THE BACTERIAL RESPONSE TO TRAWLING AND WIND-INDUCED SEDIMENT RESUSPENSION IN THE PAMLICO RIVER ESTUARY, NORTH CAROLINA

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North Carolina's large, microtidal estuarine system has been exposed to a variety of anthropogenic impacts, including alteration of watershed drainage, nutrient loading, and bottom trawling. Research on the ecological impacts of trawling has focused on direct effects such as bycatch and benthic mortality. Accordingly, little is known of potential secondary impacts of trawling in this estuarine system. One potential effect, sediment resuspension by bottom trawling, may result in a direct alteration of bacterial abundance, activities, and assemblages. Such impacts could alter water column processes, benthic processes, benthic-pelagic coupling, and food web structure.

Bacteria are ubiquitous in aquatic ecosystems, and serve vital roles as decomposers, nutrient recyclers, and food sources for higher organisms. In addition, bacteria have rapid generation times, and therefore may be the first members of the food web to demonstrate a detectable response to trawling disturbance.

The study at hand attempts to characterize the response of water column bacterial communities to sediment resuspension by wind and trawling disturbance. Field and laboratory experiments were conducted from 2001 to 2004. Field experiments were performed in South Creek, North Carolina, a sub-tributary of the Pamlico River Estuary. Trawling was simulated in laboratory microcosms containing muddy-sand or silty-clay sediment types. Total suspended solids (TSS) served as a measure of sediment disturbance.

Bacterial abundances in the water column during trawling experiments ranged from 1.5 x 10^6 to 7.9 x 10^7 cells / ml. During trawling experiments, temporal variability in abundance was high and trawling effects were rarely significant. The portion of metabolically active cells demonstrated inconsistent effects in response to trawling disturbance. Occasionally the portion of cells metabolically active in the trawl sites would be significantly smaller than the corresponding non-trawled control site. Regression analysis of wind speed and bacterial abundance indicated a significant relationship during four of seven trawling experiments. When analyzed by directional origin, Northeast, South, and Southwest winds showed the strongest relationship. No relationships between wind speed and metabolic activity were detected.

Disturbance in laboratory microcosms resulted in immediate increases in the TSS concentration. Bacterial abundances were less variable (9.2 x 10^5 to 6.5 x 10^6) during microcosm experiments, and increased sharply following a simulated trawling disturbance. However, the percentage of active cells decreased following disturbance, and bacterial productivity (g C ml^{-1} hr^{-1}) first declined, then rebounded to temporarily exceed pre-disturbance levels. These trends were apparent for both sediment types, yet most pronounced for the silty-clay sediment. Bacterial taxonomic richness and sulfate-reducer taxonomic richness analysis of total bacterial community DNA revealed no apparent changes in bacterial community structure following disturbance events in field and laboratory experiments. These data suggest that the water column of South Creek is well-mixed and sediment resuspension may have an inhibitory effect on water column bacteria. Resuspension of the upper few centimeters of the benthos did not greatly alter taxonomic richness in the water column. Our data suggest bottom trawling in the Pamlico River Estuary has little impact on the resident water column bacterial communities. Basin-wide processes such as wind and rain events, which affect sediment resuspension, runoff and nutrient loading, and stratification / destratification of the water column; are more likely to affect the bacterial community.

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CHAPTER ONE: INTRODUCTION

Statement of the Problem

The effects of disturbance on biological communities are known to influence recruitment, abundance, diversity, richness, activities, and viability of organisms (Dayton 1971; Dayton and Hessler 1972; Sousa 1984; Menge and Sutherland 1987; Sousa 2000). In recent years increased attention has been given to human induced disturbance to aquatic ecosystems such as nutrient loading, pollution, over-fishing, and habitat alteration. Understanding these events, studying them in the context of natural disturbance, describing their effects on biological communities, and predicting future and cumulative impacts is imperative for maintaining ecosystem health and for the prevention and mitigation of such deleterious activities.

An example of human induced disturbance that has received considerable attention during the last ten years is the ecological impacts of commercial bottom trawling. Globally, bottom trawling disturbs more area of seafloor than any other fishing method (Watling and Norse 1998b). Bottom trawling is a fishing method whereby nets are submerged and dragged along the benthos by a motorized vessel. Wooden or metal doors (trawl doors) are attached to opposite sides of the net opening and utilize water resistance to force the net to remain open during the tow (Figure 1.1). Both the tickler chain that attaches to the bottom opening of the net, and the trawl doors, make contact

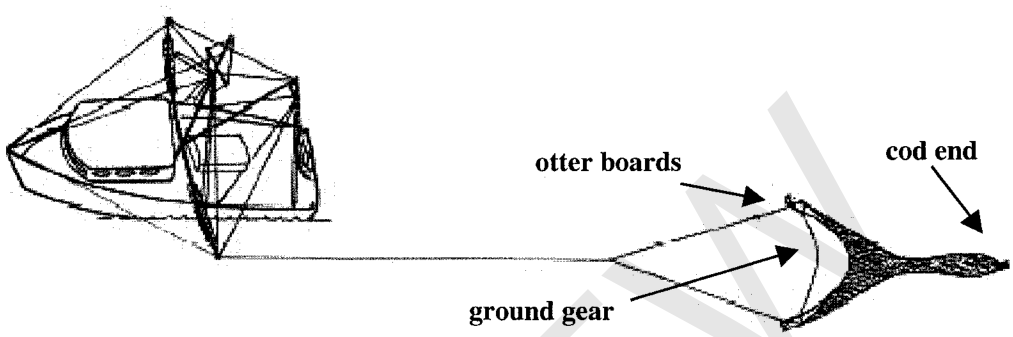

Figure 1.1. Diagram of bottom trawl gear. Bottom trawl gear consists of a cone shaped net attached to otter boards and a bridle. The otter doors create water resistance to force the net open during a tow. The ground gear consists of chains attached to the bottom of the net opening and keeps the net in contact with the benthos during a tow. The float line consists of buoyant material, is attached to the top of the net opening and helps maintain the opening. The ground gear and otter boards are in direct contact with the benthos during a tow, which results in sediment resuspension. Figure adapted from Dellapenna et al. (2006).

with the benthos which in turn can produce substantial disturbance to the seabed (Churchill 1989).

Bottom trawling can destroy critical fish habitats by altering the physical and biological character of the seabed (Churchill 1989; Kaiser 1996; Kaiser et al. 1996; Kaiser et al. 1998; Watling and Norse 1998a; Collie et al. 2000; Sanchez et al. 2000; Jennings et al. 2001a; Jennings et al. 2001b; Jennings et al. 2002; Schratzberger and Jennings 2002; Thrush and Dayton 2002; Brown et al. 2005). Bottom trawling along the rocky bottoms of the Northeast or coral reef areas of the subtropics and tropics has been shown to decrease species abundance, species diversity, and reduce the amount of benthic microhabitats (Dayton et al. 1995; Jennings and Kaiser 1998; Hall 1999; Jennings et al. 2001a; Jennings et al. 2001b; Koslow 2001). Several studies have noted significant reductions in the biomass, diversity and abundance of epifaunal (Smith et al. 2000; Koslow 2001; Schratzberger and Jennings 2002), macroinfaunal (Schratzberger et al. 2002), and benthic infaunal (Sparks-McConkey and Watling 2001) species within trawl sites. Trawling also reduces the abundance and diversity of target and non-target fish and invertebrate species by either direct fishing mortality or by altering food web dynamics (Dayton et al. 1995; Jennings and Kaiser 1998; Watling and Norse 1998b; Watling and Norse 1998a; Hall 1999; Collie 2000).

The effects of trawling disturbance are not always evident or consistent. Some researchers have observed minimal effects on macroinfaunal assemblages (Drabsch et al. 2001). A recent study completed in the Currituck-Pamlico-Albemarle estuarine system (CAPES) suggested trawling has no significant effect on the biomass of benthic microalgae and demersal zooplankton or the abundances of benthic macrofaunal animals (Cahoon et al. 2002). Further, some have suggested that areas receiving frequent trawling disturbance may favor the development of relatively smaller organisms that are able to survive the physical disturbance of a trawl event and then recolonize the disturbed area due to short generation times (Jennings et al. 2001a; Jennings et al. 2002; Schratzberger et al. 2002). Selection for specific size-classed organisms could nevertheless reduce biodiversity in the affected area (Schratzberger et al. 2002; Schratzberger and Jennings 2002), and could alter the transfer of energy through the foodweb. Such is the case where researchers observed trawling effects on size structure and production of benthic organisms, indicating an altered availability of food to higher trophic levels (Jennings and Kaiser 1998).

Most of the current literature on the effects of trawling has concentrated on direct fishing mortality, bycatch, and habitat destruction. In addition, current literature regarding the impacts of trawling has focused on hard bottom areas in which the deleterious nature of the disturbance is intuitive. Accordingly, the ecological consequences of trawling on soft bottoms have not received as much attention. It is well known that trawling can be a significant source of sediment resuspension (up to 500 mg L^{-1}) and can alter the natural pattern of sediment deposition and resuspension (Schubel et al. 1979; Churchill et al. 1988; Pilskaln et al. 1998). Comparatively little attention has been given to the effects of this source of sediment resuspension. Excavation of sediments from the benthos and injection into the water column can have multiple effects on the physical, chemical, and biological character of the seabed and overlying waters.

Suspended matter loads in the water column of up to several hundred milligrams per liter have been noted following bottom trawling in Hillsborough Bay, Florida, and sediments recently deposited following anthropogenic disturbance are more likely to return to the water column than naturally resuspended sediment (Schoellhamer 1995). The author does not speculate on the cause of the increased likelihood of future resuspension; however, the severity and frequency of anthropogenic resuspension may reduce sediment-stabilization by biotic forces (i.e. sediment biofilms). Schoellhamer does suggest the amount of sediment resuspended by anthropogenic sources could be more than ten times that resuspended by winter storms, the dominant natural source of sediment resuspension in Hillsborough Bay, Florida.

Trawling-induced sediment resuspension also impacts the benthos from which the sediments were excavated. Schoelhamer et al. (1996) measured trawling scars 4.5 cm in depth. Scars and furrows generated by trawl doors and rockhopper gear in the Barents Sea were visible by video and sidescan sonar (Humborstad et al. 2004), and penetration can vary from a depth of a few centimeters to nearly 30 cm (Churchill 1989; Dellapenna et al. 2006). Investigation of trawling along the Tuscany coast revealed that evidence of trawl scars disappear within one month of the trawling event (De Biasi 2004), while others found that trawl scars in the Spanish Mediterranean remained visible for over one year (Schwinghamer et al. 1998; Palanques et al. 2001). The depth of penetration and longevity of trawl scars depend on the type of gear utilized, substrate of the trawled benthos, and frequency of natural disturbance (Schubel et al. 1979; Palanques et al. 2001; Dellapenna et al. 2006).

Trawl gear contact with the benthos also effectively reduces the micrographic relief of bottom sediments, a feature whose importance to organisms inhabiting the benthos is becoming more evident (Freese et al. 1999; Jennings et al. 2001b). Microtopography in benthic sediments can increase the diversity of macrofaunal assemblages (Barros et al. 2004), and abundance of harpacticoid copepods (Sun et al. 1993). Heterogeneity in the sediments with regards to oxygen content is also important for nitrification-coupled denitrification (Koike and Sorenson 1988).

Trawling can also have direct effects on other aspects of sediment chemistry, which may have cascading impacts on the biology of the system. For instance, activities affecting sediment oxygen depth have only recently been considered significant issues (Kaiser et al. 1999; Jennings et al. 2001a; Humborstad et al. 2004). Studies have demonstrated that bottom trawling in soft sediments can displace the upper 1 cm of benthos thereby temporarily reducing the oxic zone in the sediments (Warnken et al. 2003). Such impacts may alter natural patterns of nutrient transfer and benthic-pelagic coupling. Trawling could accordingly cause a sudden shift in the biogeochemistry of the water column. For example, a decrease in the depth of oxygen penetration in the sediments could enhance the transfer of nitrogen, previously buried in the sediments as ammonium, into the water column. Increased availability of nitrogen in the water column could promote eutrophication or noxious algal blooms. Additional indirect effects of trawling in soft sediment systems include turnover of surficial sediments, release of buried organic matter, and an increase in nutrient flux into the water column by releasing sediment-bound nutrients (Smith et al. 2000). Accordingly, the abovementioned effects of trawling on sediment chemistry may impact benthic organisms resulting in an alteration of the resident food web.

Secondary effects of trawling on water chemistry have not been well studied, however these may also be as significant as direct effects (Ramsay et al. 1998). Nutrients and organic matter adsorbed to sediment particles and dissolved within sediment pore-waters may be liberated during sediment resuspension by bottom trawling (Fanning et al. 1982). Since nutrients are often present at much greater concentrations within the benthos than in the water column, releases associated with sediment resuspension may be considerable. Further, nutrient releases by trawling may mimic nutrient loading by storm-driven sediment resuspension events (Giffin and Corbett 2003). Sediment resuspension by trawling could in turn influence water column processes such as productivity and nutrient cycling. Storm or wind-generated sediment resuspension occurs simultaneously with wave production, and therefore oxygenation of the water column. Trawling likely differs from natural sources in this regard in that oxygenation of the water column does not occur. In addition, injection of organic matter into the water column during quiescent periods may exacerbate oxygen removal by microorganisms.

Moreover, organic matter contained in the sediments may differ from that of the water column with regards to composition (Wainright and Hopkinson 1997). Microbial responses are known to differ for various forms of dissolved organic matter (DOM) (Malmstrom et al. 2005). Resuspended organic matter contained within the sediments may be mostly refractory and unable to stimulate heterotrophic organisms, and therefore could have little or no effect on water column activities (Pusceddu et al. 2005a).