Bull Environ Contam Toxicol (2008) 80:385–389
DOI 10.1007/s00128-008-9377-x

Organ Distribution and Food Safety Aspects of Cadmium and Lead in Great Scallops, *Pecten maximus* L., and Horse Mussels, *Modiolus modiolus* L., from Norwegian Waters

Kaare Julshamn · Arne Duinker · Sylvia Frantzen · Lise Torkildsen · Amund Maage

Received: 19 December 2007 / Accepted: 12 February 2008 / Published online: 3 March 2008

Abstract The purpose of the study was to determine the levels and organ distribution of the potentially harmful inorganic elements cadmium and lead in great scallops and horse mussels from unpolluted Norwegian waters. The scallops far exceeded the EU-limit for cadmium in bivalves when all soft tissues were analysed. When only muscle and gonad were included, however, the level of cadmium was acceptable, because cadmium accumulated in the digestive gland with a mean of 52 mg/kg ww (wet weight). In horse mussel, lead was the most problematic element and the concentration varied from 1.4 to 6.6 mg/kg ww with a mean of 3.7 mg/kg ww, exceeding the EU limit of 1.5 mg Pb/kg. The highest concentration of lead was found in the kidney with an average of 120 mg/kg ww and with a maximum value of 240 mg/kg ww. The kidney tissue accounted for ~94% of the lead burden in the horse mussel. In order to consume these bivalves, only muscle and gonad of great scallops should be used for consumption and the kidney of horse mussel should be removed prior to consumption.

Keywords Cadmium · Lead · Great Scallop · *Pecten maximus* · Horse mussel · *Modiolus modiolus*

K. Julshamn (✉) · A. Duinker · S. Frantzen · A. Maage
National Institute of Nutrition and Seafood Research (NIFES), P.O. Box 2029 Nordnes, 5817 Bergen, Norway
e-mail: kju@nifes.no

L. Torkildsen
Norwegian Food Safety Authority, National Fish and Seafood Centre, Rosenkrantz gate 3, 5003 Bergen, Norway

Bivalves accumulate metals from their surroundings as they feed by filtering particles from water (Simkiss et al. 1982), including the metals originating from the seawater, food or sediment (Metian et al. 2005). Harmful substances can thereby occur at natural background levels or in elevated concentrations most of them caused by pollution. The highest values for contaminants in organisms are often found in species that can grow large and old. For shellfish, this includes species such as the great scallop (*Pecten maximus*) and the horse mussel (*Modiolus modiolus*). The great scallop is considered a delicacy, and in 2006 around 800 tons of wild and 3.6 tons of cultivated great scallops were harvested in Norway (Trond Havelin, Directorate of Fisheries, personal communication). Harvest by leisure divers is probably also extensive (Strand and Parsons 2006). The great scallop may grow to more than 15 cm and exceed 20 years of age (Brand 2006), but usually the commercial size of 10 cm is reached after 4–6 years in Norway (Strand and Parsons 2006). Lately the horse mussel has gained increased interest as human food, and between 0.46 and 11.8 metric tons a year were captured commercially between 2000 and 2006 (Trond Havelin, Directorate of Fisheries, personal communication). The horse mussel can grow to a shell length of more than 20 cm, although normal size is 10–15 cm. Because it can reach an age of more than 35 years (Anwar et al. 1990), it may accumulate elements to higher concentrations than more short-lived mussel species (Gutierrez-Galindo et al. 1999; Wilson 1977; Julshamn and Andersen 1983).

The Norwegian Food Safety Authority (NFSA) have been monitoring shellfish for undesirable substances for about 15 years, mainly focusing on *Mytilus edulis*, but also regularly including some samples of great scallops. The analysed concentrations of cadmium and lead in great scallops have shown great variation, and occasionally have exceeded the upper limits for cadmium at 1.0 mg/kg and lead at 1.5 mg/kg set by EU and Norway. It is well known that scallops accumulate high levels of metals, particularly cadmium, irrespective of pollution, and that cadmium particularly accumulates in the digestive gland of scallops (Mauri et al. 1990; Rainbow 1997; Bustamante and Miramand 2004, Metian et al. 2005).

In contrast to scallops, horse mussels have so far not been included in the monitoring programme on regular basis. In Norway, the whole soft part of the horse mussel and only the adductor muscle and gonad of the great scallop are consumed. Therefore elevated whole body levels of metals in scallops have not posed a threat in human nutrition, whereas in horse mussels consumers may be exposed to concentrations of metals exceeding the recommended limits. In 2006 there were reports from Spain claiming that Norwegian scallops imported to the country had levels of cadmium higher than the maximum levels of 1.0 mg/kg wet weight for cadmium.

The main purpose of the present study was to investigate cadmium and lead distribution in the organ tissues of the horse mussel and the great scallop in order to characterise what part of the soft tissues are safe for the consumers.

Materials and Methods

Great scallops (*P. maximus*) and horse mussels (*M. modiolus*) were sampled and analysed as a part of Norwegian Food Safety Authority's (NFSA) monitoring programme, which is run by NIFES. Wild scallops from the Frøya area (Fig. 1) have been collected every year since 2001 (Table 3). In the monitoring programme for scallops, mixed samples of only gonad and adductor muscle were analysed (n = 10). For analyses of all the different organs and tissues separately, ten scallops from wild populations in Mausund, Frøya, were collected in September 2006. Five of these scallops were dissected into digestive gland, kidney, gonad and adductor muscle, while for five specimens a mixed sample of the whole soft parts was analysed. Ten horse mussels were collected from wild populations in fjord areas around Bergen in January 2007 (Fig. 1). The horse mussels were steamed for 8 min and dissected into the following organs and tissues: kidneys, gills, digestive gland, gonad tissue and muscles (including adductor muscles and foot muscles). For five of the horse mussels organs were analysed individually, whereas for the remaining five the organs were pooled. All samples were stored at −20°C prior to homogenization, freeze drying and analysis.

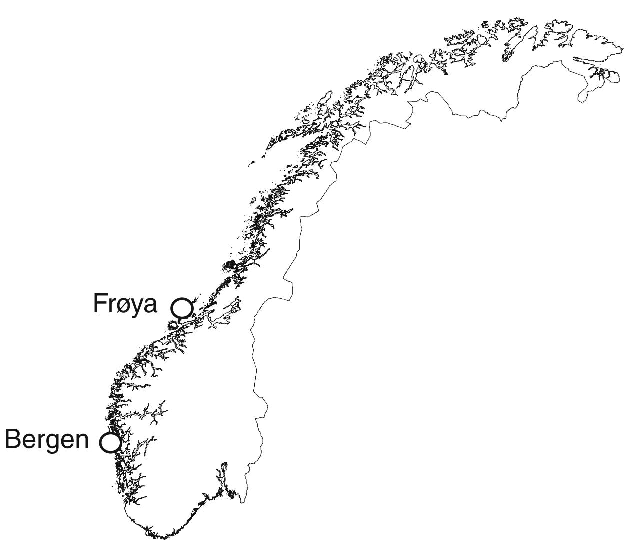

Fig. 1 Sampling sites of horse mussels and great scallops on the west coast of Norway

The concentrations of the elements were determined by inductively coupled plasma mass spectrometry (ICP-MS) after pressure digestion as described in Julshamn et al. (2007). The instrument used was an Agilent 7500c ICP-MS, and the instrument settings are given in Table 1.

The trueness and precision of the determination of total arsenic, cadmium, mercury and lead were estimated from the concurrent analyses of the Certified Reference Material Tort-2 (lobster hepatopancreas; NRCC, Ontario, Canada). The Tort-2 sample was continuously stored in a desiccator at room temperature keeping residual water content below 5%. The results obtained for all elements studied agreed well with the certified values given by NRCC (Table 2). The internal reproducibility given as RSD (%) based on 2 s varied between 4% for cadmium and 11% for mercury.

For each species and organ (muscle, digestive gland, gonad, gills and kidney), mean concentrations in milligram per kilogram wet weight (mg/kg ww) of arsenic, cadmium, mercury and lead were calculated (n = 5). The percentage distribution of each element in each organ was calculated according to the relative wet biomass of the organ, and the

Table 1 Instrumental settings for Agilent 7500c ICPMS

ICP-MS settings	
RF power (W)	1,550
Carrier gas flow (L/min)	1.2
Plasma gas flow (L/min)	15
Auxiliary gas flow (L/min)	1.0
Nebuliser	Babington nebuliser
Spray chamber	Water cooled double pass
Spray chamber temperature (°C)	2
Interface cones	Platinum
Lens voltage (V)	2–3
Mass resolution (u)	0.8
Integration time (s)	1,000

Table 2 Results from the ICP-MS analysis of the certified reference material, Tort-2 (lobster hepatopancreas), for arsenic cadmium, mercury and lead

Element	Number of analyses (N)	Mean (mg/kg)	2s (mg/kg)	RSD (%)	Certified (x ± 2s) (mg/kg)
Arsenic	15	21.5	3.6	8.4	21.6 ± 1.8
Cadmium	15	26.5	2.2	4.1	26.7 ± 0.6
Mercury	15	0.28	0.06	10.7	0.27 ± 0.06
Lead	15	0.37	0.07	9.5	0.35 ± 0.13

All results in mg/kg dry weight ± 2 s (n = 15)

concentrations of each element in total soft parts were determined.

Results and Discussion

In scallops, cadmium concentrations in mixed samples of muscle and gonad sampled for the monitoring programme ranged between 0.11 and 0.75 mg/kg ww, which was well below the EU limit of 1.0 mg/kg ww (Table 3). Because sampling was made for the monitoring programme, samples were made out of the soft parts normally consumed in Norway (i.e. muscle and gonad). It should be noticed that the higher cadmium concentrations in muscle and gonad tissues of scallops sampled in 2002 compared with those sampled during 2004–2006 probably was caused by leakage of cadmium from the digestive gland during thawing. That year the scallops were frozen prior to dissection and analysis while the other years the scallops were shipped fresh to our laboratory. When analysing the whole soft tissue of the great scallops, cadmium concentrations ranged from 3.7 to 8.4 mg/kg ww, with a mean of 5.4 mg/kg, corresponding to 27.3 mg/kg dry weight (dw). Thus, the concentrations exceeded the EU's limit of 1.0 mg Cd/kg ww, and they correspond well with the value of 29.7 mg/kg dw reported in *P. maximus* from the bay of Biscay (Bustamante and Miramand 2004). Analyses of the different scallop tissues show that cadmium accumulated in the digestive gland with 52 ± 10 mg/kg ww, corresponding to 173 mg/kg dw, which is lower than 264 and 321 mg/kg dw reported by Buestel and Miramand (2004) and Bryan (1973), respectively.

Lead concentrations in muscle and gonad of great scallops sampled for the monitoring programme during 2001–2006 ranged between 0.02 and 0.08 mg/kg ww (Table 3) and when including the whole soft tissue the concentrations were up to 0.14 (Table 4). The concentrations of lead in total soft tissue thus were well below the EU upper limit of 1.5 mg/kg ww. While cadmium accumulated mainly in the digestive gland, the kidney showed

Table 3 Concentrations of cadmium (Cd) and lead (Pb) (mg/kg ww) in mixed samples of gonad and muscle of great scallops (*P. maximus*) sampled at Frøya for the Norwegian shellfish monitoring programme during 2001–2006

Year	Number of samplings	Cd (mg/kg ww)	Pb (mg/kg ww)
2006	1	0.12	0.08
2005	5	0.11–0.23	0.02–0.08
2004	2	0.24–0.35	0.02–0.05
2002	2	0.60–0.75	0.06–0.07
2001	2	0.20	0.02

Table 4 Content of cadmium and lead (mg/kg ww) in organs of great scallop (*P. maximus*) sampled at Mausund, Frøya in September 2006 (n = 5)

Organ	Parameter	Cd (mg/kg ww)	Pb (mg/kg ww)
Digestive gland	Mean ± SD	52 ± 10	0.29 ± 0.12
	Min–max	40–68	0.17–0.50
Kidney	Mean ± SD	4.7 ± 2.2	8.2 ± 2.7
	Min–max	2.3–8.8	4.0–12.4
Muscle	Mean ± SD	0.15 ± 0.03	<0.01
	Min–max	0.11–0.21	<0.01–0.02
Gonad	Mean ± SD	0.13 ± 0.05	0.07 ± 0.01
	Min–max	0.07–0.20	0.05–0.09
Total soft tissue	Mean ± SD	5.4 ± 2.0	0.12 ± 0.02
	Min–max	3.7–8.4	0.09–0.14

Table 5 Content of cadmium (Cd) and lead (Pb) (mg/kg ww) in organ tissues of steamed horse mussel (*M. modiolus*) harvested in Norway in 2007 (n = 6)

Organ	Parameter	Cd (mg/kg ww)	Pb(mg/kg ww)
Kidney	Mean ± SD	7.2 ± 3.8	44.5 ± 28
	Min–max	2.5–12.0	16.0–85.0
Digestive gland	Mean ± SD	0.6 ± 0.4	0.88 ± 0.83
	Min–max	0.2–1.3	0.16–2.20
Gills	Mean ± SD	0.9 ± 0.4	0.23 ± 0.20
	Min–max	0.5–1.7	0.05–0.49
Gonad	Mean ± SD	0.33 ± 0.14	0.15 ± 0.11
	Min–max	0.12–0.56	0.05–0.29
Muscle	Mean ± SD	0.15 ± 0.07	0.12 ± 0.10
	Min–max	0.06–0.23	0.04–0.32
Total soft tissue	Mean ± SD	0.86 ± 0.41	3.3 ± 2.2
	Min–max	0.34–1.52	1.4–6.6

Table 6 Concentration of cadmium (Cd) and lead (Pb) (mg/kg wet weight) in organ tissues of steamed horse mussel (*M. modiolus*) sampled in Norwegian waters in 2007

Organ	Organ (%)	Cd (mg/kg ww)	Cd (%)	Pb (mg/kg ww)	Pb (%)
Kidney	7.6	7.2	61.8	41.5	94
Digestive gland	11.8	0.6	8.0	0.9	2.6
Gills	9.9	0.9	10.9	0.2	0.6
Gonad	32	0.3	12.5	0.2	1.4
Muscle	39	0.1	6.9	0.1	1.5
Total soft tissue	100	0.9	100	3.3	100

Percentage distribution of cadmium and lead in the organs is also shown, as well as the proportion of total soft tissue represented by each organ (organ %)

the highest lead concentrations among the organs in great scallops, ranging from 4.0 to 12.4 mg/kg ww, which is consistent with Bryan (1973), although those values were higher. The concentrations of total arsenic in whole soft parts varied from 2.2 to 3.1 mg/kg ww in great scallop and the highest arsenic concentrations were found in digestive gland and kidney tissues (Table 4). The mercury concentrations were as low as 0.02 mg/kg.

In horse mussels lead seemed to be a more critical element than cadmium. In whole soft tissue a mean value of 3.3 mg Pb/kg ww was found (Table 5), which was about twice the EU limit of 1.5 mg/kg for lead in bivalves. Lead accumulated mostly in the kidney of the horse mussels, with up to 85 mg/kg ww, and accounted for ~94% of the lead burden in the whole soft parts (Table 6). The high lead concentrations in kidney tissue of horse mussels from unpolluted areas are in agreement with results given in the literature. Julshamn and Andersen (1983) reported lead concentrations as high as 110 mg/kg ww in kidney of adult raw horse mussel sampled from unpolluted Norwegian waters. By removing the kidney the lead concentration of the soft part of the horse mussel would be reduced to less than 0.5 mg/kg for all individuals (Fig. 2). Additionally, the steaming increases the dry weight percentage of the soft tissues and hence also increases the concentrations of many metals compared to analyses on raw tissue. With a dry weight percentage around 30 % for the steamed samples in the present study, compared to around 15% in raw tissue (own observations), our values should be halved when comparing with EU limits and other data that are given per wet weight fresh tissue. The highest values are still above the EU limits.

Cadmium concentrations in the whole soft tissue of horse mussels ranged from 0.34 to 1.5 mg/kg ww, with a mean of 0.86 mg Cd/kg ww. Undoubtedly, some of the individual mussel specimens will therefore exceed the EU limit of 1.0 mg Cd/kg ww. Also cadmium accumulated primarily in the kidney of the horse mussel, with a mean concentration of 7.2 ± 3.8 mg/kg ww. Concentrations of cadmium in the kidney as high as 26.7 mg/kg ww are found in other unpolluted areas (Julshamn and Andersen 1983). With the kidney removed, the concentrations of

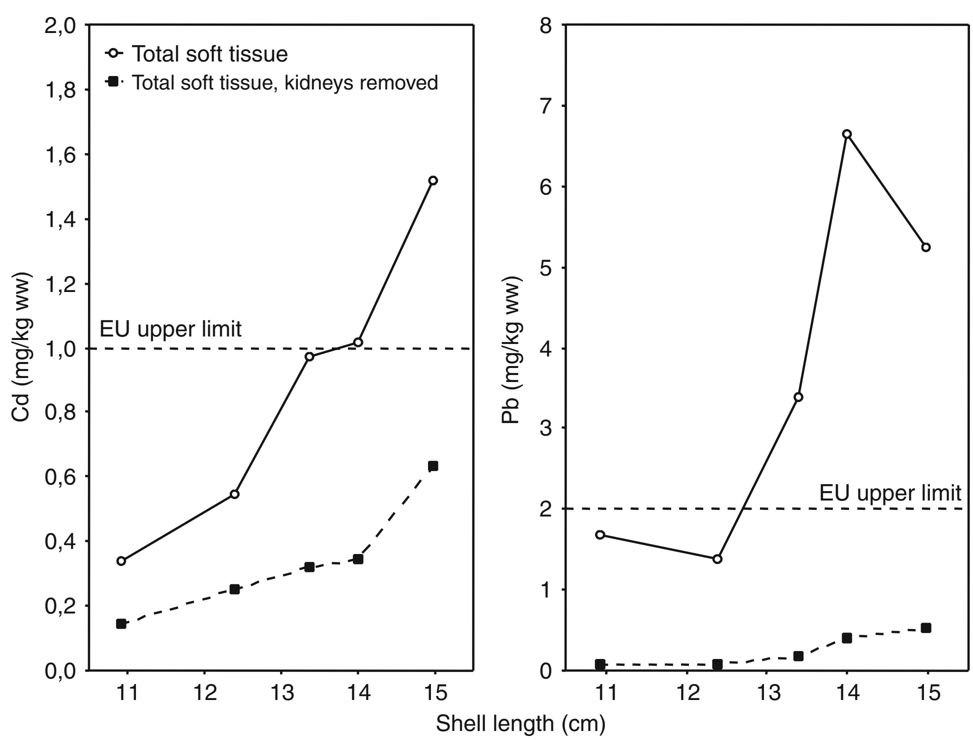

Fig. 2 Concentrations of cadmium (Cd; left) and lead (Pb; right) in steamed soft tissues of horse mussels (*M. modiolus*) of different size, with and without kidneys

cadmium and lead were below the EU limits for all the analysed individuals (Fig. 2).

The concentrations of mercury in soft tissue ranged from 0.03 to 0.07 mg/kg ww in horse mussel. Also for mercury the kidney showed the highest mercury concentration among the different organs in the horse mussel, with a mean value of 0.35 mg/kg ww. The concentrations of total arsenic in whole soft parts ranged from 1.7 to 2.9 mg/kg ww in horse mussel which is in the lower concentration range found in other seafoods (Julshamn et al. 2004).

Our findings show that if the great scallop and the horse mussel are to be accepted as food in the human diet the organs containing the highest concentration of metals must be avoided. This can be achieved by eating only the muscle and gonad of scallops and by removing the kidney of horse mussels prior to consumption. This will require lessons in risk communication.

References

Anwar NA, Richardson CA, Seed R (1990) Age determination, growth rate and population structure of the horse mussel *Modiolus modiolus*. J Mar Biol Assoc UK 70:441–457

Brand A (2006) Scallop ecology: distributions and behaviour. In: Shumway SE, Parsons GJ (eds) Scallops: biology, ecology and aquaculture. Elsevier, Amsterdam, pp 651–744

Bryan GW (1973) The occurrence and seasonal variation of trace metals in the scallops *Pecten maximus* (L.) and *Chlamys opercularis* (L.). J Mar Biol Assoc UK 53:145–166

Bustamante P, Miramand P (2004) Interspecific and geographical variations of trace element concentrations in Pectinidae from European waters. Chemosphere 57:1355–1362

Gutierrez-Galindo EA, Villaescusa-Celaya JA, Arreola-Chimal A (1999) Bioaccumulation of metals in mussels from four sites of the coastal region of Baja California. Cienc Mar 25:557–578

Julshamn K, Andersen KJ (1983) Subcellular distribution of major and minor elements in unexposed mollusks in Western Norway. 3. The distribution and binding of cadmium, zinc, copper, magnesium, manganese, iron and lead in the kidney and the digestive system of the horse mussel *Modiolus modiolus*. Comp Biochem Physiol A Physiol 75:17–20

Julshamn K, Lundebye A-K, Heggstad K, Berntssen MHG, Bøe B (2004) Norwegian surveillance programme on inorganic and organic contaminants in fish caught in the Barents Sea, Norwegian Sea and North Sea in the period from 1994–2001. Food Addit Contam 21:365–376

Julshamn K, Måge A, Skaar Norli H, Grobecker K, Jorhem L, Fecher P (2007) Determination of arsenic, cadmium, mercury and lead by ICP-MS in foods after pressure digestion: NMKL Collaborative study. J Aoac Int 90:844–856

Mauri M, Orlando E, Nigro M, Regoli F (1990) Heavy-metals in the Antarctic scallop *Adamussium colbecki*. Mar Ecol Prog Ser 67:27–33

Metian M, Hedouin L, Barbot Q, Teyssie JL, Fowler SW, Goudard F, Bustamante P, Durand JP, Pieri J, Warnau M (2005) Use of radiotracer techniques to study subcellular distribution of metals and radionuclides in bivalves from the Noumea Lagoon, New Caledonia. Bull Environ Contam Toxicol 75:89–93

Rainbow PS (1997) Trace metal accumulation in marine invertebrates: marine biology or marine chemistry? J Mar Biol Assoc UK 77:195–210

Simkiss K, Taylor M, Mason AZ (1982) Metal detoxification and bioaccumulation in mollusks. Mar Biol Lett 3:187–201

Strand Ø, Parsons GJ (2006) Scandinavia. In: Shumway SE, Parsons GJ (eds) Scallops: biology, ecology and aquaculture. Elsevier, Amsterdam, pp 1067–1091

Wilson DP (1977) *Modiolus modiolus* (L.) in small mid-tidal rock pools at Penrhyn Bay, North Wales. Est Coast Mar Sci 5:215–216