Abundance and Biomass of Heterotrophic Flagellates, and Factors Controlling Their Abundance and Distribution in Sediments of Botany Bay

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Abstract
The abundance and biomass of heterotrophic flagellates were estimated monthly in sediments of Botany Bay during March 1999–February 2000. The annual abundance and biomass were in the ranges of 0.46–4.70 × 10^5 cells/cm^3 and of 0.30–8.61 µgC/cm^3, respectively. The majority of heterotrophic flagellates (93–100%) were less than 10 µm in length and few flagellates were larger than 10 µm. Of the total microbial carbon biomass, heterotrophic flagellates made up about 5% (but at times up to 35%). The contribution of heterotrophic flagellates varied from month to month, and among the sites. The abundance of heterotrophic flagellates was negatively correlated with sediment grain size and positively correlated with the abundance of bacteria, algae (autotrophic flagellates and diatoms), and their probable grazers. A best subsets regression analysis showed that bacterial and algal abundance are the most important factors controlling the abundance of heterotrophic flagellates. When the previously reported grazing rates on bacteria were applied, heterotrophic flagellates would consume a maximum of 64% of bacterial standing stock daily in Botany Bay, suggesting that heterotrophic flagellates are important as bacterivores. However, the importance of heterotrophic flagellate grazing probably varies significantly among the sites and from month to month.

Introduction
Heterotrophic protists are numerically important components of the microzooplankton assemblages in aquatic environments [17, 23, 41, 65, 75]. They function as predators on bacteria and small phytoplankton, and as prey for larger zooplankton [36, 70, 71, 77]. By grazing and excretion they release (remineralize) and promote recycling of elements essential for the growth of phytoplankton and other microbes [11, 29, 46, 51, 69, 72, 73]. For that reason, heterotrophic protists are recognized as an important component in microbial food webs. They also function in part as energy transporters. In addition, excretion by grazers may be dominated by protists because the weight-specific excretion rate is inversely related to size, suggesting that heterotrophic flagellates may be the major remineralizers within the protozoan groups because excretion rates are relatively higher in flagellates than other larger protists [20].
Heterotrophic flagellates are argued to be the major grazers of bacteria [e.g., 40, 41, 70, 71]. They typically occur at concentrations of about \(10^3-10^5\) cells/mL in planktonic ecosystems [9, 10, 52, 53, 56] and are potentially consumed by ciliates, cladocera, copepods, and rotifers [7, 37, 67, 77, 81]. Their abundance and growth may be controlled by food resources (bacteria, algae, dissolved organic carbon) and predation [35]. Some researchers have found a positive correlation between the abundance of bacteria and heterotrophic flagellates [10, 18, 35, 56], but this relationship has been doubted because the correlation may be tenuous [e.g., 30, 31, 43]. Lack of coupling between the abundance of bacteria and heterotrophic flagellates can be explained because of the presence of many other potential bacterivores (mixotrophic flagellates, ciliates, rotifers, and cladocera) and because of the presence of potential grazers of heterotrophic flagellates [54 and references within].

The significance of heterotrophic flagellates in planktonic microbial food webs of aquatic environments has received much attention. However, their benthic counterparts have been less studied because of difficulties in extracting and enumerating microbes from sediments [4]. We may assume that heterotrophic flagellates (or protists) play an important role in benthic microbial food webs [2, 4, 22] because all components of the microbial food web are more abundant in sediments than in water columns [e.g., 23, 50, 64]. There have been a few studies that indicate that heterotrophic flagellates are important numerically and ecologically in sediments [e.g., 22, 23, 41, 75], but they have not been studied as intensively as in the water column. Despite the methodological problems, there has been a recent increase in interest in the structure and dynamics of benthic microbial food webs [1, 4, 19, 22, 23, 38, 41, 64, 75].

There have been few prior studies on the composition, abundance, biomass, or trophic interactions of various components of the benthic microbial food web in Botany Bay. There have been two taxonomic studies of heterotrophic flagellates of Botany Bay, carried out by Bernard et al. [8] at Quibray Bay and Lee and Patterson [57] at Port Botany. There was also a study on the colonization of intertidal microscopic organisms on fiberglass panels (or a biofilm) at Quibray Bay [3]. Underwood [82] reported the abundance (\(\sim 30 \times 10^5\) cells/cm²) of intertidal microalgae on a rocky shore in Botany Bay. Additionally, there were some ecological studies on the temporal and spatial variation of macrobenthos such as amphipods, bivalves, caprellids, gastropods, and polychaetes in the bay [e.g., 61, 62].

This study was carried out to measure the abundance and biomass of heterotrophic flagellates and to examine which factors influence their abundance and distribution. Abiotic and biotic factors were measured monthly during March 1999–February 2000: temperature, salinity, pH, grain size, chlorophyll \(a\), and the abundances and biomass of algae, bacteria, ciliates, flagellates, foraminifers, and nematodes.

### Materials and Methods

#### Study Sites

Botany Bay (Fig. 1) is located within the Sydney metropolitan area on the eastern coast of New South Wales, Australia and is fed by two rivers, the Cooks River and the Georges River. The maximal tidal range in the bay is about 2 m. The intertidal shoreline of Botany Bay consists of three main habitats: rocky areas, soft sediments (sandy beaches and mudflats) without macroalgae or other large plants, and vegetated soft sediments (mangrove swamps and seagrass beds) — each occupying about 30% of the shore [74].

Four sampling sites in Botany Bay (Fig. 1) were chosen for this study and were all intertidal sandy sediments through with slightly different compositions of grain size: Port Botany, Kogarah Bay, Quibray Bay and Woolooware Bay. Two other sites (Avoca Beach, about 95 km north of Sydney — 33° 28’ 30″S; 151° 26’ 40″ E; and Watsons Bay, located on the southern shore of Sydney Harbour — 33° 50’ 80″S; 151° 16’ 90″ E) were included to