Cadmium bioaccumulation at different stages of the life cycle of cephalopods: a radiotracer (^{109}Cd) investigation

Paco Bustamante

Olivier Cotret

Bruno Danis

Jean-Louis Teyssié

Scott W. Fowler

Pierre Miramand

Michel Warnau

Introduction

High levels of cadmium in the liver and kidney of marine mammals and seabirds have been reported in polar and sub-polar regions, areas which are not known to be subjected to particularly high inputs of cadmium (Schneider *et al.*, 1985; Wagemann *et al.*, 1990; Caurant & Amiard-Triquet, 1995). Similarly, very high cadmium concentrations in polar and sub-polar cephalopods have been recorded (Bustamante *et al.*, 1998). Since cephalopods are a primary food source for many cetaceans and seabirds, it has been proposed that a cephalopod-rich diet may be linked to the high metal concentrations found in these top predators (Honda & Tatsukawa, 1983; Muirhead & Furness, 1988; Bustamante *et al.*, 1998).

Despite the probable crucial role of cephalopods in the transfer of cadmium along food webs, only very few studies have examined heavy metal behaviour and fate in cephalopods. For example, these organisms are well known to concentrate cadmium to extremely high levels in their digestive gland (Martin & Flegal, 1975; Finger & Smith, 1987; Miramand & Bentley, 1992); however, the reason for such a high bioaccumulation is still poorly understood. Therefore, the present study has examined the biokinetics of uptake and loss of cadmium in a typical cephalopod, the common cuttlefish *Sepia officinalis,* in order to characterise the bioaccumulation and retention potential of cadmium in this organism. In the present work, bioaccumulation in *S. officinalis* was investigated using ^{109}Cd in combination with low (realistic) cadmium concentrations in order to directly measure Cd bioaccumulation in various body compartments of the cuttlefish.

Adult individuals, collected by net fishing off Monaco or provided by the « Musée Océanographique de Monaco »; were acclimatised for several weeks to laboratory conditions before experimentation. Numerous eggs were obtained during acclimation of adults and they were maintained at constant temperature (17±1°C) in continually aerated sea water. After 8 to 10 weeks, hatching of the cultured eggs furnished several dozen juvenile cuttlefish.

Cadmium bioaccumulation could thus be studied at different stages of the life cycle of *S. officinalis, viz.* in embryos, early juveniles and adults. In addition, bioaccumulation was investigated following exposures to the metal via sea water, sediment, or food.

At the end of the exposure periods, ^{109}Cd was measured by g-spectrometry in 3 compartments of eggs (capsule membrane, periembryonar liquid, and embryo), 3 body compartments of juveniles (digestive gland, cuttlebone, and remainder), and 13 body compartments of adults (digestive gland, branchial hearts, branchial appendages, gills, kidneys, ink sack, digestive tract, genital tract, ovocytes, skin, muscles, cuttlebone, and remainder).

Results and discussion

Results showed that during embryonic development, cadmium was efficiently taken up from sea water by the eggs (concentration factor reaching 46 after 8 days of exposure). However, most of the ^{109}Cd burden was found associated with the capsule membrane of the egg. Thus, the capsule most probably acts as a very efficient shield against internal cadmium incorporation, which in turn suggests that this metal could be highly toxic for early embryos.

Once this shield is lost (after hatching), the cuttlefish bioconcentrates waterborne cadmium. Indeed, juveniles as well as adults take up cadmium quite efficiently, particularly in muscles (62% of body burden) and digestive gland (25%). When non-contaminated conditions are restored, whole-body loss of cadmium in *S. officinalis* is relatively slow (biological half life: ca. 65 days) and its kinetics are best described by a two-compartment exponential model. In addition, the ^{109}Cd burden increases in digestive gland during the depuration period reaching 70% of the total body burden after one month of depuration. This would indicate either a higher retention efficiency of cadmium in digestive gland than in the other organs, or a preferential translocation of cadmium from different organs to the digestive gland.

Despite their habit to spend most of their time on the bottom sediments, bioaccumulation of ^{109}Cd from contaminated sediment remained very low after one month of exposure. Among the different organs, the digestive gland contained most of the metal at the end of the exposure period.

Regarding cadmium exposure through the food, data analysis indicates that ingested cadmium is taken up very efficiently by *S. officinalis* (Figure 1). Calculated assimilation efficiencies (AE) were as high as 60% for both age groups. Loss of ^{109}Cd ingested with food (brine shrimps *Artemia sp* for juveniles; mussels *Mytilus galloprovincialis* for adults) was much slower than loss of cadmium taken up via sea water, indicating a very strong retention efficiency of dietary cadmium by juvenile as well as adult *S. officinalis*. As for the other exposure modes tested (sea water and sediments), most of the cadmium ingested with food was found in the digestive gland. The proportion of ^{109}Cd body burden in the digestive gland reached 90% after one month of loss.

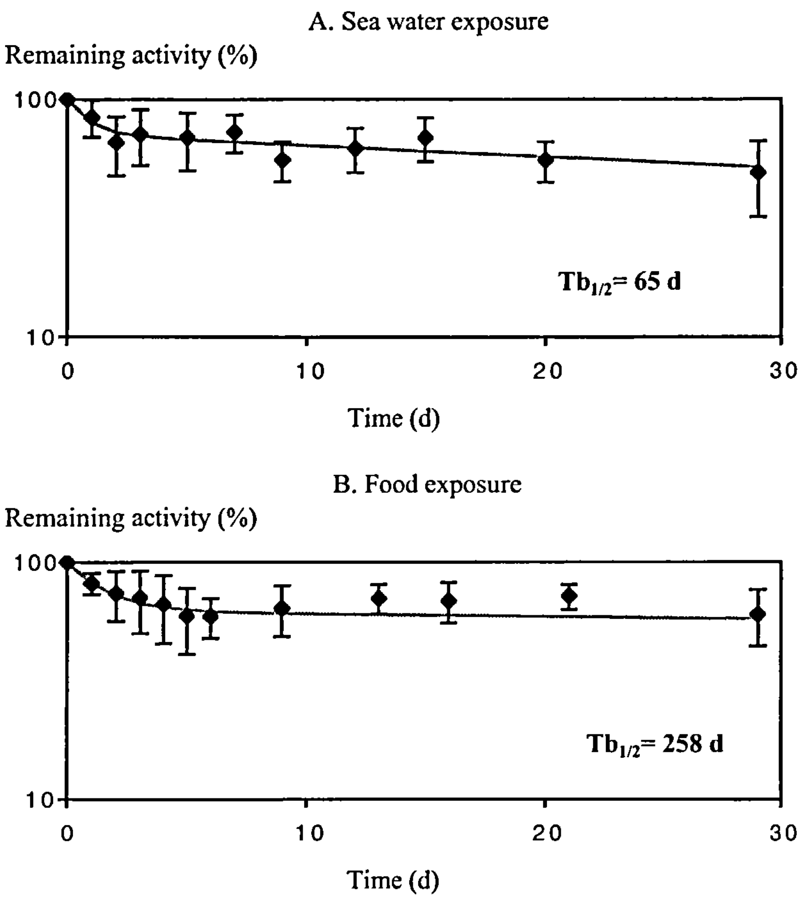

Figure 1
A. Loss of ^{109}Cd in whole juvenile cuttlefish previously exposed to radiolabelled sea water for 36 h (mean remaining activity ± SD, n =8 at day 0 and n=4 at day 29) B. Loss of ^{109}Cd in whole cuttlefish previously fed with radiolabelled *Artemia salina* (mean remaining activity ± SD, n =8 at day 0 and n=5 at day 29).

Our results clearly demonstrate that food is a major route of cadmium bioaccumulation in the cephalopod *S. officinalis.* Whatever the source of cadmium (water or food), the digestive gland is always the primary organ that accumulates the metal. This form of metal storage may be related to the detoxification function of the digestive gland (e.g., metal trapping by metalloproteins), which could explain why cadmium reaches extremely high concentrations in this organ.

Bibliography

BUSTAMANTE P., CAURANT F., FOWLER S. W., MIRAMAND P., 1998 — Cephalopods as a vector for the transfer of cadmium to top marine predators in the north-east Atlantic Ocean. *Sci. Tot. Environ.*, 220: 71-80.

CAURANT F., AMIARD-TRIQUET C., 1995 — Cadmium contamination in pilot whales *Globicephala melas*: source and potential hazard to the species. *Mar. Pollut. Bull.*, 30 (3): 207-210.

FINGER J. M., SMITH J. D., 1987 — Molecular association of Cu, Zn, Cd and ^{210}Po in the digestive gland of the squid *Nototodarus gouldi. Mar. Biol.*, 95: 87-91.

HONDA K., TATSUKAWA R., 1983 — Distribution of cadmium and zinc in tissues and organs, and their age-related changes in striped dolphins, *Stenella coeruleoalba. Arch. Environ. Contam. Toxicol.*, 12: 543-550.

MARTIN J. H., FLEGAL A. R., 1975 — High copper concentrations in squid livers in association with elevated levels of silver, cadmium, and zinc. *Mar. Biol.*, 30: 51-55.

MIRAMAND P., BENTLEY D., 1992 — Concentration and distribution of heavy metals in tissues of two cephalopods, *Eledone cirrhosa* and *Sepia officinalis*, from the French coast of the English Channel. *Mar. Biol.*, 114: 407-414.

MUIRHEAD S. J., FURNESS R. W., 1988 — Heavy metal concentrations in the tissues of seabirds from Gough Island, South Atlantic Ocean. Mar. Pollut. Bull., 19: 278-283.

SCHNEIDER R., STEINHAGEN-SCHNEIDER G., DRESCHER H. E., 1985 — "Organochlorines and heavy metals in seals and birds from the Weddell Sea". *In* Seigfried W. R., Condy P. R., Laws R. M., (eds) *Antarctic nutrient cycles and food webs.* Springer, Berlin, Heildeberg, New York: 652-655.

WAGEMANN R., STEWART R. E. A., BÉLAND P., DESJARDINS C., 1990 — "Heavy metals and selenium in tissues of beluga whales, *Delphinapterus leucas*, from the Canadian Arctic and the St. Lawrence estuary". *In* Smith T.G., ST AUBIN D. J., GERACI J. R. (eds) *Advances in research on the beluga whale, Delphinapterus leucas.* Can. Bull. Fish. Aquat. Sci., 224: 191-206.