Lack of Cesium Bioaccumulation in Gelatinous Marine Life in the Pacific Northwest Pelagic Food-Web

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Abstract Bioaccumulation of cesium with increasing trophic position is well known across nearly every ecosystem for most organisms. In the marine environmental, typical (concentration ratios (Bq/kg in tissue: Bq/kg in seawater) range from 50–100 in lower trophic levels to 300–10,000+ for apex predators. Recent surveys of 7 gelatinous organisms off the coast of Oregon ranging in trophic position from 1.0 to 3.0 revealed a concentration ratio maximum of 12.5 and typical concentration ratios no higher than 4.4. The implications on human diets and ecosystem shifts for large radiocesium releases are discussed.

Keywords Cesium bioaccumulation • Marine life • Pacific Ocean • Pelagic food-web

1 Introduction

Accumulation of radiocesium with increasing trophic position has been well known since the 1960s. Most radioecological assessments at that time were driven by nuclear weapons testing, and concerned with human food safety in Western diets rather than ecosystem effects, which come from trophic levels of ~ 2.7 (e.g. pandalid shrimp, forage fish) up to and exceeding 4+ (e.g. older large tunas) [6]. In pelagic marine environments like those sampled in this study, the preferential retention of Cs with respect to K has been shown to increase by a factor of 2.4 per trophic step [3]. Recommended concentration ratios (CRs) for Cs vary by species to some degree, from 50 in crustaceans to 100 in fish [1], although observed CRs in higher predators can range much higher (~ 200 –300 in albacore, 400–500 in sharks analyzed alongside the gelatinous organisms reported here). Cephalopod molluscs, however, break this trend with CRs typically closer to 10–20.

In the years following the release of substantial quantities of Cs-137 and Cs-134 (among other radionuclides) from reactors at the Fukushima Daiichi Nuclear Power

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Station, this overall focus on Western diets has lead to surprises relative to expectations. For example, tea plants at the time of the release did not yet have new leaves (those harvested), eliminating foliar uptakes as a pathway. Nonetheless, some tea leaves harvested the following season still showed substantial radiocesium uptake. As gelatinous organisms are essentially wholly absent from Western diets, there has been far less study on cesium retention. Thus, there are surprises in store with regards to human dietary concentrations of radiocesium in jellyfish. It is hoped that this survey of various gelatinous organisms will help serve as a first approximation of expected outcomes in dietary jellyfish such as *Rhizostomatidae* and *Stomolophidae*.

2 Methods

Organisms were collected off the coasts of Oregon and Washington either directly from surface trawls or via dip nets. Collections are from 2012–2014, conducted as part of research cruises conducted by the National Marine Fisheries Service. After identification, samples were kept frozen until processed. Before radio-analysis, samples were first baked to dryness at 100 °C, before being carefully dry ashed at a maximum temperature of 450 °C and a maximum temperature increase of 100 °C per hour. Recovery of cesium through ashing was verified to be unity, within the range of counting uncertainty ($\sigma = 4.074\%$), by processing IAEA-414 freeze dried fish tissues [5]. Samples were analyzed for Cs-137 concentrations on a high-purity germanium γ spectrometer. The 72.5 mm diameter, 68 mm long closed-end coaxial detector has 70% relatively efficiency and 2.0 keV resolution [full-width at half-maximum] at 1.33 MeV and 1.0 keV at 122 keV. To account for differences in detection geometry arising from differing volumes of ash, samples of known activity were counted at various fill volumes and a weighted least-squares fit for the absolute efficiency based on the fill volume was produced. Uncertainties in count rates, mass, geometry-altered efficiency, and chemical yield (on the basis of the yield using the IAEA-414 standards) were propagated.

3 Results and Discussion

Initial analyses of 1000 g by wet weight (standard sub-sample weight for other phyla being analyzed) yielded no detectable concentrations. Increasing this to the entire mass of each collection yielded detectable levels in only 1 of all collections despite wet weights up to and exceeding 10,000 g. Table 1 reports the results of radio-analysis for the 7 collections reported here. However, the minimum detectable activity (MDA) as based on the Currie limit¹ and reported in terms of Bq/kg

¹The Currie limit is based on a decision level that produces a 5% false positive rate, and defines the minimum activity necessary at such a decision level to expect a 5% false negative rate.

Table 1 Activities/MDAs of analyzed organisms

Sample ID	Species	Composition	Cs-137 Act Bq/kg fw	Cs-137 rel err (1 σ)	Wet mass (g)	Collected
JP1	<i>Pleuro brachia</i> sp.	Bulk	0.0125	38.86%	3246	July 2013
JS1	<i>Salpa fusiformis</i>	Bulk	0.0044	<MDA	2706	July 2013
JE1	<i>Phacellophora camtschatica</i>	Individual	0.0036	<MDA	5726	July 2013
CAR1	<i>Carenaria</i> sp.	Bulk	0.0044	<MDA	871	July 2013
JT1	<i>Thetys vagina</i>	Bulk	0.0060	<MDA	3041	July 2013
JBig	<i>Phacellophora camtschatica</i>	Individual	0.0108	<MDA	10,458	July 2013
C42	<i>Chrysaora fuscescens</i>	Bulk	0.0038	<MDA	9880	October 2013

Most samples consisted of bulk samples of multiple individuals. *Phacellophora* were large enough to analyze as individuals. MDAs calculated as the Currie limit e.g. activity for 5% false negative rate given detection limit

constrain the maximum possible bio-accumulation for these organisms to well beyond the bounds of those seen practically all other marine biota. Assuming a surface water concentration of 1 mBq/kg, 6 of the 7 samples have practically no bio-accumulation whatsoever: MDAs for bulk samples of the salps *Salpa fusiformis* and *Thetys vagina*, the medusae *Chrysaora fuscescens* and the two individual medusa *Phacellophora camtschatica* yield CRs of just 3.6–4.4. The mollusc *Carenaria* featured a CR no higher than 4.4, remarkably low compared to that recommended for most other non-cephalopod molluscs of 60 [1], which may be due to its dietary inclusion of gelatinous prey such as thaliacians and relative jelly-like body composition: it features only a vestigial shell a few mm in size and extremely soft translucent tissue, and by appearance outside of the water can be easily misidentified as a torn fraction of *Salpa fusiformis*.

The only sample with both sufficient biomass and bio-accumulation to be directly quantified still had resulting concentrations yielding a remarkably low CR. The small ctenophore *Pleurobrachia* had a CR of just 12.5 ($\sigma = 38.85\%$), producing a total number of counts only barely above the decision level.

With regards to trophic level [6], these results are extremely surprising. All of these organisms, by trophic level, are at least comparable with forage fish such as sardine and smelt, with the latter having 10 times as much bio-accumulation at the maximum possible here. Further, as all but one of these are maximum levels constrained by MDAs, the actual CRs could be much lower...as ionoconformists it is not out of the question to consider a CR of 1 for the lower trophic position samples. In the case of *Phacellophora*, it occupies a trophic position above 3.0, specializing in predating on the gelatinous organisms like those sampled here. This

puts it on par with young albacore and bluefin tuna in terms of trophic level, which have CRs of 200+ [2, 4].

One implication of this result is that, at least with regards to food safety, dietary jellyfish are likely to remain safe for consumption even in cases of substantial contamination. Drinking water standards for Cs-137 are several orders of magnitude below those for most foods owing to the much larger quantities of water consumed by a human. For example, the EPA in the US has a drinking water standard of 7.4 Bq/L (approximately 7.4 Bq/kg) for Cs-137, whereas the FDAs derived intervention level for Cs-137 in food products is 1,200 Bq/kg. Given the CRs presented here even for the highest trophic positions of gelatinous organisms, jellyfish should remain a relatively safe food product even when harvested in water well of 100 times past the safe drinking water standards.

Another implication of these results is one that has been mirrored in other areas of anthropogenic effects on marine ecosystems: jellyfish blooms. In the event of a radiocesium release of a large enough magnitude to produce population level effects in that ecosystem, the doses to gelatinous organisms can be expected to be tens to hundreds of times lower than that to crustaceans, fish and even macroalgae. Although no in-depth studies have been conducted on the radiosensitivity of gelatinous organisms, there is nothing to suggest they would be especially radiosensitive to offset this greatly decreased dose. Because of their extremely simple immune system that lacks the an equivalent “weak-link” of bone-marrow, and an intestine that is replaced directly by mitosis rather than the “weak-link” of crypt cells, the general indication is that they would show at least moderate radioresistance. One might expect, then, that ecosystem-affecting anthropogenic radiocesium releases might lead to jellyfish blooms and increased competition with forage fish much, much as been observed from anthropogenic eutrophication and apoxia (albeit for a different set of sensitivity/resistance mismatches).

4 Conclusion

Gelatinous organisms seem to show remarkably low retention of radiocesium when compared to their competitors in the food web. Even with 24 h counting periods, several kilograms of sample tissue to concentrate and a relatively high-efficiency HPGe in a low-background environment, only one of all gelatinous samples collected exceeded the detection threshold for Cs-137. CRs were no higher than 4.4 and may very well have been 1.0 for some of the organisms collected. Jellyfish may thus serve as a preferential food source during periods of high levels of radiocesium contamination, and may experience more population growth due to lack of competition in the event contamination levels are sufficient to produce population level effects in the ecosystem. More work on radiosensitivity of jellyfish and the means by which they maintain such low levels of retention are needed in the future.

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