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Pollution of the Scheldt estuary and its effects on salt-marsh biota

Abstract

In the Scheldt estuary contaminants (excess of nutrients, trace metals, organic hydrocarbons, radionuclides) are accumulated by recirculation processes within the estuarine environment. Excess of nutrients can be traced in the salt and brackish marshes by the phosphate content of the soil which increases to tenfold of the phosphate content of the non-polluted Oosterschelde salt marshes. Excess of nutrients is reflected in the vegetation by a lower species diversity and an excessive plant growth burdening the decomposition processes of the ecoystem.

Trace-metal contamination occurs in all salt-marsh biota in a way specific to metals and organisms. They do not reduce plant population diversity and growth in a perceptible way but may have had some genetic consequencies. Reduction of biological activities may be found in the herbivorous and detritivorous food chains in which metals - but also organic hydrocarbons - may be passed on through the trophic levels. Sheep grazing in a metal-contaminated brackish marsh, however, appeared to have no harmful effect, especially if grazing is adapted to the existing seasonal variations in the trace-metal concentrations of food plants. Human use of *Salicornia europaea* and *Aster tripolium* as wild vegetables, however, is dissuated for those plants growing in heavily contaminated marsh areas, on the basis of maximum permissible levels of metal in cultivated vegetables such as spinach.

1. Introduction

The estuary of the river Scheldt belongs to the most heavily polluted river outlets of Western Europe (Förstner & Wittmann, 1979). The river is contaminated by different groups of pollutants. Domestic wastes, mainly contianing high concentrations of nutrients such as nitrogen and phosphorus, have been discharged into the river already form old times when the big Flemish urban and trade centres arose. Trace metals (Cd, Cu, Zn, Pb, Cr, Ni, Hg, etc.) were discharged gradually from about 1850 on, together with the settlement of the modern industrial plants along the river and the spillage of their products by the local population. Organic hydrocarbons (pesticides, PCBs, etc.) were added after World War II, as well as radionuclides.

In a general way, estuaries function as sinks of most of these substances. The estuarine circulation of the overlying freshwater flowing outward, and the sea water wedging inward at depth, traps suspended materials and the substances adsorbed on them within the brackish part of the estuary. This recirculation of the mud gives thus rise to longer residence times of suspended matter than the dissolved components in the water, which s in fact flowing through the turbidity maximum (Salomons & Förstner, 1984). In this way contamianted rivers also contribute to the pollution of the sea and to more remote coastal ecosystems. Some pollutants found in the Duch Wadden Sea, for instance, were traced bck to discharges of the river Rhine into the North Sea (Essink & Wolff, 1978). Alltogether the rivers contribute for about 33% (Cd, Cu, Pb) to 45% (Zn, Ni) or even 60% (Cr) to the total trace metal input to the North Sea (Norton, 1982). The Scheldt, however, shares for only 1-3% in this total river input, against 10-30% for te Rhine, dependent ont he metal concerned.

In this paper the fate of some anthropogenic pollutants in the Scheldt estuary is discussed. Besides the excess of nutrients brought in by domestic wastes and the recent introduction of radionuclides most attention is paid to trace metals. The toponyms used in this paper are located in Figure 1.

2. Pollution audits of the Scheldt estuary

According to Van der Kooij (1982) about 40,000 tons yr^{-1} nitrogen is brought form belgium into the Dutch part of the Scheldt estuary called the Westerschelde. That is about 70% of the total N input in this part of the estuary. For phosphorus these figures are 4,500 tons yr^{-1} or60% of the total P input.

Wollast (1983) summarized the data on N and P fluxes through estuaries to the ocean. He found that the contribution due to human activities is clearly several times higher than the natural fluxes. Indeed, for the Scheldt estuary the Dutch polders embanked round 1900 in the neighbourhood of the Belgian frontier are called the cesspool of Antwerp, in popular language, indicating the high nutrient richness of these former salt-marsh deposits.

Table 1.

Metal balance (tons yr^{-1}) for the Scheldt estuary. After Salomons et al. (1981) in Salomons & Förstner (1984)

	Inflow	Outflow	Outflow in % of inflow
Zinc	1,271 (1,420)	111 (320)	9 (23)
Lead	353 (300)	26 (22)	7 (7)
Copper	311 (253)	33 (63)	11 (25)
Nickel	128	53	41
Cadmium	48	5	10

Values in brackets refer to flux calculations by Wollast & Peters (1978).

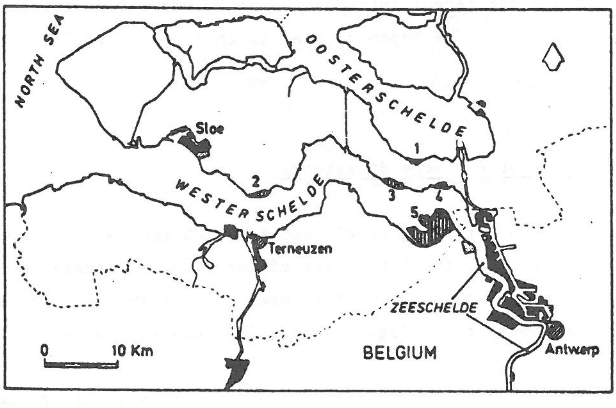

Figure 1. Map of the Scheldt estuary with toponyms used in this paper. 1. Krabbendijke, 2. Ellewoutsdijk, 3. Waarde, 4. Bath and 5. Saeftinge salt marsh.

For trace metals more data are available. Table 1 shows a metal balance, which indicates that most metals accumulate 90% or more in the estuarine sediments. Nickel is an exception passing for about 40% to the North Sea. This means that most metals are still accumulating in the estuarine environment. How these metals disperse over the different sediments is not really known. Most metals, however, adsorb for the greater part to clay and silt particles as well as particulate organic matter. It may therefore be concluded that at least accreting salt marshes are relatively important sinks for trace metals.

The recent environmental introduction of artificial radionuclides by atmospheric fall-out and nuclear-power plant release is also established in the Scheldt estuary (Duursma et al., 1985). Estuarine distribution of plutonium isotopes is characterized by a seaward concentration increase, for the greater part governed by an uptake of marine dissolved plutonium by estuarine sediment particles. Duursma et al. (1985) pointed out that at that moment the effluents released by the nuclear fuel reprocessing plants of La Hague (Fr.) and Sellafield (GB) are the major source of this contamination. Although it is not yet known how these accumulation processes will extend, the total alpha activity of the isotopes in the Scheldt estuary is very low, and represents only 0.1% of the alpha radiation caused by natural radionuclides of the uranium and thorium series.

3. Excess of nutrients and its effects on salt-marsh biota

Domestic effluents released by the Flemish urban centres into the river Scheldt enter the estuary from the upstream side. It may be assumed that their distribution over the estuary largely corresponds with the distribution of fluvial suspended matter. Salomons & Eysink (1981) found that the ratio of fluvial to marine mud in suspended matter of the Scheldt estuary is more or less constant (70% fluvial mud) in the salinity range between 5 and 15 $^{o}/oo$ S. Supply of excess nutrients to the system may be spread especially over that section, which extends into the Dutch part of the estuary.

The deposition of these excess of nutrients can be illustrated with the phosphate content of salt-marsh soils. Phosphates are much less bioavailable and also much less mobile than nitrogen compounds. Figure 2

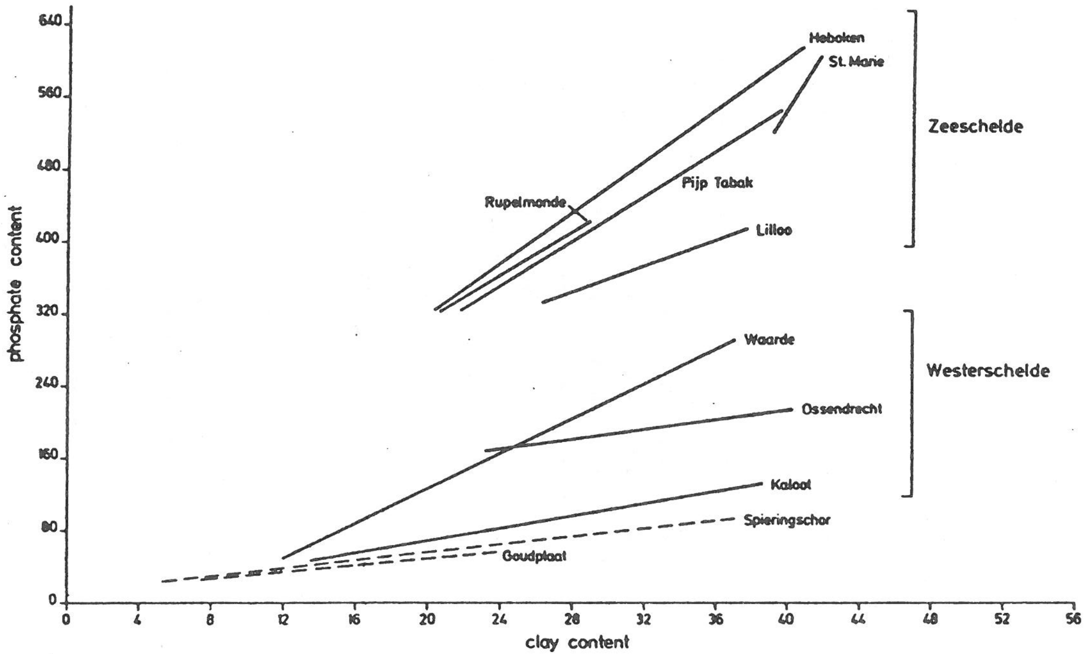

Figure 2. Regression lines of phosphate content (mg P_2O_5 extracted with 1% citric acid in 100 g dry soil) against clay content (% particles ≤ 16 μm) in the soils of individual salt marshes occurring in the Oosterschelde (dashed lines), the Westerschelde and the Zeeschelde. Derived from Beeftink <u>et al</u>. (1977).

shows that in the eastern part of the Westerschelde, and especially in the Belgian part of the estuary, highly elevated P-contents occur, compared with those of the Oosterschelde salt marshes.

Nitrogen is used for the greater part directly by autotrophic organisms. It has been observed that salt-marshes in the brackish part of the Westerschelde show an excessive plant growth when ungrazed, giving way to dominance of salt-tolerant ruderals such as Elymus pycnanthus, Atriplex hastata, Phragmites australis and Sonchus arvensis (Beeftink, unpubl.). In brackish marshes where grazing from old times has recently stopped, the vegetation has been changed within a few years from a stable pattern of species-rich plant communties into communities in which these ruderals take a dominant place. Especially the true halophytes which extended into the brackish zone under the grazing regime, are then at a disadvantage: Salicornia europaea, Spergularia maritima, Limonium vulgare, Halimione portulacoides and Artemisia maritima.

The conclusion is that estuarine eutrophication clearly changes the composition of the vegetation in the brackish marshes by favouring salt-tolerant ruderal species at the cost of the species of which growth rate is less activated by excess of nutrients. Cattle grazing, more than sheep grazing, can neutralize this skew community development into more balanced species assemblages (Beeftink, 1977).

The high production of biomass in the production line of the salt-marsh ecosystem has also consequences for the decompositon line. It is expected indeed that the detritivorous plant and animal species in- and outside the salt marsh proper can manage that heaps of food. It may however also be assumed that the species composition in this functional line will be shifted in the direction of the species which are favoured by the availability of a more uniform food.

4. Trace-metal pollution and its effects on salt-marsh biota

Usually trace metals are deposited in the salt-marsh soil in close connection with the amount of the finely grained sediment fractions. In Figure 3 Zn-analyses of monthly samples illustrate this correlation with the clay content of the soil. During 1983 sedimentation of clay particles in the sample plot of the middle marsh caused a gradual increase of Zn concentration parallel to an increase in clay content. The sample plots from the lower (top) and upper marsh (bottom) did not show this sedimentation process.

The Cd concentrations found in the same sample, however, had quite another course with time supposing that other mechanisms govern its supply to the soil (Figure 3). Since Cd is considered one of the most mobile trace metals with a relatively large portion in a dissolved state, irregular dredging activities or industrial discharge, or even variations in the salinity of the local inundation water and the frequency of inundation can easily play a part.

If we compare the metal/clay regression lines of different metal-contaminated salt-marsh soils with those of unpolluted sediments (base-line data), it is possible to estimate the concentration factor of these polluted salt-marsh soils or estuary for the metal in question. Table 2 gives such figures for the Wester- and Oosterschelde, and shows that Cd, Hg, Pb and As are among the most enriched metals in the first-mentioned estuary.

Uptake of trace metals by the plants varies greatly. The concentration factor

$$CF = \frac{\text{concentration in organisms (here above-ground parts)}}{\text{concentration in sediment (total)}}$$

varies from roughly 0.1 to 1, with maxima of 2 for *Puccinellina maritima* and 6 for *Artemisia maritima* (both Cd and Cu: Beeftink et al., 1982). The between-habitat concentration factor for Cd in young shoots of Westerschelde species compared with similar samples from the less polluted Oosterschelde plants varies from 21 in *Aster tripolium*, 17 and 14 in *Atriplex hastata* and *Salicornia europaea*, respectively, to 7 in *Triglochin maritima* and 4 in *Spartina anglica*. *Puccinellia maritima* and *Artemisia maritima* are in this case exceptions as well: *Puccinellia* because it seems to accumulate trace metals not significantly more in higher polluted habitats (except Cd), and *Artemisia* because it highly accumulates Cd and Cu even from less polluted soils. Their between-habitat concentration factor is therefore usually only 1 to 2 (data derived from Beeftink et al., 1982).

For different trace metals the plant/habitat concentration factor can be specifically different. So, *Puccinellia* accumulates more Pb than Cd per unit of dry weight, but *Aster tripolium* more Cd than Pb. Inundation of the plants with tidal water containing suspended matter can add to the plants high amounts of metal-loaded attached mud. Peaks of attached mud occur especially in early spring, after the period with storm floods and in the beginning of the growing season. Parallel to this periodicity in the magni-

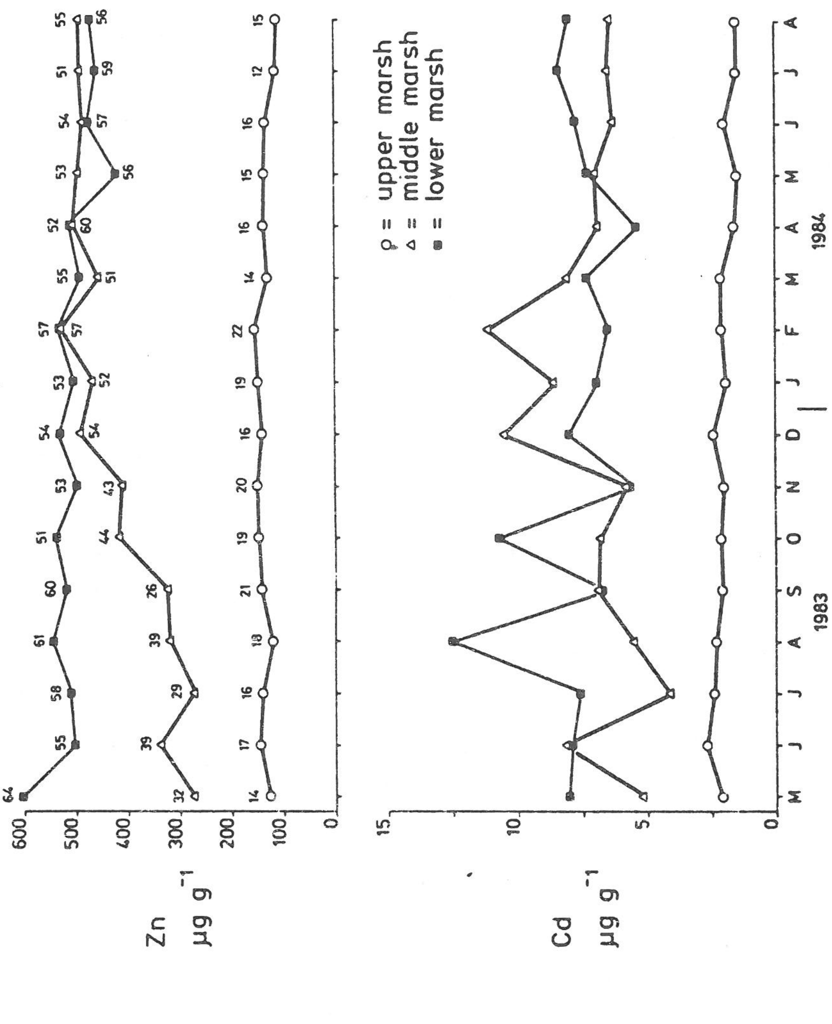

Figure 3. Zn and Cd concentrations ($\mu g.g^{-1}$ dry weight) in the soil of the Saeftinge salt marsh, Westerschelde. Monthly samples from three sites at 0–20 cm depth. The figures in the Zn-graph indicate the percentage of clay particles (≤ 16 µm) in the samples. Derived from Beeftink & Nieuwenhuize (1986).

Table 2.

Concentration factor (CF*)for trace metals in salt marshes of the Wester- and Oosterschelde

Derived from Beeftink *et al.*, 1982.

Trace metals ($mg.g^{-1}$)	Cu	Zn	As	Cd	Hg	Pb
Westerschelde	48-80	390-420	48-74	2.5-7.6	1.4-1.9	114-134
Oosterschelde	22-29	143-157	27	0.5-1.1	0.4	49-72
Standard references**	21-57	93-115	11-13	0.3	0.1-0.4	20-31
Concentration factor*						
Westerschelde	2	4	4-5	8-25	3-10	4-6
Oosterschelde	-	1-2	1-2	2-3	-	2-3

* $CF = \frac{Cn}{Bn}$, where Cn = concentration of element n, and Bn = geochemical background value of element n, both estimated from deposits with similar clay content (particles ≤ 16 μm).

**Base-line data from shales, fossil Rhine sediments, and uncontaminated Dutch and German sediments (for an inventory of these data see Beeftink & Rozema, 1986).

tude of plant-attached mud maximal values of Pb were found in unwashed Aster and Puccinellia samples taken in March and April, but, again, Cd did not show such a correlation (Beeftink & Nieuwenhuize, 1986).

Analysis of different plant tissues reveals that in general trace-metal concentrations are maximal in the root system of the plants, and they decrease with increasing distance from the shoots (Figure 4). Only inflorescences may have somewhat elevated metal concentrations: Cu, Pb and Zn in Plantago maritima, Zn in Elymus pycnanthus. This distribution is indication that in general the trace metals are taken up by the root system, and are dispersed from there by internal translocation processes. Exceptions from this distribution pattern are the highly elevated Cd and Zn concentrations in the leaves of Aster tripolium. These values suggest a direct uptake by these leaves, either from the metal-loaded attached mud (perhaps Zn), or from the tidal water loaded with the metal in a dissolved form (perhaps Cd). Ernst & Bast-Cramer (1980) reported Pb-accumulation in honey and pollen of Aster tripolium from airborne contamination. The distribution of this very less mobile element in the plants of Figure 4 suggests an additional contamination source (tidal water or air) as well.

The question remains whether populations of salt-marsh plants may be influenced in their ecology by trace-metal pollution. From studies on agricultural and wild plant species trace-metal toxicity manifests itself in chlorotic phenomena and changes in the mineral nutrition of leaves, in anomalies in flower color and stunted growth forms (for references see Ernst, 1974).

Most plant species do not grow at all in strongly metal-enriched substrates such as mine-waste deposits. Some species (Silene maritima, S. cucubalus, Minuartia verna, Plantago lanceolata, Agrostis tenuis, Holcus lanatus, etc.) have metal-tolerant genotypes allowing them to build up genetically adapted populations. Among halophytes no examples are known up to now, except the Armeria maritima complex of which both salt- and metal-tolerant groups are present (Ernst, 1974; Lefèbvre, 1974), and the salt-tolerant Agrostis stolonifera (Wu et al., 1975). Metal toxicity levels may be higher in halophytes than in non-halophytes, because the first have more ion-regulating mechanisms, resulting in either exclusion, excretion and/or accumulation of salts, than the latter. The salt secreting halophytes Armeria maritima, Limonium vulgare and Glaux maritima, for instance, secrete not only a variety of ions by means of their salt glands, but also

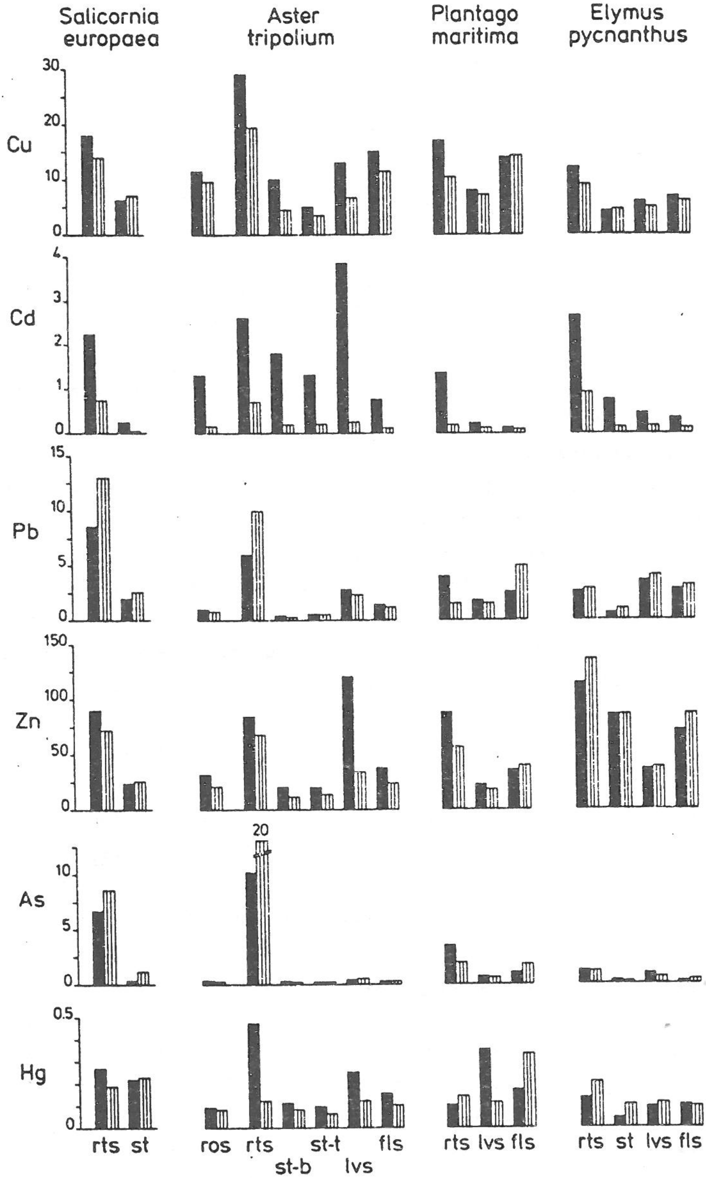

Figure 4. Distribution of Cu, Cd, Pb, Zn, As and Hg ($\mu g.g^{-1}$ dry weight) in the tissues of four plant species from the Waarde, Westerschelde (black), and Krabbendijke, Oosterschelde, salt marshes. Rts = roots, st = stems (b at basis, t at top), lvs = leaves, fls = flowers, ros = rosette leaves. Date of sampling 25 September 1978. After Beeftink & Nieuwenhuize (1986).

different trace metals (Ernst, 1974; Rozema et al., 1985).

Toxic phenomena manifesting theirselves in an obvious reduction of plant growth, chlorosis or flower anomaly, are not found in the salt marshes of the Westerschelde. But that does not mean that a high metal contamination may not cause a lowering of some physiological activities in, for instance, the germination process (see Mrozek, 1980; Mrozek & Funicelli, 1982). Moreover, metal contamination of the Scheldt estuary dates back already from the middle of the last century (industrial revolution), and possible toxic effects may long be extinguished. Some genetic adaptation may therefore not excluded among the plant populations growing in the highest contaminated salt marshes.

Other toxic effects must be found in the herbivorous and vegetative detritivorous food chains. Especially the organisms at the top of these chains can be loaded by considerable amounts of metals. A recent study on the effect of trace-metal contamination on the health of flocks of sheep grazing in a Westerschelde brackish marsh, however, did not reveal signs of any acute or chronic intoxication (Baars et al., 1986). The amounts of Cd in kidney and liver, and of Fe in liver were enhanced, but not to a potentially toxic level. The results of this study suggest that sheep are selective in their consumption of metal-enriched food, and that the metal elements are only limited bioavailable, leaving the animals for the major part by renal and fecal excretion. Besides, a management adapted to seasonal variatons in trace-metal contamination will take away much of its possible harmful effect.

More important can be the health effects of trace metals on man by the consumption of salt-marsh products. Both Salicornia and Aster are plants highly in demand as vegetables by the local people of the south-west Netherlands. Salicornia is collected from May to the end of July by cutting the herbaceous twigs. Aster from April to the end of June by cutting the rosette leaves. Some people, most elderly, eat these species 2 to 3 times a week, and store them in the freezer as a delicacy in wintertime. Therefore, both species can provide a substantial part in the diet of some people. In Table 3 maximal concentrations of Cd, Hg, Pb and As found in these natural vegetables are presented, and compared with the provisional limits for consumption (standard values) accepted in the Netherlands. The Table reveals that especially Cd concentrations may exceed these limits, but also Pb and As can accumulate to higher levels than accepted for human consumption.

Table 3.

Maximal trace-metal concentrations in vegetables from the Westerschelde and standard values for consumption (fresh weight).

Derived from Beeftink *et al.*, 1982.

Metal	Max. concentrations in plants		Standard values
	Salicornia	Aster	LAC Annual Report 1980
Cd ($\mu g \cdot g^{-1}$)	38-260	263-540	50-100
Hg ($\mu g \cdot g^{-1}$)	4-9	3-10	20-30
Pb ($mg \cdot g^{-1}$)	0.2-0.8	0.4-0.9	0.3-1.2*
As ($\mu g \cdot g^{-1}$)	50-140	29-63	100

*In Federal German Republic

These figures indicate, that persons who are used to eat these wild vegetables as a regular food, should be dissuaded from gathering in the brackish marshes of the Westerschelde.

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