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Baseline paper

^{90}Sr and ^{137}Cs in Arctic echinoderms

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ABSTRACT

Radionuclides in the Arctic echinoderms have seldom been studied despite their considerable environmental importance. This manuscript covers the results of ^{90}Sr and ^{137}Cs measurements in common echinoderm taxa collected from the Svalbard Bank in the Barents Sea and from two High-Arctic fjords (Isfjorden and Magdalenefjorden). We focused on the echinoid, *Strongylocentrotus droebachiensis*, the asteroid, *Henricia sanguinolenta*, and the ophiuroid, *Ophiopolis aculeata*. For all echinoderms, the analysis revealed a negative correlation between ^{90}Sr activity and the mass. Thus, we concluded that metals are accumulated faster at a young age when the growth is most rapid. The highest average activities of ^{137}Cs followed the order *O. aculeata* > *H. sanguinolenta* > *S. droebachiensis*. This suggests that bioaccumulation was highly taxon-dependent and could reflect differences in the isotope exposures associated with the diet of echinoderms. The study provides a baseline for understanding radionuclide processes in the High-Arctic benthic echinoderm communities.

The Arctic region is substantially a pristine area, but this unique part of the globe has also been contaminated by anthropogenic radioactive nuclides. The primary sources of radionuclides in the Arctic are: fallout from atmospheric nuclear weapons testing during the 1950s and 1960s and radionuclides discharged from reprocessing plants. The major global source of ^{90}Sr and ^{137}Cs was stratospheric and tropospheric fallout resulting from nuclear weapon tests. Ninety one of the 543 atmospheric weapon tests conducted around the world, were carried out in the Arctic region by the Former Soviet Union (FSU) at Novaya Zemlya (UNSCEAR, 2000). As a consequence total input from global fallout to the high-latitude part (60°–90°N) of the World Ocean was 16.1 PBq of ^{90}Sr and 25–30 PBq of ^{137}Cs (Aarkrog, 1994, 2003). Another major source was the discharge from reprocessing plants at Sellafield (UK) and La Hague (France). Sellafield, which discharged radionuclides into the Irish Sea, has been a major contributor of radioactive contamination to the marine environment. After mixing in the North Sea, the plume of ^{90}Sr and ^{137}Cs migrates further northward, swept by the Norwegian Coastal Current, Norwegian Atlantic Current, and West Spitsbergen Current traversing around the west coast of Svalbard (Karcher et al., 2010). It is estimated that these two plants delivered 10–15 PBq of ^{137}Cs to the Arctic Ocean (Kershaw and Baxter, 1995; Carroll et al., 2002). The total input of ^{90}Sr from reprocessing plants was 7 PBq, so we can see that definitely less ^{90}Sr than ^{137}Cs got into the North Atlantic. The deposition of ^{137}Cs to the Arctic region after the Chernobyl accident was estimated to be 4.1 PBq (Aarkrog, 1994). Input of ^{90}Sr was marginally low because the release of this radionuclide was an order of magnitude lower than that of ^{137}Cs and 90% of the ^{90}Sr was deposited within the borders of the FSU. In the Arctic region, the total influx was about 40 PBq of ^{137}Cs and 20 PBq of ^{90}Sr, amounting to 3.7% and 3.1%, respectively of the total emission of these nuclides into the environment (Kershaw and Baxter, 1995; Carroll et al., 2002; Aarkrog, 2003).

Despite the relatively low taxonomic diversity in polar seas (Piepenburg et al., 1997; Piepenburg, 2000; Anisimova and Cochrane, 2003; Stöhr et al., 2012), echinoderms make a major contribution to the Arctic marine communities and frequently are regarded as their epibenthic dominants (Ambrose et al., 2001; Kędra et al., 2013). Current studies have shown echinoderms to be sensitive to changes in the environmental conditions such as the temperature or ambient seawater chemistry (Dupont et al., 2013). Echinoderms also play ecologically important roles; for example, sea urchin – kelp interactions can be significant (Steneck et al., 2002); complete overgrazing may result in barren grounds, thus changing one ecosystem state to another (Kortsch et al., 2012). In some northern waters, asteroids and ophiuroids comprise as much as 80% of the benthic biomass (Zenkevitch, 1963), and similar figures are known from many local communities worldwide. Polar echinoderms use diverse life strategies and behavior (Borszcz et al., 2014) as well as high reproductive rates to produce a large amount of biomass in extreme Arctic settings and thereby become important in carbon cycling (Ambrose et al., 2001; Iken et al., 2010). Echinoderms also take part in benthic remineralization (Ambrose et al., 2001), and after death, their remains contribute carbonates to the

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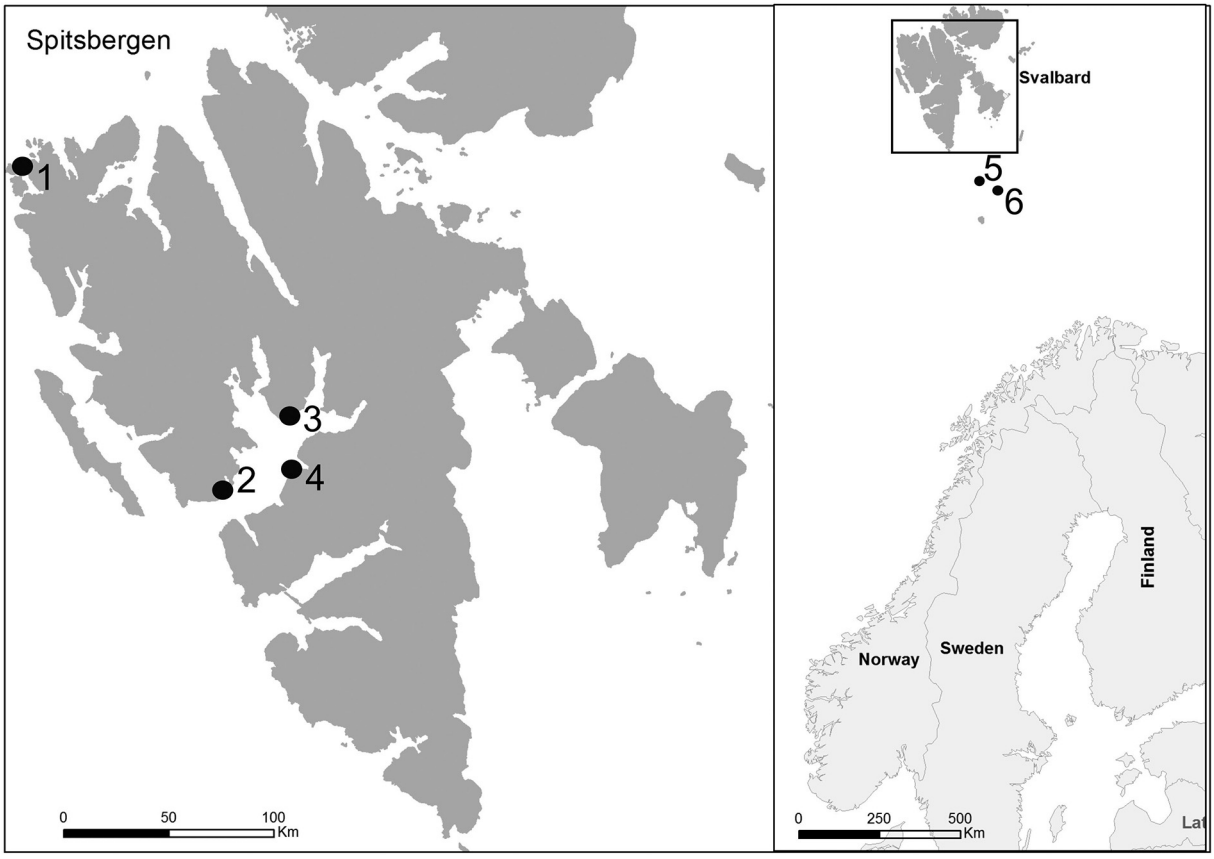

Fig. 1. Sampling stations for echinoderm.

sediments (Lebrato et al., 2010). Echinoderms in the Arctic Ocean are also prey for different higher trophic level organisms including fishes, crabs, actinarians, and echinoderms among others. Likewise, they are also predators/scavengers of several species. Furthermore, some echinoderms are edible and thus have commercial/aquaculturing value (Scheibling, 1996; Scheibling and Hatcher, 2001). In this way echinoderms can be responsible for transporting radionuclides across the trophic web (Heldal et al., 2003) and deserve more investigation. The objective of this research was to determine concentrations of two important radionuclides in the Arctic, ^{90}Sr and ^{137}Cs, in selected common European Arctic echinoderm species.

Forty three echinoderm samples representing three common species, the echinoid, *Strongylocentrotus droebachiensis*, (20 samples), the asteroid, *Henricia sanguinolenta*, (10 samples) and the ophiuroid, *Ophiopolis aculeata*, (13 samples), have been collected between 2009 and 2012 (Fig. 1). It should be noted that the term echinoids is synonymous with sea urchins (Class: Echinoidea), asteroids with starfishes (Class: Asteroidea), and ophiuroids with brittle stars (Class: Ophiuroidea), and all of them are classified systematically as echinoderms (Type: *Echinodermata*, e.g., Smith, 1984). Samples were obtained from two Arctic seas (Barents Sea and Greenland Sea), in six locations situated in the open sea and in fjord settings. Samples from Isfjorden were collected by scuba divers; all other samples were collected during cruises on-board of *r/v* Oceania using benthic dredging. After collecting, specimens were preserved in a buffered 4% formaldehyde solution. The sample sizes were predetermined by the availability of material at various locations and thus by the ecological distribution and natural abundance (Table 1).

Before analysis, echinoderm specimens were ashed at a temperature of 450 °C in a muffle furnace. The ^{137}Cs activity in echinoderms was measured using a gamma spectrometry system: an HPGe detectors with a relative efficiency of 43% and a resolution of 1.8 keV for the 1332 keV peak of ^{60}Co. The detector was coupled to an 8192-channel computer analyzer and GENIE 2000 software. The time measure for each sample for ^{137}Cs was 80,000 s (for some samples measuring time was 160,000 s) (Table 1). The ^{90}Sr activity in echinoderms was determined after γ-ray measurements. Firstly, the sample residue was digested with concentrated nitric acid on a hotplate. This process decomposed most of the organic matter. After digestion, the residue was collected on hard filter paper and discarded. The filtrate was diluted with distilled water to 150 ml. The following reagents: 100 ml of 8% oxalic acid, 20 mg of natural strontium, and ammonium (to raise pH to 4–4.5) were added to the diluted filtrate. The solution was heated to 80 °C in order to completely precipitate the strontium oxalate. The precipitate was collected on hard filter paper and allowed to dry in ambient conditions. The oxalate was then converted to carbonate at 650 °C in a muffle furnace. Next, the strontium carbonate was separated from calcium carbonate with 65% HNO_3. Radium removal was done by precipitation with $BaCrO_4$ in the presence of a buffering agent (pH = 5.5). 20 mg of stable yttrium was added, and the samples were allowed to stand for 21 days to reach complete equilibrium between ^{90}Y and ^{90}Sr (Volchock et al., 1957). The yttrium was then precipitated as a hydroxide, converted to oxalate, and collected on a pre-weighed filter. Beta activity of the samples was measured using Low-Level Beta Counter FHT 7700 T (ESM Eberline) with the background count rate of 0.01 counts s^{-1} and the lowest detectable activity of 3 mBq per sample. The time measure for each sample for ^{90}Sr was 21,600 s. The reliability and accuracy of the applied method of ^{90}Sr and ^{137}Cs determination were verified by participation in HELCOM-IAEA-446 Proficiency Test on the Determination of Radionuclides in Marine Fucus Sample (Laboratory no. 7). Dry macroalgae biomass may be recognized as a substitute for the ashed echinoderms biomass (Pham et al., 2014).

The average activity concentration of ^{90}Sr in *O. aculeata* was 4.6 Bq $kg_{d.w.}^{-1}$ (from 1.4 Bq $kg_{d.w.}^{-1}$ to 8.3 Bq $kg_{d.w.}^{-1}$), in the asteroid *H.*

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