Chapter 12

REMOTE SENSING OF HARMFUL ALGAL BLOOMS

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1. Introduction

Problems associated with blooms of unicellular marine algae, known as Harmful Algal Blooms (HABs), are global and appear to be increasing in severity and extent (Anderson et al., 1995). These phenomena have many economic, ecological, and human health impacts, such as mass mortalities of fish and marine mammals; economic loss due to reduced tourism, fish stocks, and shellfish harvests; and a suite of public health problems associated with the consumption of contaminated fish and shellfish, in addition to direct exposure to toxins. These blooms may also alter marine habitats, through shading, overgrowth induced anoxia, and adverse effects on various life stages of fish and other marine organisms (Anderson et al., 1995; Shumway, 1990, 1995).

What is a harmful algal bloom? A HAB is most accurately defined as an increase in the concentration of a phytoplankton species that has an adverse impact on the environment (Smayda, 1997). The most severe and important impacts of HABs result from toxin production. A suite of toxic syndromes have been associated with marine phytoplankton and include: Amnesic Shellfish Poisoning (ASP), Neurotoxic Shellfish Poisoning (NSP), Paralytic Shellfish Poisoning (PSP), Diarrhetic Shellfish Poisoning (DSP) and Ciguatera Fish Poisoning (CFP). Most of these syndromes occur through consumption of shellfish made toxic by ingestion of the toxin-producing phytoplankton. However, the term HAB can also describe non-toxic blooms that impact the environment indirectly through high biomass accumulation (e.g., anoxia or the alteration of trophic structure) or mechanically with such results as fish kills due to the ingestion of phytoplankton that have spines, or adverse effects on the life stages of various marine organisms including starvation (Anderson et al., 1995; Landsberg, 2002).

HABs have a broad impact. ASP has led to deaths of hundreds of California sea lions that consumed toxic anchovies (Scholin et al., 2002). The brevetoxin that causes NSP has caused massive fish kills and has led to mass mortality of dolphins in 1987, and endangered (and herbivorous) Florida manatees in 1982, 1996, and 2003 (Landsberg, 2003). Brevetoxins, when aerosolized by waves, can also cause respiratory distress in humans. Anoxia, resulting from highly concentrated phytoplankton blooms occurring in well-stratified water can lead to “jubilees” or strandings, where crabs or lobsters have walked out of the water to escape anoxic conditions (e.g. Pitcher and Calder, 2000). Blooms of *Aureococcus anophagefferens*, or “brown tides”, overwhelm planktonic biomass and starve filter-feeding bivalves, who cannot use it as a food.

Although HABs are commonly referred to as “red tides” by the public, this term does not provide a good description of these phenomena. HABs are not caused by the tides; they can be many colors and are not necessarily harmful. HABs are produced by several classes of microalgae, which are characterized by different colors ranging from...
blue-green to golden-brown to red. These classes include diatoms, dinoflagellates, raphidophytes, cyanobacteria, prymnesiophytes, pelagophytes and silicoflagellates (Landsberg, 2002). Although several of these species are found globally, they may only cause toxic events in particular regions of the world. Landsberg (2002) produced a comprehensive review of taxonomic and ecologic information on HABs and should be consulted for primary references on any specific HAB species. The roles of various species and their impacts are important from a remote sensing perspective. In the case of NSP and ASP, caused by the dinoflagellates, *Karenia* spp and *Alexandrium* spp, respectively, shellfish beds are closed when the concentration exceeds 5 cells ml$^{-1}$, the equivalent of 0.05 μg L$^{-1}$, which is below the limit for remote detection (Tester et al., 1998). Domoic acid, which causes ASP, is not always associated with high *Pseudo-nitzschia* spp. biomass, so detection of this diatom is not sufficient for detection of a domoic acid event.

Monitoring and providing early warning for toxic HABs is critical for protecting public health, wild and farmed fish and shellfish, and endangered species (such as marine mammals). Current monitoring efforts are done by measuring the concentration of toxic cells in the water and toxin levels in shellfish tissue. As these efforts are logistically demanding and labor intensive, methods which improve the efficiency of field data collection are considered essential. Accordingly, HAB monitoring programs have an intense interest in remote sensing as a tool to detect and provide the location and extent of HABs, in real-time. This chapter discusses the current and potential uses of remote sensing for HAB monitoring efforts.

2. Remote Sensing Techniques

The potential use of remote sensing for HABs was first demonstrated by Mueller (1979). An experimental ocean color sensor attached to an aircraft fortuitously flew over southwest Florida where a bloom including *Karenia brevis* (*Gymnodinium breve* at the time) was ongoing. Significant discoloration was evident in the resultant image. As the instrument was developed to simulate the Coastal Zone Color Scanner (CZCS), which was launched in late 1978, the potential for satellite detection of blooms was raised. Haddad (1982) used thermal data from the geostationary environmental satellites (GOES), to locate a tongue of cooler water which corresponded to the location of a *K. brevis* bloom off the west coast of Florida. However, the use of remote sensing for HAB monitoring became possible following the development of operational high resolution sensors such as the Advanced Very High Resolution Radiometer (AVHRR), in the mid 1980’s (e.g. Tester et al., 1991; Keafer and Anderson, 1993; Gower, 1994). The general utility and characteristics of various sensors for HABs was outlined by Tester and Stumpf (1998).

The application of remote sensing to the detection and monitoring of various HAB-causing organisms has taken several approaches (Table 1). These involve detection using purely optical methods, such as Mueller (1979) presented; detection of ecological characteristics, such as the use of sea surface temperature (SST) to detect water masses conducive to growth of a particular species, and bio-physical associations such as co-occurrence with fronts or other species.

2.1 OPTICAL METHODS

Optical techniques are based on the simple premise that HABs cause discoloration of the water, hence the term “red tide”. Blooms that dominate the biomass will change the