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Radioactive impacts on nekton species in the Northwest Pacific and humans more than one year after the Fukushima nuclear accident

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ABSTRACT

This study investigated the radioactive impacts on 10 nekton species in the Northwest Pacific more than one year after the Fukushima Nuclear Accident (FNA) from the two perspectives of contamination and harm. Squids were especially used for the spatial and temporal comparisons to demonstrate the impacts from the FNA. The radiation doses to nekton species and humans were assessed to link this radioactivity contamination to possible harm. The total dose rates to nektons were lower than the ERICA ecosystem screening benchmark of 10 μGy/h. Further dose-contribution analysis showed that the internal doses from the naturally occurring nuclide ^{210}Po were the main dose contributor. The dose rates from ^{134}Cs, ^{137}Cs, ^{90}Sr and ^{110m}Ag were approximately three or four orders of magnitude lower than those from naturally occurring radionuclides. The ^{210}Po-derived dose was also the main contributor of the total human dose from immersion in the seawater and the ingestion of nekton species. The human doses from anthropogenic radionuclides were ~ 100 to ~ 10,000 times lower than the doses from naturally occurring radionuclides. A morbidity assessment was performed based on the Linear No Threshold assumptions of exposure and showed 7 additional cancer cases per 100,000,000 similarly exposed people. Taken together, there is no need for concern regarding the radioactive harm in the open ocean area of the Northwest Pacific.

1. Introduction

The Fukushima Nuclear Power Plant was damaged by the tsunami that resulted from the 9.0 magnitude Tohoku earthquake on March 11, 2011. This incident caused the largest nuclear accident since the Chernobyl disaster and the worst nuclear accident in terms of the contamination of the marine environment by radioactivity (Buesseler, 2014; Lin et al., 2016). Large amounts of radioactive contaminants, including ^{134}Cs ($t_{1/2}$ = 2.07 y), ^{137}Cs ($t_{1/2}$ 30.07 y), ^{90}Sr ($t_{1/2}$ = 28.6 y), and ^{110m}Ag ($t_{1/2}$ = 250 d) were released into the Northwest Pacific. The amount of radionuclides that were released into the atmosphere and ocean was estimated to be 520 PBq, approximately 10–15% of that associated with the Chernobyl Nuclear Accident, which released 5200 PBq of radioactive materials (Livingston et al., 2000; Steinhauser et al., 2014). The radioactivity that was released by the Fukushima Nuclear Accident (FNA) was dispersed over Japanese land, the ocean, and other continents, at relative percentages approximately of 19%, 80%, and 1%, respectively (Christoudias et al., 2013; Yoshida and Kanda, 2012). Although the ocean has a great capacity to dilute and disperse radioactive materials because of its large volume and complex current systems, radionuclides with long half-lives will remain in the marine environment for long periods. Seawater and marine organisms may be affected by radioactive contamination. Different levels of contamination in the surface water and the ocean interior have been reported (Yu et al., 2015; Men et al., 2015; Aoyama et al., 2013; Honda et al., 2012; Kaeriyama et al., 2013, 2014; Kameník et al., 2013; Buesseler et al., 2011; Kumamoto et al., 2014, 2015; Povinec et al., 2013). These data revealed that the Fukushima-derived radiocesium that was released into the Northwest Pacific Ocean has been transported eastward by surface currents and southward across the Kuroshio Extension current in subsurface layers. This radioactive contamination has already spread to most regions of the North Pacific Ocean. There is concern over the contamination of marine organisms because the radiation doses might harm marine organisms and because seafood might contain radiotoxicity due to the biological concentration and transmission of anthropogenic radionuclides in the marine food chain.

How should we assess the impacts of FNA on marine organisms or humans? This paper assesses these impacts from two perspectives:

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contamination or pollution, and harm or effects. Contamination or pollution is not always "harmful" because organisms have some tolerance to these radionuclides. Only a certain degree of contamination or pollution can induce harm or other effects. Thus, we ought to assess the impacts of FNA in terms of both the activity concentrations in the marine biota and the radiation dose to the species itself and humans.

12 monitoring cruises were performed during the period 2011–2016 (one cruise every half year) to assess the impacts of the released radioactive contaminations in the Northwest Pacific. The third monitoring cruise occurred during May-June 2012. In addition to seawater samples, 10 nekton species were sampled during this cruise. The seawater monitoring results were published in January 2015 (Men et al., 2015). As a supplement to the seawater monitoring results, this paper focused on the results of nekton monitoring and the FNA-derived radiation doses to nekton species and human beings. In this work, the main Fukushima-derived radionuclides in nekton species were measured, the radiation doses to the nekton species itself and humans were computed and their corresponding dose rates were assessed.

2. Materials and methods

2.1. Sampling

Nekton species samples were collected between May and June in 2012, such as squid (*Ommastrephes bartramii*), snake mackerel (*Gempylus serpens*), pelagic stingray (*Pteroplatytrygon violacea*), rough triggerfish *(Canthidermis maculatus),* Japanese amberjack (*Seriolina nigrofasciata)*, flying fish (*Cheilopogon pinnatibarbatus*), grouper (*Epinephelus awoara*), pufferfish (*Takifugu reticularis*), bream (*Scolopsis vosmeri*) and wrasse (*Choerodon azurio*). Except for rough triggerfish, Japanese amberjack and flying fish, which were collected with a net, the nekton species were sampled by angling. The sampling stations were shown in Fig. 1. The nekton species that were sampled in the open ocean of the Northwest Pacific included squid, snake mackerel, pelagic stingray, flying fish, rough triggerfish and Japanese amberjack. The species that were sampled in the Taiwan Bank Fishing Ground included grouper, pufferfish, bream and wrasse. Photo of these nekton species was shown in Fig. 2.

To establish background data, we searched for marine organism samples that were collected in the Northwest Pacific before the FNA

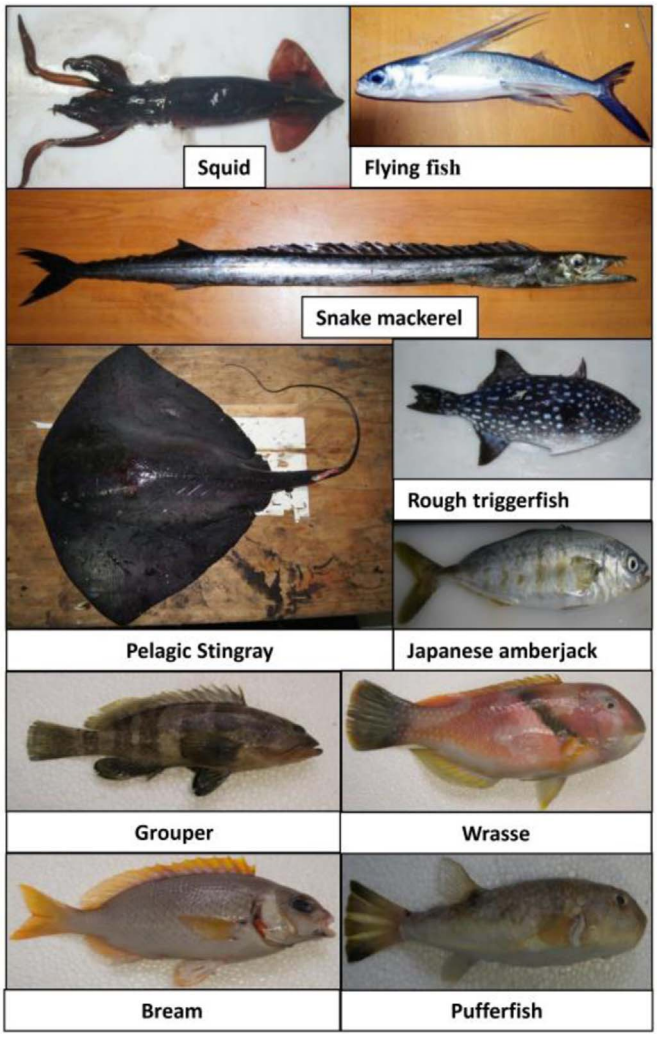

Fig. 2. Photo of the studied nekton species.

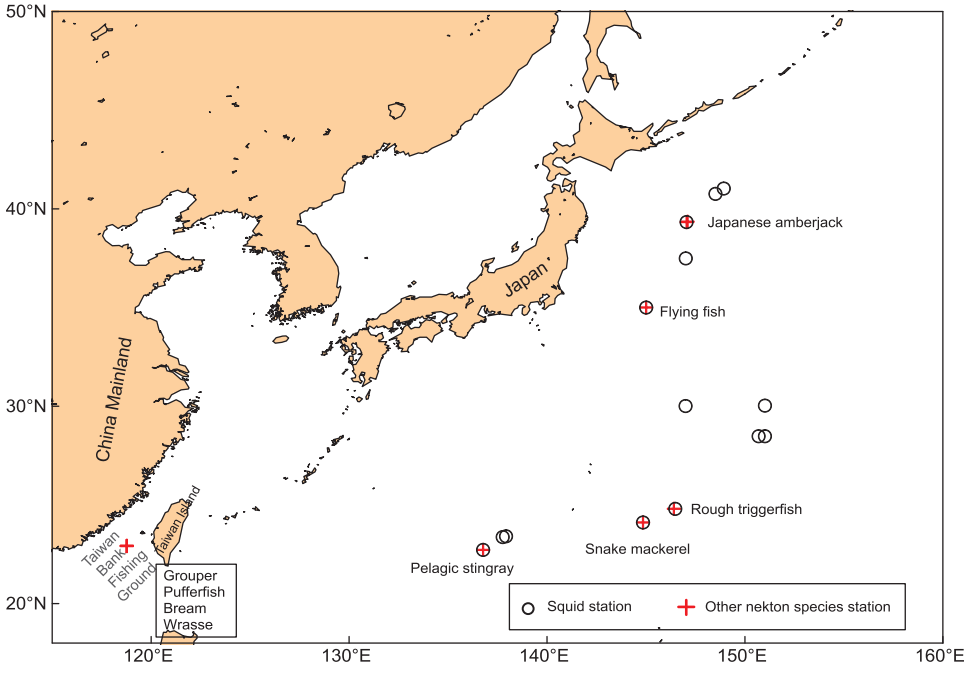

Fig. 1. Map of the sampling stations.