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Aquaculture 254 (2006) 411 – 425
Aquaculture
www.elsevier.com/locate/aqua-online

Quantifying aquaculture-derived organic matter in the sediment in and around a coastal fish farm using stable carbon and nitrogen isotope ratios

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Received 28 July 2005; received in revised form 2 October 2005; accepted 7 October 2005

Abstract

The stable carbon and nitrogen isotope ratios of the sedimentary organic matter (SOM) collected from 41 stations in and around a coastal fish farm in Japan were measured to quantify aquaculture-derived organic matter in the sediment. SOM in the fish-farm area (within 30 m from the edge of cages) is characterized by its reduced $\delta^{13}C$ (mean $\Delta\delta^{13}C=-0.4‰$) and enriched $\delta^{15}N$ (mean $\Delta\delta^{15}N=+0.9‰$) values, which reflect the deposition of C_3-plant-derived and fish-derived elements, respectively. Compositions of waste feed (WF) and fecal matter (FM) in SOM at each station was determined based on the isotopic compositions of feed ($\delta^{13}C=-20.2‰$, $\delta^{15}N=9.7‰$), fish feces ($\delta^{13}C=-24.3‰$, $\delta^{15}N=6.3‰$) and marine organic matter in the sediment ($\delta^{13}C=-19.9‰$, $\delta^{15}N=5.5‰$). The sediment in the fish-farm area was characterized by high WF and FM ratios in SOM (28.8% and 11.9%). As the distance from the fish cages increased, aquaculture-derived organic matter decreased exponentially. The spatial extent of waste dispersal extended to an area up to 300 m, whereas dissolved oxygen of the bottom water and acid volatile sulfides in the sediment were affected even at stations 600 m away from the fish farm. There was a significant negative relationship between the aquaculture-derived nitrogen content in the sediment and the mean current velocity, suggesting that areas (water depth = ca. 18 m) where the near-bed current velocity is >8 cm/s will not receive excessive accumulation of organic wastes.

Keywords: Fish farm; Stable isotopes; Waste feed; Fecal matter; Current velocity; Sediment

1. Introduction

Intensive fish farming in coastal waters generates large amounts of particulate organic wastes in the form of waste feed (unconsumed feed) and fecal matter. Such particulate organic wastes settle onto the seabed and produce enriched sediments, which result in deoxygenation of the bottom water, the production of reduced compounds such as ammonium and sulfides and changes in the structure of benthic communities (reviewed by Gowen et al., 1991; Wu, 1995; Findlay and Watling, 1997; Pearson and Black, 2001). Such environmental deterioration often produces negative consequences for farm management.

The degree and extent of the impacts from fish farming have been investigated, and it has been revealed that the impacts on the benthic environments are localized; that is, the effects do not usually extend beyond 25 to 250 m distance (reviewed by Brown et al.,

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doi:10.1016/j.aquaculture.2005.10.024

1987; Gowen et al., 1991). In most of these previous investigations, dispersion and deposition of organic wastes have been quantified by the analysis of bulk organic matter in the sediment in terms of carbon and nitrogen elements and gross indicator such as ignition loss and chemical oxygen demand (COD). However, bulk organic matter alone may not provide an adequate estimate of the extent to which organic matter from aquaculture disperses, because the bulk organic matter is composed of various sources. A knowledge of the net accumulation of aquaculture-derived organic matter (AOM) in the sediment is necessary for the objective assessment of the potential environmental impacts arising from fish farming. Metals such as Cu and Zn (Chou et al., 2002) and lipids (Johnsen et al., 1993; Henderson et al., 1997; McGhie et al., 2000) in the sediment have also been used as tracers of aquaculture wastes. However, such attempts provided little insight into the quantitative aspects of aquaculture-derived organic matter. It is necessary to find a reliable and convenient tracer to quantify aquaculture-derived organic matter in the sediment.

Stable isotope analysis has been used successfully not only in determining sources of nutrition for consumers and trophic relationships among organisms but also in assessing the mixing ratio between different sources of organic matter such as terrestrial plants and marine phytoplankton (e.g., Wada et al., 1987). Recently, the stable isotope technique has been used to trace the fluxes of aquaculture wastes entering the food webs of a shrimp pond (Yokoyama et al., 2002), a lake (Grey et al., 2004), a tidal creek (Costanzo et al., 2004) and nearshore waters (Vizzini and Mazzola, 2004), and transformations of particulate matter in a recirculating sea bass rearing system (Franco-Nava et al., 2004). Stable isotope analyses have also been used to determine the influence of waste deposition from mariculture fish farms to sediments (Ye et al., 1991; McGhie et al., 2000; Yamada et al., 2003). Ye et al. (1991) first tried to quantify the contribution of aquaculture-derived organic carbon (AOC) to total organic carbon in the sediment based on the $\delta^{13}C$ values for fish feed (−21.53‰), fish feces (−20.48‰), settling organic matter at a station under a cage (−19.25‰) and a reference station (−13.03‰), and sedimentary organic matter (SOM) under a cage (−21.76‰). They calculated the $\delta^{13}C$ value for AOC as −24.14‰ and estimated the dispersion and effects of fish-farm wastes on marine sediments. Their methods, however, may not be applicable to other localities, because the $\delta^{13}C$ value for the background organic matter was markedly enriched probably due to the contamination of organic matter from seagrass, and the substances in AOC, of which $\delta^{13}C$ was more depleted than values for the feed and feces, were not identified. The other isotopic studies provided scarce information about quantitative aspects of AOM.

In the present study, we tried to differentiate waste feed and fecal matter from bulk SOM using the dual isotope technique. The purpose of our research is to: (1) develop a method to quantify waste feed and fecal matter in the sediment using stable carbon and nitrogen isotope ratios, (2) determine the spatial extent of AOM around a fish farm, and (3) examine the relationship between deposition and accumulation of AOM into the sediment and environmental factors.

2. Materials and methods

2.1. Study area

Gokasho Bay has a ria style coastline with an area of 22.2 km^2 and a mean depth of 12.7 m (Fig. 1). Freshwater flows into the bay mainly from the Iseji River, which drains 39 km^2 of forested land covered by evergreen broad-leaved trees (C_3 plants) that are almost free of anthropogenic influence. The average flow rate of this river is 1.1 m^3/s (Iwasaki et al., 1997). Amplitude of tidal current in the middle layer at the mouth of Gokasho Bay is 20 cm/s, whereas the mean velocity reduces to 2 to 8 cm/s in the middle to inner part of the bay where fish cages are located (Abo, 2000).

In Gokasho Bay, fish farming has steadily developed since the introduction of yellowtail culture in 1962. Since 1976, the production of cultured fish including yellowtail *Seriola quinqueradiata* and red sea bream *Pagrus major* in the bay has been over 1300 mt. In 2002, 1490 t of fish were produced by supplying moist and dry feed pellets by a combination of manual and automatic feeding. Most fish cages are distributed in the Hazama-ura cove, where 1248 t of fish including 844 t of red sea bream and 280 t of yellowtail were produced from 17,000 m^2 of fish cages (Tokai Regional Agricultural Administration Office, 2004). The cages in this Hazama-ura fish farm are aligned in 24 rows in the northern part (the northern cage rows) and in 18 rows in southern part (the southern cage rows). Fish farming in three rows of cages in the southern area (arrows in Fig. 1) has been left fallow since January in 2000. Yokoyama (2002) described the seasonal trend in organic matter load in this fish farm: during a period from January to April, the volume