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Journal of Experimental Marine Biology and Ecology 346 (2007) 66–75

Journal of EXPERIMENTAL MARINE BIOLOGY AND ECOLOGY

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Seastar response to organic enrichment in an oligotrophic polar habitat

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Received 5 December 2006; received in revised form 23 February 2007; accepted 2 March 2007

Abstract

The high Antarctic marine system, including McMurdo Sound, is food limited. Benthic scavengers, especially the seastar *Odontaster validus*, respond rapidly to sources of organic material, however, fecal material from the McMurdo Station sewage outfall is not consumed. Laboratory and field experiments showed that *O. validus* responded quickly (within hours) to organically enriched sediments, but that the presence of the anaerobic bacteria *Beggiatoa* spp. modified seastar behavior. In the lab, anoxic sediments, even more strongly than the presence of *Beggiatoa*, caused seastar avoidance. In the field, *Beggiatoa* caused seastar avoidance even of organically enriched sediments. The large mass of organic material remaining from pre-sewage treatment years at the McMurdo outfall is currently completely covered by a thick *Beggiatoa* microbial mat. *O. validus* and other megafaunal scavengers are abundant nearby but do not feed on the sewage organics that are covered by the microbes. The outfall deposit is thus likely to exist for a long period of time, undergoing slow anaerobic microbial degradation rather than rapid processing by megafaunal scavengers. This is an example of competition between constituents of the microbial and megafaunal communities and espouses the need for an ecosystem approach to ecology rather than community analysis within a limited size class (i.e. mega-, macro-, meio-, or micro-fauna).

Keywords: Anoxic; Antarctica; *Beggiatoa*; Microbial; *Odontaster validus*; Sewage

1. Introduction

Seasonal primary production in the high Antarctic is limited to a few months of the year, and consequently the Antarctic benthos is food-poor except during the seasonal bloom (Dayton et al., 1986; Asper and Smith, 1999; Becquevort and Smith, 2001). During the winter months, when there is no sunlight, primary productivity is limited to microbial chemosynthesis. Even during the spring and fall months light levels under the thick layer of sea ice are so low that little photosynthetic productivity occurs (Knox, 1970). As the sea ice thins and breaks out in late summer, light penetrates and causes an intense bloom of ice algae, phytoplankton, and benthic microphytes. In conjunction with plankton advected in from elsewhere, this material settles to the seafloor and provides food for rich benthic communities. The bloom usually lasts for approximately 2 months at 77°51′S (McMurdo Station).

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0022-0981/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.jembe.2007.03.004

Benthic motile scavengers, especially seastars, have been observed consuming seal feces as a possible way to cope with this lack of food during much of the year. Near McMurdo Station, Weddell seals (*Leptonychotes weddellii*) are the most frequently observed mammals in nearshore waters (Stirling, 1969; Kooyman, 1981; Testa and Sinniff, 1987) and are abundant from October through March. Animals congregate at natural thin spots, such as tidal cracks, where there is easy access to air. The concentration of animals at such places results in localized concentrations of fecal material on the seafloor. Fecal material is rapidly scavenged by the seastar *Odontaster validus* and other megafaunal species, disappearing on a time scale of hours to days, though where *O. validus* numbers are low (e.g. the west side of McMurdo Sound) seal feces persist for weeks (pers. obs.). *O. validus* is a broadly generalist scavenger and predator; its diet includes sponges, bivalves, and detritus (including algal material) in roughly equal proportions (Dayton et al., 1974).

A similar organic food source that is not utilized by benthic scavengers, though they are locally abundant, is the sewage outfall at McMurdo Station. Prior to 2003, macerated human waste from the station population of 1200 (summer) to 200 (winter) was discharged directly into the marine environment. The outfall effluent contained only human waste and did not have the high chemical loads of municipal outfalls in more populated areas, though the volume was relatively large because the effluent was untreated (Perkins, 1998). This rich resource of organic material was unexploited by *O. validus*, but instead was covered with a thick mat of *Beggiatoa* spp. bacteria. *Beggiatoa* is a sulfide oxidizing bacteria that lives at the anoxic/oxic interface and often forms dense mats over organic or other sulfide-rich sediments (Brune et al., 2000).

Potential differences between the McMurdo sewage pile and seal fecal piles include size, content, and microbial constituents. Seal fecal piles are cm across; the sewage pile is meters across. Though Weddell seals are carnivorous and humans are omnivorous, the extremely varied dietary habits of *O. validus* (Dayton et al., 1974; Kidawa, 2005) indicate that waste materials from both could be utilized as food resources by the seastars. There is a dense mat of *Beggiatoa* that covers the sewage pile but a similar mat has not been observed on seal feces near McMurdo, though *Beggiatoa* mats develop on seal feces where *O. validus* are not abundant. Freshly deposited sewage does not have a developed *Beggiatoa* layer either, but is isolated from seastars and other benthic scavengers by several meters of *Beggiatoa*-covered material.

In general, rich and discrete organic resources are rapidly utilized by scavengers, but in situations where the organic deposit is too large to be completely consumed immediately (e.g. fish kills, whale falls, sewer outfalls), a microbial community develops that may discourage or compete with megafaunal scavengers (Burkepile et al., 2006). In situ observations suggest that *O. validus* actively avoid contact with *Beggiatoa* (pers. obs., pers. comm. Robbins), though other echinoderms have been observed in contact with *Beggiatoa* (Levin, 2005, pers. comm. Dayton, Thrush). The possible sequestration of a food resource by a microbial mat and potential competition between a microbial and a megafaunal organism (sensu Janzen, 1977; Hochberg and Lawton, 1990; Burkepile et al., 2006) led to this study on *O. validus* response to organic material.

The underlying conceptual hypothesis is that the sewage pile near McMurdo Station is too large for rapid consumption by megafaunal scavengers, allowing colonization by prokaryotes that then maintain dominance. Undisturbed by the movements of scavengers, the large pile becomes anoxic as microbes break down the organic material. Eventually, *Beggiatoa* forms a continuous mat over the outfall material that maintains the anoxic character and isolates the organics from scavengers, such as *O. validus*, that require an oxic habitat. We tested the effects of organic enrichment and *Beggiatoa* bacteria on *O. validus* substrate choice in the laboratory and the field, following these subhypotheses;

H_{01}. Organic enrichment has no impact on *O. validus* movement patterns.

H_{02}. *Beggiatoa* mats have no impact on *O. validus* movement patterns.

Site-specific variables that may also influence seastar response include sediment grainsize, and prior exposure and potential physiological acclimatization to *Beggiatoa* or organic enrichment. To test for these, collection sites for seastars and sediment were included as variables in the lab experiments. In addition, previous studies have shown that some seastar species move preferentially upcurrent with a crosscurrent component (Sloan and Campbell, 1982; Drolet and Himmelman, 2004; Pisut, 2004), and furthermore the impact of slope/topography on *O. validus* movement is unknown. Either of these factors could impact field experiments. Thus, we tested the following additional subhypotheses.

H_{03}. Substrate grainsize has no effect on *O. validus* substrate choice.