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Effects of field contamination by metals (Cd, Cu, Pb, Zn) on biometry and mechanics of echinoderm ossicles

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ABSTRACT

Echinoderms are known to readily incorporate metals in their calcified endoskeleton. It is currently unclear if this has an impact on the skeleton function or if this can be considered as a detoxification mechanism. In the present work, populations of the sea urchin *Echinus acutus* and the starfish *Asterias rubens* were studied in stations distributed along a metal contamination gradient in a Norwegian fjord (Sørfjord). Ossicles involved in major mechanical functions – sea urchin spine and starfish ambulacral plate – were analyzed for their metal concentration (Cd, Cu, Pb and Zn) and their biometric and mechanical properties.

Starfish plates were more contaminated by Cd, Pb and Zn than sea urchin spines. Cu concentrations were at background levels. In *E. acutus*, metals principally affected size. In *A. rubens*, material stiffness and toughness were decreased in the most contaminated station. This reduction is attributed either to the direct incorporation of metals in the calcite lattice and/or to deleterious effects of metals during skeleton ontogenesis. The contrasting incorporation of metals in the skeleton of the two investigated species accounts for the different impact of the metals, including in terms of fitness. The present results clearly indicate that, at least in *A. rubens*, incorporation of metals in the skeleton cannot be considered as a detoxification mechanism.

1. Introduction

Echinoderms are widely distributed and play a key ecological role in numerous ecosystems (Jangoux and Lawrence, 1982). Their body wall includes a well-developed mineralized skeleton made of discrete ossicles located in the dermis. Each ossicle consists of a three-dimensional network of mineralized trabeculae, the stereom, delimiting an internal and complementary network filled by connective tissue, the stroma. The stereom consists of magnesium calcium carbonate and of 0.1% (w/w) organic material (the intrastereomic organic matrix, IOM) (e.g., Weiner, 1985). Most of the mineral phase is in the form of high-magnesium calcite (i.e., a solid solution of $CaCO_3$ and $MgCO_3$, Chave, 1952). Each ossicle diffracts X-ray as a single crystal (Donnay and Pawson, 1969). As many other minerals produced by living organisms, the echinoderm skeleton has remarkable properties in comparison with its inorganic equivalent. For instance, the stereom trabeculae break along conchoïdal fractures instead of the expected rhombohedral cleavage of calcite (Donnay and Pawson, 1969). This has been attributed to the inhibition of rhomboedral cleavage planes by the IOM (Berman et al., 1988; Aizenberg, 2006).

Adult echinoderms may accumulate large amounts of metal contaminants including lead and cadmium (den Besten et al., 1989; Temara et al., 1996, 1997a,b, 1998; Flammang et al., 1997; Warnau et al., 1998; Auernheimer and Chinchon, 1997; Boisson et al., 2002; Erk et al., 2005). In comparison with other body compartments, the skeleton eliminates metals at a much slower rate when the animal is returned to uncontaminated conditions (Warnau et al., 1995a; Temara et al., 1996; Boisson et al., 2002; Coteur et al., 2003a,c). A possible detoxification role of the skeleton has been suggested (D'Andrea, 1994; D'Andrea et al., 1996; Temara et al., 1997a,b; Boisson et al., 2002). On the other hand, reduced growth and abnormal morphology of echinoderm skeleton plates were attributed to metal contamination in both experimental and field conditions (D'Andrea, 1994; D'Andrea et al., 1996; Dafni, 1980; Temara et al., 1997b, 1998). Currently, it is not clear whether metals do effectively impair the skeletal formation. In particular, the mechanical properties of echinoderm skeleton have never been investigated from this point of view. However, biomechanics of skeleton structures has most of the time a great importance for the organism fitness (Currey, 1999; Meyers et al., 2008).

The sea urchin spine has been studied as a mechanical structure from 1969 (Weber, 1969). In the field, sea urchin spines are essentially submitted to bending, and the spine architecture is well

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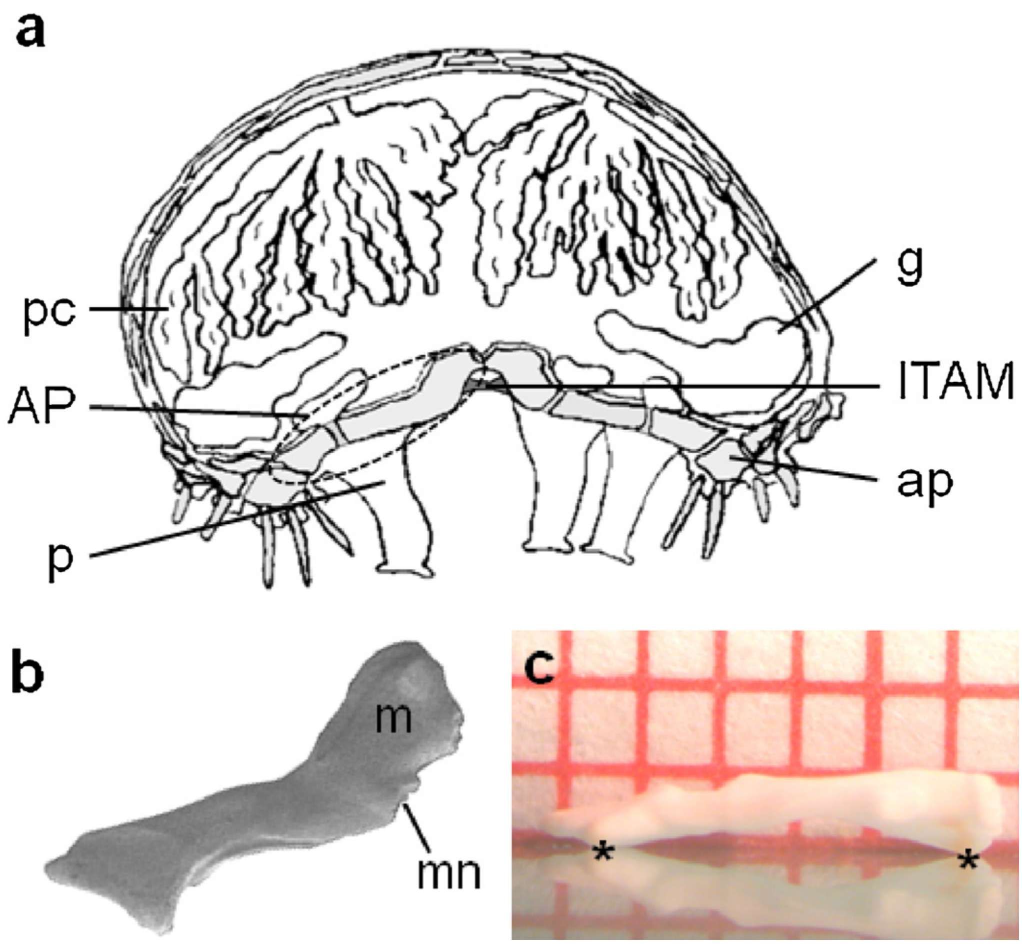

Fig. 1. (a) Transverse section of *Asterias rubens* arm with main skeleton plate and internal organ location, AP: ambulacral plate, ap: adambulacral plate, itam: inferior transverse ambulacral muscle, pc: pyloric caecum, p: tube foot, g: gonad; (b) *A. rubens* ambulacral plate (SEM) with the location of the insertion of the inferior transverse ambulacral muscle (m) and its notch (mn); (c) *A. rubens* ambulacral plate in position to measure the bending effective length, *supporting point.

adapted to face bending moments from all directions (Burkhardt et al., 1983). The crushing strength of the spine appears to be comparable to that of mollusc shells (Weber, 1969; Currey, 1975), and the spine apparent Young's modulus E (characterizing the stiffness of the skeleton material) and the spine hardness H were found to be lower than that of inorganic calcite (Burkhardt et al., 1983; Schinner et al., 1995; Moureaux et al., 2010). The forces acting on starfish ambulacral plates, i.e. the main ossicles on the oral face of the starfish ray, were also studied, especially at the critical moment of mussel opening (Eylers, 1976). Forces coming from podia activities, nearby plates and muscles were shown to be concentrated at the insertion of the inferior transverse ambulacral muscle (Fig. 1).

The aim of the present study was to assess the possible impact of metals on biometric and mechanical properties of the adult echinoderm skeleton. For that purpose, isolated ossicles involved in major mechanical functions – sea urchin spine and starfish plate – were sampled on individuals with contrasted contamination levels and analyzed for their metal concentration and their biometric and mechanical properties.

2. Materials and methods

2.1. Study area and sampling sites

The study area was the Sørfjord (Southwest Norway) stretching over 37 km between Odda and its opening in the Hardangerfjord. The fjord is 1–3 km wide and 390 m in maximum depth (Fig. 2) and it presents a well known gradient of metal contamination. Three smelters (zinc, titanium and iron) at the fjord head had discharged wastes contaminated by cadmium (Cd), copper (Cu), lead (Pb) and zinc (Zn) into the fjord waters from 1920 to 1986, resulting in highly contaminated sediments and animals (Coteur et al., 2003a). From 1986, dumping in the fjord has been reduced, then stopped. Nevertheless, the Sørfjord remains a hot spot of contamination by metals

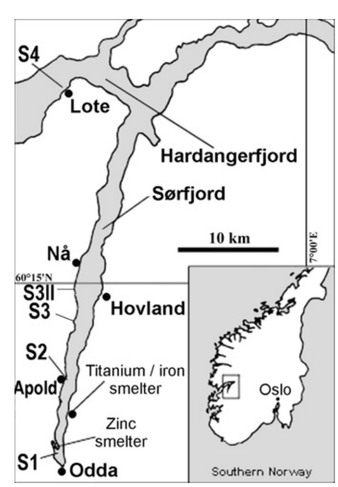

Fig. 2. Location of the sampling stations S1, S2, S3, S3II and S4 in the Sørfjord (Southern Norway).