THE VARIABILITY AND SIGNIFICANCE OF SELENIUM CONCENTRATIONS IN SHOREBIRD FEATHERS

A. A. GOEDE

Interfaculty Reactor Institute, Technical University Delft, Mekelweg 15, 2629 JB Delft, The Netherlands

(Received March 1990)

Abstract. The selenium distribution in the flight feathers of a marine wader, the Oystercatcher (*Heamatopus ostralegus*), is investigated. In the wing the highest concentrations are found in the outer primaries, notably primary 8. The inner tail feather exceeds the primary 8 concentration. Within the vane of a single feather, the highest concentrations are found in the tip, the lowest at the basis of the feather. The results are discussed in relation to the use of the feather as an indicator of selenium exposure.

In comparing marine wader species shortly after completion of the feather growth, a negative relation is found between the fresh primary 8 vane concentration and body weight of the species. A functional role of selenium in respect to the metabolic rate is suggested.

Introduction

Recent research pointed out that marine waders in western Europe accumulate large amounts of Se in liver and kidney (Goede, 1985; Goede and de Bruin 1985). Also the feather vanes of primary 8 show high Se concentrations that increase with time. After formation, feathers lose all vascular and nervous connections and hence become physiologically isolated from the rest of the bird. This implicates that increasing feather concentrations after completion of the feather growth, must be due to external contamination. The variability of Se concentrations in marine wader feathers is further investigated with a view to the use of the feather as an indicator of Se exposure.

During the wing moult of waders, the primaries and secondaries are shed subsequently in small numbers or one by one in the sequence 1 to 10. Primary 10 is the outermost wing flight feather, secondary 10 is the innermost wing flight feather. The primary moult takes approximately 3 months, the secondary moult starts halfway through the primary moult and finishes simultaneously (Boere, 1976). Hence, the primaries with low ordinal number are exposed longer to external contamination than the higher numbered primaries. On the other hand, the outermost, highest numbered, primaries are more prone to external contamination from the environment. Therefore, the distribution of Se within the flight feathers is investigated.

Dmowski *et al.* (1984) found an irregular pattern of Pb and Cd concentrations within the tissue of single flight feathers. The pigmented parts of the feathers had higher Pb levels compared to the surrounding white parts, while both Pb and Cd concentrations increased towards the tip of the feathers. Lead is found to contaminate the feathers after moult, Cd is a suspect element in this respect (Goede and de Bruin, 1984). Therefore the distribution of Se within the feather and in relation with pigmented parts is also looked into.

Environmental Monitoring and Assessment **18**: 203–210, 1991.

Additionally Se primary 8 concentrations of several wader species sampled in the Dutch Wadden Sea are compared.

Material and Methods

Oystercatchers (*Haematopus ostralegus*), were used to investigate Se distribution in the flight feathers. The birds (traffic victims, catching casualities or found dead in the period 1979-1985) all died at or nearby the coast of the Dutch Wadden Sea, 10 birds in spring-mid summer (i.e. 6 to 10 months after wing moult) and one bird in November (i.e. just after completion of the wing moult). The following feather parts were analysed for Se: the vanes of primaries and secondaries (remiges) 2, 4, 6, 8, and 10 of one wing (primary 10 is the outermost, secondary 10 the innermost wing flight feather. Figure 1 X-axis) and the vanes of an inner (no 6 or 7) and one but outer (no 2 or 11) tail feather (rectrices).

Distribution of Se within the feather vane of the regime and rectrice with the highest concentrations, was determined by dividing the vane in five (primary 8 $n=9$) or four (inner tail feather $n=1$)) equal parts of 2.8-3.0 cm long.

The percentages of black and white parts in the feather vanes were determined by weighing these parts, cut from a photo of the feathers.

Primary 8 of several wader species (Dunlin *Calidris alpina,* Knot *Calidris canutus,* Redshank *Tringa totanus,* Bar-tailed godwit *Limosa lapponica,* Oystercatcher) were collected from live birds approximately 2-3 weeks after its growth was completed. These birds were all caught at the same locality: the eastern part of the dutch Wadden Sea, though in different years.

Surgical gloves were worn when the feathers were pulled out the wing. Prior to analysis, the feathers were shaken in deionised water for 1 min to remove superficial contamination and dried at 60 °C for 30 min. The analysis was performed by instrumental neutron activitation analysis: the sample was irradiated in a thermal flux of 1.2×10^{13} neutrons. $cm^{-2}. s^{-1}$ for 17 s and the isotope ^{77m}Se counted for 30 s starting 17 s after irradiation, on a Ge semi-conductor gamma spectrometer. The error in the measurements is on average less than 5%.

Results

Within the feathers of a wing (6 to 10 months old $n=10$), selenium concentrations in the secondaries are at one level but raise with the ordinal number of the primaries. Peak concentrations are found in primary 8. The primaries 7 and 9 of two wings were also analysed and the results confirm this. Concentrations in the outermost primary are at the level of primary 6 (Figure 1a). In the November bird, which had just renewed its plumage, concentrations in the outermost primaries are similar to the inner primaries (Figure 1b). Selenium concentrations in the vane of primary 8 are positively correlated with each of the other primaries, secondaries and tail feathers of the same bird (Spearman Rank Correlation test, inner tail feather: $p < 0.05$, others: $p \leq 0.01$ Figure 2 with 4 examples).

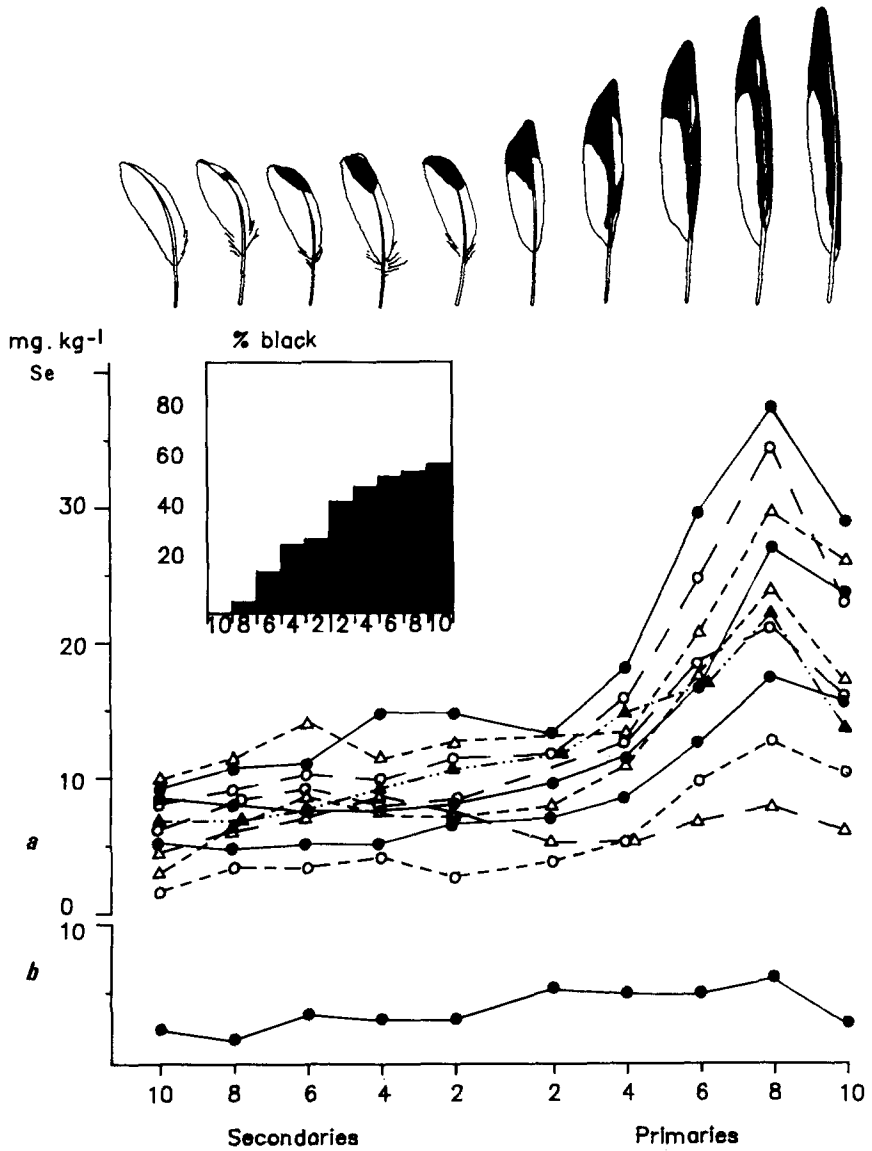

Fig. 1. Selenium concentrations in primary and secondary vanes of 11 Oystercatchers and the distribution of black parts in these black and white coloured feathers. (a) feathers 6-10 months old (wings of 10 birds); (b) feathers a few weeks old (wing of 1 bird).

The inner tail feather exceeds primary 8 in Se concentration ((Figure 2a). No relation is found between the distribution of black parts in the feather (determined in 1 wing) and the distribution of Se concentrations in the feathers as determined in 10 wings (Figure 1a).

Within the vane of a single feather, the tip shows the highest contamination with Se (primary 8, n=9, Figure 3). Though concentrations in the tip vary greatly (12.2-92.2 mg kg^{-1}), concentrations at the basis are very similar (4.2 ± 1.6 mg kg^{-1}). A similar decrease in concentration from tip to basis in the vane was found for an inner tail feather: part 1, 2, 3, and 4 showed Se concentrations of respectively 123.4, 70.7, 32.9, and 6.5 mg kg^{-1}. Again no relation is found between the percentage of black in the feather part (Figure 3, average of 3 feather data) and the Se concentration.

The average primary 8 vane Se concentration (sample sizes given in Figure 4) of the 6 different wader 'species' (5 species, 1 subdivided in males and females) sampled in the eastern Dutch Wadden Sea, are related to the average body mass of the species (Figure 4). The relation is best described by the allometric equation

$$[\text{Se, mg kg}^{-1}] = 192.6\,[\text{BM, } g]^{-0.54}$$

(n=6, p=0.01, χ^2=1.5, 95% confidence interval exponent = 0.05, BM=body mass derived from Cramp and Simmons, 1983).

Discussion

The use of feather material as a bio-indicator of element exposure has become common. A wide variability in the element concentrations is found between feathers of a single bird (Furness *et al.*, 1986), within the tissue of a single feather (Dmowski *et al.*, 1984) and within the feather lifetime (Ranta *et al.*, 1978). In case of Se, all three phenomena are encountered. Selenium concentrations increase with time in the feather vane (Goede and de Bruin, 1985), differ between the feathers of a single bird (Figure 1, Goede *et al.*, 1989)) and vary in the vane of a single feather (Figure 3). This has important consequences for the use of feather material as an indicator of Se exposure. In comparing a species from different locations (Goede, 1988) or different species from one location as in the present study, it is essential that material of a similar feather species as well as feather tissue of similar age is used.

The significance of a feather element concentration in relation to the exposure of the bird to that element, depends on how the element reached the feather. When external contamination is involved, the feather concentration is not necessarily linked with internal exposure of the bird.

In case of Se, it was already postulated that the marine wader itself smears out excreted Se from the preen gland, with the feather oil, on the feather (Goede and de Bruin, 1984). The assumption that the preen gland is involved in Se excretion when the bird is exposed to this element, is inforced by the observation that the positive relation between preen gland and kidney concentration can change. Just after breeding before the bird arrives in the marine environment, the gland concentrations is only 33% of the kidney concentration. In the marine environment where the organ Se concentrations increase rapidly after

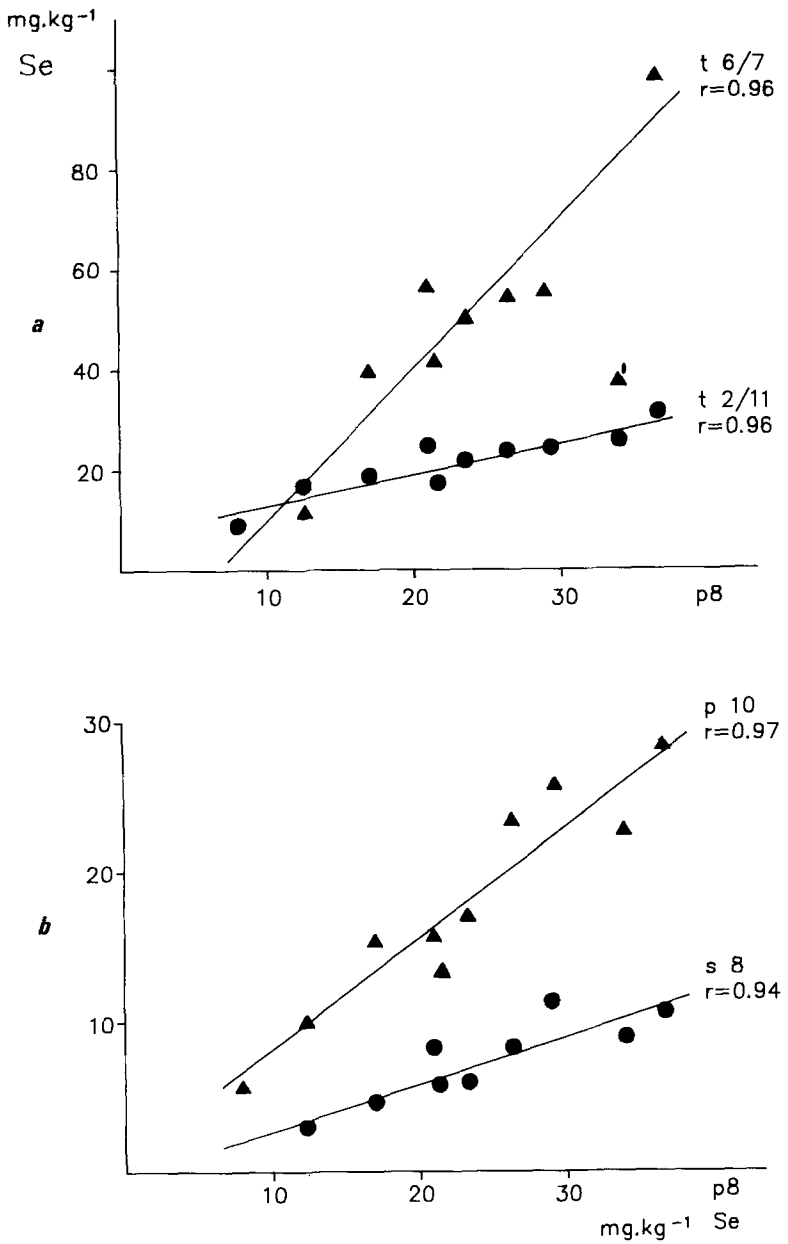

Fig. 2. Relation between selenium concentrations in primary 8 (p8, X-ax) and (a) inner tail feather (t6/7) and one but outer tail feather (t2/11), (b) primary 10 (p10) and secondary 8 (s8). C^{11} not used in calculating the correlation coefficient, probably moulted in spring (Ginn and Melville, 1983).

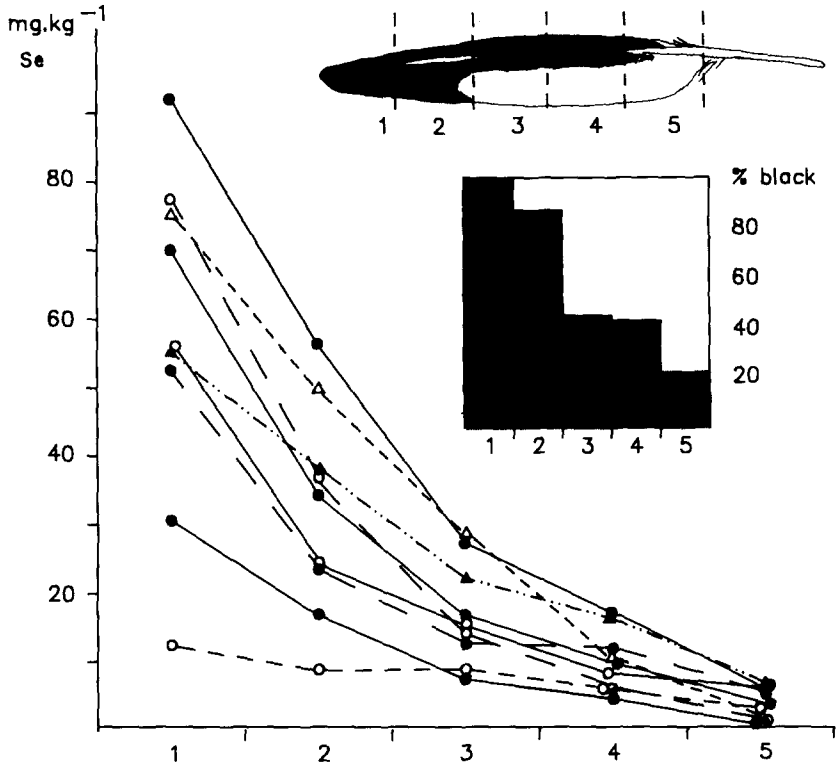

Fig. 3. Distribution of selenium within 5 parts of the vane of primary 8 ($n = 9$, part 1 = tip, part 5 = basis of the vane) and the percentage black in this feather species.

arrival of the bird, this raises to 66% of the kidney concentration (Goede *et al.*, 1989). Which means that when the wader is exposed to Se, the preen gland increases relatively even more in concentration than the kidney, indicating an active role in excretion. Furthermore, shortly after moult a positive relation between preengland and primary 8 Se concentration is found (Goede and de Bruin, 1985).

The results presented here also substantiate this assumption. The distribution of Se within the feather again indicates external contamination. The distribution within the wing however, excludes contact contamination from the environment, since the outermost and longest wing feather, primary 10, is not the most contaminated. Another contamination mechanism must have been active, a contamination mechanism that 'favours' specific feathers notably primary 8 and the inner rectrice. Only the bird itself is able to cause such a selective contamination by preening. The strong relation between primary 8 and primary 10 concentration (Figure 2) shows that Se leaching from the outer primary is not a feasible possibility. In previous work (Goede and de Bruin, 1984) a leaching experiment is described in which the new four outer primaries of both wings of a wader were used. It seemed that after washing for some time in a 3.5% KCl solution, the vane Se concentration decreased. However the results presented here show that even in

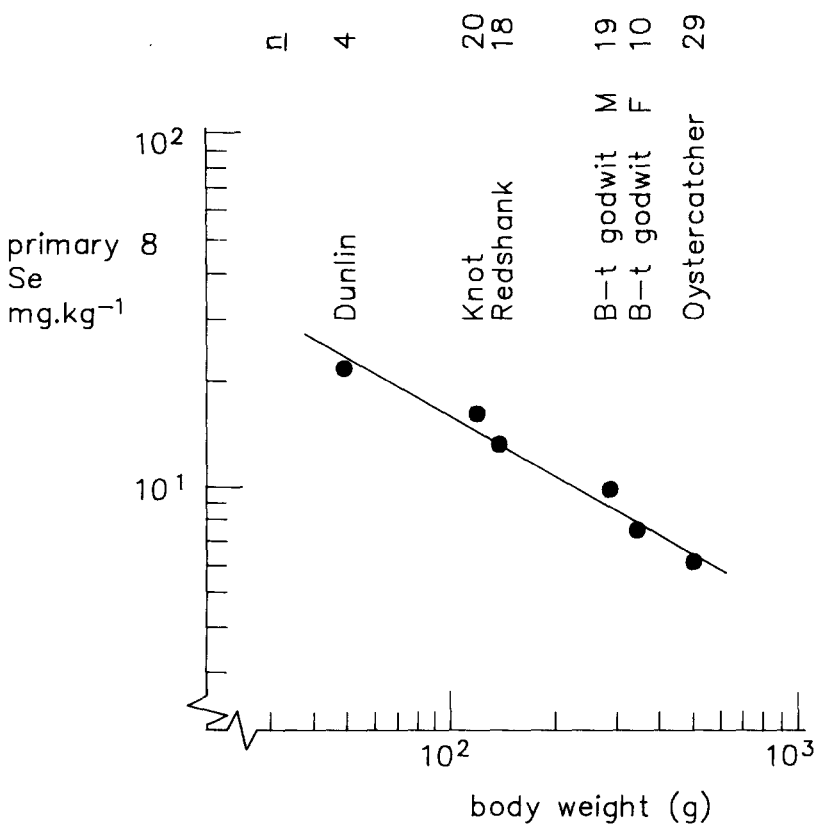

Fig. 4. Selenium concentration in primary 8 vanes (collected 2-3 weeks after completion of growth) in relation to body mass in several marine wader species sampled in the eastern Dutch Wadden Sea M=male, F=female, n=sample size.

new feathers, concentrations in the outer primaries can differ. In the November bird primary 10 has half the concentration of primary 8 (Figure 1b). Therefore no conclusions can be drawn from this former leaching experiment.

So in this particular case, where the feather is externally contaminated with Se, the concentrations nevertheless reflect the internal exposure history of the bird.

An intriguing and highly significant correlation is found between the average Se concentration in the fresh primary 8 vane and body mass of Dutch marine waders. Despite the small sample size (n=6), the exponent relating these two variables approximates the exponent -0.39 (χ^2=1.2, 95% confidence interval 0.05) encountered in relating energy requirements per gram body weight to body weight in free-living birds (derived from Walsberg, 1983). This suggests that the excretion or turnover of Se might be correlated with the metabolic rate of the bird. Metabolic rate in temperate wintering shorebirds is relatively high (Kersten and Piersma, 1987). In this respect it is interesting to note that Behne *et al.* (1988) found that the thyroid, which regulates the metabolic rate, is one of the specific target tissues of Se. Furthermore, Jensen *et al.* (1986) came to the conclusion that

Se may be necessary for providing the optimum thyroid conditions for activity of thyroid peroxide.

References

Behne, D., Hilmert, H., Scheid, S., Gessner, H., and Elger, W.: 1988, Evidence for Specific Selenium Target Tissues and New Biologically Important Selenoproteins', *Biochem. et Biophys. Acta* **966**, 12-21.

Boere, G. C.: 1976, 'The Significane of the Dutch Wadden Sea in the Annual Life Cycle of Arctic, Subarctic and Boreal Waders', *Ardea* **64**, 210-291.

Cramp, S. and Simmons, K. E. L. (eds.): 1983, *The Birds of the Western Palearctic*, Vol. 3. Oxford University Press, Oxford.

Dmowski, K., Gast F., Müller P. and Wagner, G.: 1984, 'Variability of Cadmium and Lead Concentrations in Bird Feathers', *Naturwissensch.* **71**, 639-640.

Furness, R. M., Muirhead, S. J. and Woodburn, M.: 1986, 'Using Bird Feathers to Measure Mercury in the Environment: Relationship Between Content and Moult', *Mar. Pollut. Bull.* **17**, 27-30.

Ginn, H. B. and Melville, D. S.: 1983. *Moult in birds*, BTO Guide 19, British Trust for Ornithology, Beech Grove, Tring.

Goede, A. A. and Bruin, M. de: 1984, 'The Use of Bird Feather Parts as a Monitor for Metal Pollution', *Environ. Pollut.* **8**, 281-298.

Goede, A. A. and Bruin, M. de: 1985, 'Selenium in a Shorebird, the Dunlin from the Dutch Waddenzee', *Mar. Pollut. Bull.* **16**, 115-117.

Goede, A. A.: 1985, 'Mercury, Selenium, Arsenic and Zinc in Waders from the Dutch Wadden Sea', *Environ. Pollut.* **37**, 287-309.

Goede, A. A.: 1988, 'Element Composition of Feathers Characterize Knot *Calidris canutus: A Testcase', Wader Study Bull.* **52**, 11-14.

Goede, A. A., Nygard, T., Bruin, M. de and Steinnes, E.: 1989, 'Selenium Mercury, Arsenic and Cadmium in the Lifecycle of the Dunlin *Calidris alpina,* a Migrant Wader', *Sci. Tot. Environ.* **78**, 205-218.

Jensen, L. S., Colnago, G. L., Takahashi, K. and Akiba, Y.: 1986, 'Dietary Selenium Status and Plasma Thyroid Hormones in Chicks', *Biol. Trace Elem. Res.* **10**, 11-18.

Kersten, M. and Piersma, T.: 1987, 'High Levels of Energy Expenditure in Shorebirds: Metabolic Adaptations to an Energetically Expensive Way of Life', *Ardea* **75**, 175-187.

Ranta, W. B., Tomassini, F. D. and Nieboer, E.: 1978, 'Evaluation of Copper and Nickel Levels in Primaries from Black and Mallard Ducks collected in the Sudbury district, Ontario. *Can. J. Zool* **56**, 581-586.

Walsberg, G. E.: 1983, 'Avian Ecological Energetics', in D. S. Farner, J. R. King and K. C. Parkes (eds.), *Avian Biology* 7, Acad. Press, New York, pp. 161-200.