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Trophic structure in a pilot system for the integrated multi-trophic aquaculture off the east coast of Korean peninsula as determined by stable isotopes

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ABSTRACT

To assess the potential for nutritional exploitation of caged-fish-derived waste through the use of extractive co-cultured species in a pilot system for an integrated multi-trophic aquaculture (IMTA), we compared their C and N stable isotope ratios with those of uncultured macroinvertebrates in and around the system. Black rockfish were co-cultured with sea cucumber, oyster, and two macroalgae as extractive species. Isotope signatures of the co-cultured sea cucumber at the IMTA site differed from those at the control site, indicating their assimilation of aquaculture wastes. In contrast, $\delta^{13}C$ and $\delta^{15}N$ of individual taxa of the cultured oyster and uncultured invertebrates were consistent between sites, suggesting a minor contribution of the aquaculture waste to benthic and pelagic food chains in and around the IMTA system. These results provide evidence of the suitability of using sea cucumber as an extractive species to reduce the impact of a monoculture system on the ambient environment.

1. Introduction

The aquaculture industry has increased rapidly worldwide over several decades, with an average annual growth rate of 6.9% (FAO, 2009). However, intensive fish farming leads to a diverse range of negative effects on the surrounding environment. Among the most critical problems are the large amounts of organic waste and inorganic nutrients released from uneaten feeds and from feces and excretions of cultured fish, which can cause eutrophication, harmful algal blooms, reduction in levels of dissolved oxygen, and even changes in benthic communities (Troell et al., 2003; Holmer et al., 2008; Yokoyama et al., 2009; Silva et al., 2012). It is clear that such environmental pollution has a negative impact on aquaculture management, which can lead to reduced levels of production as a result of disease or death of fish (Pillay, 2004; Cao et al., 2007).

There has been increasing interest in alternative ecological approaches for improved management of coastal aquacultures. Integrated multi-trophic aquaculture (IMTA) has received much attention as a bioremediation method that can be used to mitigate environmental pollution and maintain the sustainability of aquacultures (Troell et al., 2003; Neori et al., 2004; Silva et al., 2012). IMTA is a form of ecological engineering that combines the biological processes of cultured fish and extractive co-cultured species to remove waste loadings associated with intensive aquaculture systems (Troell et al., 2009). Co-culturing practices involving macroalgae (Chopin et al., 2001; Neori et al., 2004; Yu et al., 2014) and suspension or deposit feeders (Redmond et al., 2010; Lander et al., 2013; Yokoyama, 2013) have been used to perform the role of biofilters to reduce the amount of aquaculture-derived inorganic nutrients and particulate organic waste. In this context, a key point in evaluating the success of IMTA is the observation of effective bioremediation of the extractive co-cultured species. Accordingly, it is necessary to assess whether the extractive species co-cultured with the target fish assimilate the aquaculture-derived waste in the IMTA system. Knowledge about the trophic transfer of inorganic/organic wastes from the cage fish farms to co-cultured species in the IMTA systems has advanced in recent years (Vizzini and Mazzola, 2004; Jan et al., 2014). However, further research is needed to improve IMTA systems because of diversification of target fish and co-cultured species, fish feed, and hydrological conditions.

Analysis of stable carbon and nitrogen isotopes has been widely used to assess nutritional sources for consumer species,

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to study trophic interactions within communities, and to analyze trace organic matter derived from aquaculture systems (Fry and Sherr, 1984; Kang et al., 2003; Redmond et al., 2010; Wai et al., 2011). The use of stable isotopes is based on the assumption that isotope signatures of consumers reflect those of assimilated dietary sources because of predictable enrichments of heavy isotopes through metabolism (Boeckle et al., 2011; Layman et al., 2012). The carbon isotope ratios of consumer tissues are usually close to those of their diets, within about 1‰, making an elucidation of the origin of the organic matter possible (DeNiro and Epstein, 1978; Fry and Sherr, 1984). In contrast, nitrogen isotope ratios are enriched by 2–4‰ per trophic level and thus are typically used to estimate the trophic position of a consumer (Post, 2002; McCutchan et al., 2003). Therefore, stable isotope measurements have been successfully applied to elucidate the trophic relationship of fish in IMTA systems (Gao et al., 2006; Redmond et al., 2010; Jan et al., 2014) as well as in natural ecosystems (Jennings et al., 2002; Vizzini and Mazzola, 2009).

Since aquaculture-derived waste tends to differ in isotope signatures (commonly ^{15}N enriched and ^{13}C depleted) from those of natural origin, measurements of isotope signatures for an aquaculture system are expected to provide information on the flux of aquaculture-derived waste that is incorporated into the adjacent food web (Ye et al., 1991; Vizzini and Mazzola, 2004; Yokoyama et al., 2006). If aquaculture-derived waste in the IMTA system enters the adjacent food web through assimilation by primary producers or consumers, they should have isotopic signatures that differ from those of the adjacent natural ecosystem. In the present study, this hypothesis is tested by comparing stable isotope ratios of several organisms in the IMTA system with those in their natural counterparts. To test our hypothesis, we analyzed stable isotopic ratios of organic matter sources, including primary producers and co-cultured macroalgae, and caged-fish-derived organic waste (fish feed and feces), and animals (i.e. fed fish and suspension or deposit feeders) in an IMTA system that was installed off the east coast of Korea. The present study aimed to identify the trophic pathways of organic matter in the system and to assess the potential for nutritional exploitation of caged-fish-derived waste through the use of extractive co-cultured organisms. We anticipated that the investigation would improve our understanding of whether the IMTA system design has a bioremediation potential to reduce aquaculture-derived waste in coastal ecosystems.

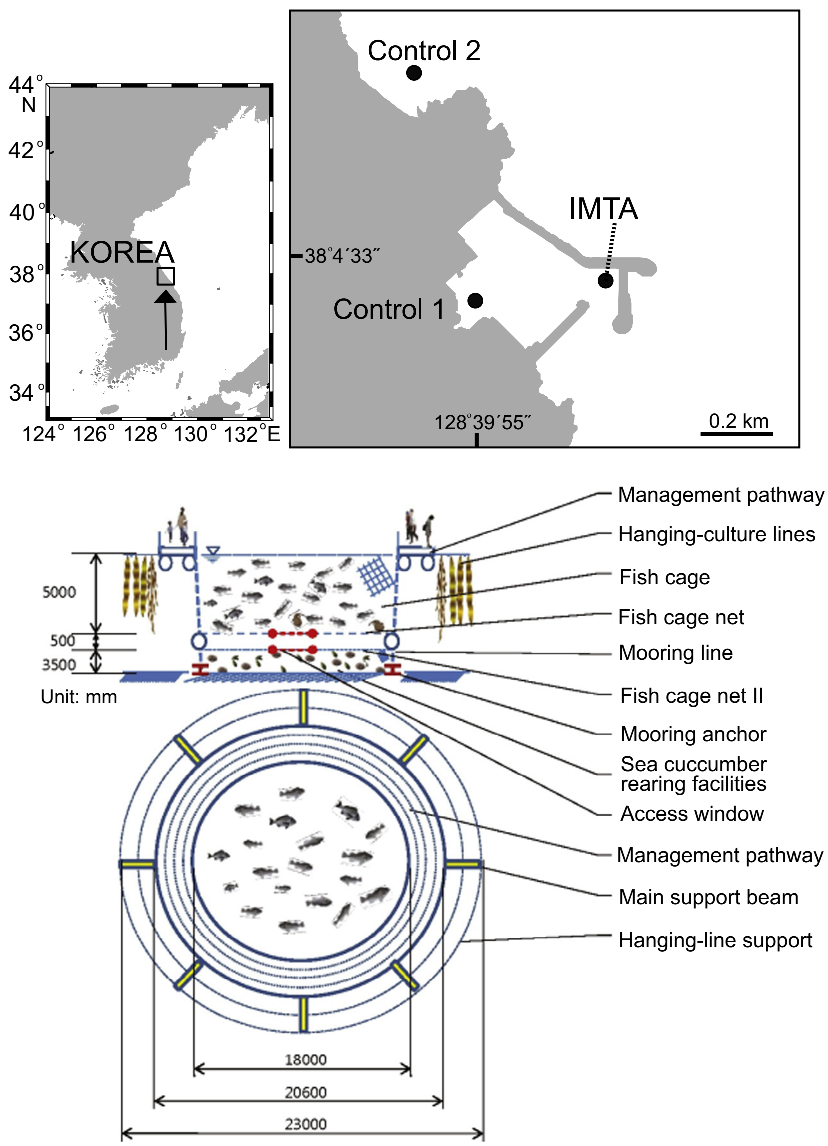

Fig. 1. Map of the study area on the east coast of Korea, showing the IMTA system and two control sites (filled circles).

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