論文の内容の要旨

論文題目：Analysis of carbon dynamics in the Sanriku coastal ecosystem using radiocarbon isotopic compositions

（放射性炭素同位体比を用いた三陸沿岸生態系の炭素動態の解析）

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The Sanriku coastal region, in the northeast of Honshu, Japan, is a region of mixing between the Oyashio (cold and nutrient-rich aged water mixed with North Pacific Deep Water) and Kuroshio (warm and nutrient-poor water). Seasonal intrusion of the Oyashio enhances primary productivity and may provide an important food resource for organisms in Sanriku. In addition, numerous small enclosed or semi-enclosed bays along the coast of the Sanriku region receive inputs of terrestrial organic matter, which is composed of materials of various ages. Old organic matter might flow into the embayment ecosystem and enter its food web. Recently, radiocarbon (^{14}C, with a half-life of 5,730 years) analysis has been used in ecological studies. Measuring the abundance of radiocarbon ($\Delta^{14}C$) provides information regarding age, which is useful for identifying water masses and determining the contributions of old carbon resources to marine environments.

The primary goal of this study was to elucidate the carbon cycle of the Sanriku coastal ecosystem using the radiocarbon technique, with a focus on the benthic food web. In particular, this study focused on four hypotheses: (1) the Oyashio and Kuroshio are major carbon sources in the Sanriku region and can be distinguished by $\Delta^{14}C$; (2) Oyashio-derived carbon can be detected using $\Delta^{14}C$ values of benthic primary producers (macroalgae); (3) Oyashio-derived carbon is a significant carbon source for offshore megabenthos because of its high productivity; (4) aged organic matter is incorporated into benthic consumers at a higher trophic level in the coastal ecosystem.

In chapter 1, I provided an overview on the basic principles of radiocarbon dynamics and their applications in oceanographic and ecological studies. This chapter also introduced general background and objectives of my study.

In chapter 2, I investigated the spatial-temporal distributions of $\Delta^{14}C$ in dissolved inorganic carbon (DIC) in the Sanriku region and compared these data with oceanographic conditions to confirm their relationship. Surface water samples (depth: 0–200 m) were collected at 13 stations during four cruises conducted between 2014 and 2016, for determination of $\Delta^{14}C$-DIC values. My results revealed that the Sanriku region has two carbon sources that can be distinguished by $\Delta^{14}C$ signatures: warm waters (Kuroshio, Tsugaru, and surface layer waters) with high $\Delta^{14}C$ values (ca. 31‰), and cold waters (Oyashio and cold Oyashio) with low $\Delta^{14}C$ values (ca. –66‰). In addition, my data showed that the $\Delta^{14}C$ values provide information concerning the extent of mixing between warm and cold waters. This study will provide a basis for using $\Delta^{14}C$ as a water mass tracer.

In chapter 3, I explored whether the $\Delta^{14}C$-DIC signals of Oyashio and Kuroshio waters could be detected in primary producers (macroalgae). Cultivation of macroalgae (*Undaria pinnatifida*) was conducted in Otsuchi Bay on the Sanriku coast between November 2013 and April 2014. The $\Delta^{14}C$ values of pinnae (leaflet-like structures, formed in chronological order) at different positions were compared with their $\Delta^{14}C$-DIC values during photosynthesis. During the cultivation period, Oyashio intrusion occurred from early March to early April, accompanied by a reduction in bay water $\Delta^{14}C$-DIC from 15.7 ± 8.6‰ to –57.1 ± 20.7‰. The $\Delta^{14}C$ of the pinnae reflected $\Delta^{14}C$-DIC, as pinnae formed in early March had significantly higher $\Delta^{14}C$ (3.0 ± 5.4‰), compared to pinnae formed in early April (–23.6 ± 7.5‰). These results suggest that the ^{14}C-depleted signal of the Oyashio is recorded in the $\Delta^{14}C$ of *U. pinnatifida* pinnae and can be used as an indicator of the relative contribution of Oyashio and Kuroshio in supporting biomass production. These results demonstrate the utility of $\Delta^{14}C$ for examining the dependency of consumers on food containing carbon from different water masses, as macroalgal $\Delta^{14}C$ signatures should be transferred to their consumers.

In chapter 4, I investigated the relative contributions of warm and cold water masses to food provisioning for deep-sea benthic megafauna using $\Delta^{14}C$. I determined the $\Delta^{14}C$ values of benthic invertebrates in seven taxa (three deposit-feeding holothurian species, one suspension-feeding Bivalvia, and three predatory species including Gastropoda and Asteroidea) inhabiting the deep seafloor (depth: 444–2988 m) of two latitudinal transects, the OT line (39°20'N) and ON line (38°25'N). The relative contributions of two water masses to the diets of benthic megafauna were estimated using the isotope mixing model. The estimated contribution of Oyashio-derived carbon to such diets generally exceeded 50%, except for Solasteridae spp. (42%). These results show the relatively large contribution of the Oyashio to the food sources of benthic megafauna, despite the fact that Oyashio generally intrudes into the surface layer in the Sanriku area for only 1–2 months of the year.

Significant differences in $\Delta^{14}C$ were found among taxonomic groups, even along the same latitudinal line. Solasteridae spp. (predator) had a significantly higher $\Delta^{14}C$ level than deposit-feeding sea cucumbers (*Bathyplotes* sp., *Scotoplanes* sp.) on the OT line; *Limopsis belcheri* (suspension feeder) had a significantly lower $\Delta^{14}C$ than deposit-feeding sea cucumbers (*Bathyplotes* sp. and *Parastichopus* sp.) and *Neptunea* spp. (predator) on the ON line. These results indicate differences in the relative contribution of food provisioning from the Oyashio system among taxonomic groups and latitude.

In chapter 5, I investigated the source and age of the organic carbon that supports benthic invertebrate biomass in Otsuchi Bay using $\Delta^{14}C$ as an indicator of age and $\delta^{13}C$ as an indicator of a marine or terrestrial source. I determined the $\Delta^{14}C$ and $\delta^{13}C$ values for benthic invertebrates belonging to 14 taxa (including Maldanidae, other polychaetes, Synaptidae, and Nemertea), and two forms of organic matter (sedimentary organic matter and suspended particulate organic matter) that are potential food sources for benthic invertebrates in the surrounding environment. $\Delta^{14}C$-DIC in the bay water was also analyzed to estimate the possible range of $\Delta^{14}C$ signatures of aquatic primary producers, including phytoplankton and benthic algae.

The $\Delta^{14}C$ values of invertebrates varied in the range of –9.8 to 42‰, and were generally similar to those of DIC (3.2 to 35‰). The $\delta^{13}C$ values of most invertebrate taxa were in the range of –20 to –16‰, corresponding to the typical range of $\delta^{13}C$ values for marine phytoplankton and benthic algae. The $\Delta^{14}C$ values of sedimentary organic matter and suspended particulate organic matter varied much more widely among locations and seasons than among DIC and benthic invertebrates, with ranges of –321 to 30‰ (3046 years before present to modern) and –150 to 4.0‰ (1240 years before present to modern), respectively. The relationships among $\Delta^{14}C$, $\delta^{13}C$, and C/N ratio suggest that sedimentary organic matter is a mixture of modern carbon derived from terrestrial vascular plants and old carbon, presumably derived from sedimentary rocks (kerogen); in contrast, suspended particulate organic matter is a mixture of modern carbon derived from marine phytoplankton and resuspended sediments. Thus, I concluded that benthic invertebrates in this bay assimilate only modern carbon originating from contemporaneous autotrophs, despite the widespread occurrence of old carbon in the suspended particulate organic matter and sedimentary organic matter of Otsuchi Bay.

In chapter 6, I synthesized my results and discussed future research perspectives.