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Effects of sediments on larval settlement of abalone *Haliotis diversicolor*

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ABSTRACT

The effects of deposited sediments on the settlement of the abalone *Haliotis diversicolor* Reeve were examined through both field observations and a laboratory experiment. Occurrences of newly settled post-larvae (shell length <500 μm) and the amount of suspended and deposited sediments were monitored at two stations (Stns 1 and 2), which experienced different sediment deposition conditions, located at Nagai on the coast of Sagami Bay, Japan. Quantities of suspended sediments at the two stations varied considerably during the survey period, but no significant difference was detected between the stations. Mean volume densities of sediments deposited on cobbles were significantly higher at Stn 2 than at Stn 1. Densities of newly settled post-larvae from the 2001 to 2004 cohorts were significantly higher at Stn 1. A laboratory experiment was conducted to assess the effects of sediment quantity and quality on larval settlement. Two substances with different physical properties, kaolin and clamshell powder, were used as sediments. Larvae were subjected to four different sediment treatments with crustose coralline algae (CCA) substrates; thin and thick treatments for both kaolin and clamshell powder. Negative (without CCA) and positive (with CCA) controls without sediments were also established. The rate of metamorphosis decreased as sediment thickness increased in both the kaolin and clamshell powder treatments. Larvae in the kaolin treatments appeared to be trapped by the kaolin, and most could not metamorphose successfully. There were no trapped larvae in the clamshell powder treatments. The results indicate that the quantity and physical properties of sediments deposited on substrata affect the settlement and behaviour of larval abalone. Experimental results suggest that the lower densities of newly settled post-larvae observed at Stn 2 may have been a result of larger quantities of deposited sediments, which reduced the availability of suitable substrate for larval settlement.

1. Introduction

The recruitment process plays a critical role in the population dynamics and community structures of benthic marine organisms (Caley et al., 1996). For benthic invertebrates with complex life histories, and which develop from an initial planktonic larval stage to a final benthic adult stage, recruitment success is influenced by both settlement success and early post-settlement mortality (Hunt and Scheibling, 1997).

One potential factor affecting larval settlement is terrestrially derived runoff, which may have complex effects on marine organisms because of its chemical and physical properties (Gillanders and Kingsford, 2002). The global increase in water turbidity and sediment load in coastal areas as a consequence of anthropogenic activities including agriculture, construction, deforestation, and industrial and domestic discharges has promoted interest in the impacts of sedimentation on rocky shore organisms. Sediments are harmful to a variety of subtidal species (reviewed by Airoldi, 2003), even preventing propagules from settling (Arakawa and Matsuike, 1992; Airoldi, 2003). For some coral species, sediments decrease fertilisation, settlement and survival (Hodgson, 1990; Babcock and Davies, 1991; Gilmour, 1999). The importance of sedimentation for the structuring of subtidal algal communities on rocky reefs has been reported (Dayton, 1985; Airoldi and Cinelli, 1997; Airoldi, 2003). However, studies examining the effects of sediments on settlement and survival during early life stages are limited for invertebrate species other than corals (Phillips and Shima, 2006; Walker, 2007).

Abalone species (Haliotidae, Mollusca) are one of the dominant grazers on rocky shore coasts, occurring widely from tropical to temperate areas, and are economically important worldwide as target species in coastal fisheries. Fluctuations in abalone stocks, which are strongly affected by the strength of annual recruitment, may impact reef biodiversity, community structure and dynamics, and fishery management. In recent years, abalone resources in Japan have rapidly declined mainly due to the low natural recruitment (Kawamura et al., 2002a). As increases of deposited sediments on rocky reefs have been noted by abalone fishermen, sedimentation is listed as one of the possible factors

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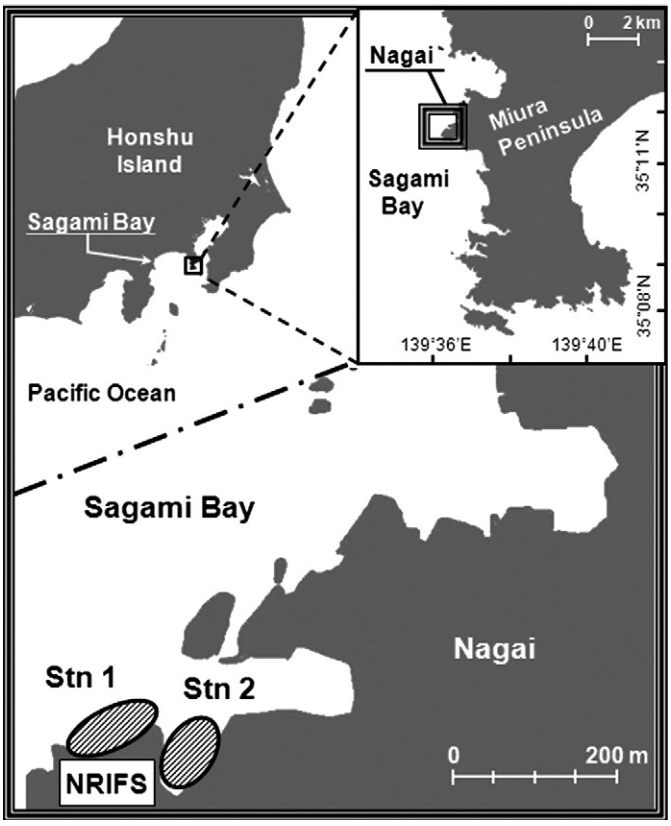

Fig. 1. Locations of sampling stations and the National Research Institute of Fisheries Science (NRIFS) at Nagai in Sagami Bay, Japan.

affecting abalone recruitment (Kawamura et al., 2002b). For many abalone species, crustose coralline algae (CCA) strongly induce rapid larval attachment and metamorphosis (reviewed by Roberts, 2001). The metamorphosed individuals grow on CCA surfaces for at least several months following settlement (e.g., Kawamura et al., 1998; Onitsuka et al., in press). Sediments that accumulate on CCA surfaces may prevent larval abalone from metamorphosing, and consequently reduce their recruitment. A previous study experimentally demonstrated the effects of suspended sediments on the survival of larval sea urchins and abalone during swimming periods (Phillips and Shima, 2006). The effects of drilling mud on the fertilisation, early development, survival and settlement of red abalone (*Haliotis rufescens*) were examined in laboratory experiments (Raimondi et al., 1997). However, the effect of deposited sediment on larval abalone settlement in natural habitats has never been studied.

Here we examined the effects of deposited sediments on the settlement of the abalone *Haliotis diversicolor* through both field observations in a natural habitat and a laboratory experiment. *H. diversicolor* is a relatively small abalone species with a maximum shell length (SL) of about 10 cm. It inhabits shallow subtidal areas in subtropical and temperate zones of the western North Pacific (Geiger, 1999). Densities of newly settled post-larvae (<500 μm SL) were compared between two stations that experience different conditions in terms of sediment deposition. The laboratory experiment examined the effects of sediment quantity and quality on the settlement of larval *H. diversicolor*.

2. Materials and methods

2.1. Field study site

The field study was conducted at two stations (Stns 1 and 2) on the rocky, subtidal shoreline area at Nagai on the coast of Sagami Bay in central Japan (35°11'N, 139°36'E; Fig. 1). Both stations were 0.5–3.0 m deep, consisted of rocky reefs with many cobbles covered with CCA but few large macro-algae. Because current velocity was higher at Stn 1, less sediment was found on the reefs and stones compared to Stn 2 (Onitsuka et al., in press).

2.2. Sampling of newly settled post-larvae

Newly settled post-larvae of *H. diversicolor* were widely observed on cobbles covered with CCA in shallow rocky reefs around Nagai in 2001 and 2002 (Onitsuka unpubl. data). For many abalone species, previous studies have demonstrated that CCA induces strong and rapid larval settlement (attachment and metamorphosis; e.g., Roberts, 2001). To collect post-larval *H. diversicolor*, cobbles covered with CCA were collected from August 2001 to January 2002, July to November 2002, July to December 2003, and June to October 2004. Three cobbles (15–40 cm in the longest dimension) were haphazardly collected approximately weekly from each station during the expected spawning season, from June to November (Onitsuka et al., 2007a). After the spawning season, three cobbles at each station were collected at least once a month. Each cobble was put into a ziplock bag while underwater at each station, immediately returned to the laboratory (National Research Institute of Fisheries Science at Nagai; Fig. 1), and immersed in a 10% ethanol-seawater solution for approximately 10 min to anaesthetise the abalone. Animals were then detached from the cobble in a 10% ethanol-seawater solution using a brush and collected in a plankton net (100-μm mesh). The contents of each collection were stored in a 5% formalin-seawater solution. Newly settled post-larval *H. diversicolor* in each collection were identified based on larval SL (Onitsuka et al., 2007b) and counted under a dissecting microscope. The length, width and height of each cobble were measured, and the total surface area of a cobble was calculated as the surface area of a rectangular parallelepiped (Sasaki and Shepherd, 2001). Densities of abalone on the cobbles were expressed as numbers per m^2 of cobble surface area.

2.3. Sediment sampling

From late June to early October 2004, suspended sediments (including sand and silt) flowing into each station were collected by a sediment collector (Fig. 2). The collector consisted of 12 plastic tubes (diameter = 12 mm; height = 179 mm) set and fixed to a metal tube holder, which was fixed to a metal lattice with heavy concrete blocks on the seafloor (Fig. 2). A sediment collector was placed at each station. All plastic tubes were exchanged at approximately weekly intervals. Each tube was sealed underwater and immediately brought to the laboratory. For measurement of wet volumes, the sediments collected in each tube were transferred and settled to the bottom of a graduated cylinder (10 mL) during a few days. Volume of the

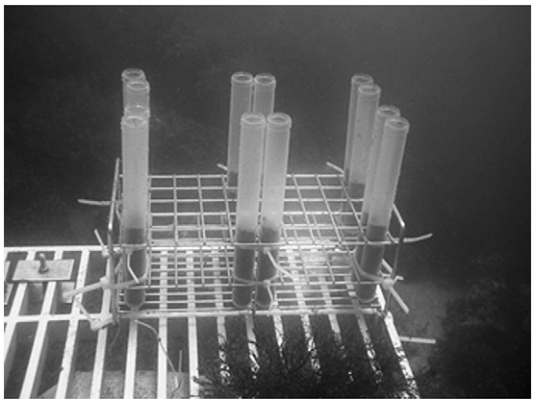

Fig. 2. A sediment collector placed on the sea bottom.