trace metal concentration in mussels (*Mytilus edulis planulatus* L) transplanted into southern Australian waters. Mar Pollut Bull 28:392-396

Ruiter A (1995) Contaminants in fish. In: Ruiter A (ed) Fish and Fishery Products. Composition, Nutritive Properties and Stability, Cab International, Wallingford, UK, p 261

Skei J, Knutzen J, Klungsøyr J (1994) Miljøgiftundersøkelse i Bergen havneområde og Byfjorden 1993. Fase 1. Miljøgifter i spiselige organismer og bunnsedimenter. NIVA-rapport 0-93017, Oslo, Norway

Underwood EJ, Mertz W (1987) Introduction. In: Mertz W (ed) Trace Elements in Human and Animal Nutrition-Fifth ed., Vol 1. Academic Press, San Diego, California, p 1

Zar JH (1984) Biostatistical analysis, Second ed. Prentice-Hall Inc., Eaglewood Cliffs, New Jersey