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The growth dynamics of *Karenia brevis* within discrete blooms on the West Florida Shelf

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Abstract

As part of the ECOHAB: Florida Program, we studied three large blooms of the harmful bloom forming dinoflagellate *Karenia brevis*. These blooms formed on the West Florida Shelf during Fall of 2000 off Panama City, and during Fall 2001 and Fall 2002 off the coastline between Tampa Bay and Charlotte Harbor. We suggest that these blooms represent two different stages of development, with the 2000 and 2001 blooms in an active growth or maintenance phase and the 2002 bloom in the early bloom initiation phase. Each bloom was highly productive with vertically integrated primary production values of 0.47–0.61, 0.39–1.33 and 0.65 $g\,C\,m^{-2}\,d^{-1}$ for the 2000, 2001 and 2002 *K. brevis* blooms, respectively. Carbon specific growth rates were low during each of these blooms with values remaining fairly uniform with depth corresponding to generation times of 3–5 days. Nitrogen assimilation by *K. brevis* was highest during 2001 with values ranging from 0.15 to 2.14 $\mu mol\,N\,L^{-1}\,d^{-1}$ and lower generally for 2000 and 2002 (0.01–0.64 and 0.66–0.76 $\mu mol\,N\,L^{-1}\,d^{-1}$ for 2000 and 2002, respectively). The highest *K. brevis* cell densities occurred during the 2001 bloom and ranged from 400 to 800 $cells\,mL^{-1}$. Cell densities were lower for each of the 2000 and 2002 blooms relative to those for 2001 with densities ranging from 100 to 500 $cells\,mL^{-1}$. The 2000 and 2001 blooms were dominated by *K. brevis* in terms of its contribution to the total chlorophyll *a* (chl *a*) pool with *K. brevis* accounting generally for $>70\%$ of the observed chl *a*. For those populations that were dominated by *K. brevis* (e.g. 2000 and 2001), phytoplankton C biomass ($C_{p,0}$) constituted $<30\%$ of the total particulate organic carbon (POC). However, in 2002 when diatoms and *K. brevis* each contributed about the same to the total chl *a*, $C_{p,0}$ was $>72\%$ of the POC. The fraction of the total chl *a* that could be attributed to *K. brevis* was most highly correlated with POC, chl *a* and salinity. Nitrogen assimilation rate and primary production were highly correlated with a greater correlation coefficient than all other comparisons.

Keywords: Phytoplankton; Algal blooms; Biomass; Pigments; Growth rate; Nitrogen assimilation

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1. Introduction

Over the past 20–30 years, coastal environments have experienced an increasing frequency of blooms of various harmful algae (HAB; Anderson et al., 2002). In these bloom events, phytoplankton increase in number to much higher cell densities than would normally be the case, often leading to discoloration of coastal waters, and thus providing the rationale for their common name of "red tides." These HAB events can lead to a wide range of environmental, health and societal or economic problems. Mostly, the harmful impacts are due to the common HAB characteristic of production of various toxins and the bioaccumulation of these toxins within the food web. Some of the more usual impacts of HAB events include fish and shellfish kills, human illnesses or potentially human deaths from consumption of contaminated fish or shellfish, or respiratory distress though inhalation of aerosols that contain either the toxins or the cells containing the toxins. In some cases, HABs have been associated with mortalities in aquaculture pens or ponds (Hoagland et al., 2002). Fish kills may also be the result of severe oxygen depletion that derives from the respiration that occurs within these dense blooms, often in combination with warm surface water temperatures and water column stratification. Often these dense blooms are associated with surface foams and slicks that have impacts on tourism and beach or boating-related recreational activities (Hoagland et al., 2002; Van Dolah et al., 2001). At the same time as we were observing the increase in frequency of HABs, the scientific community observed a trend toward increased coastal eutrophication (Howarth et al., 2002; Rabalais and Nixon 2002; Seitzinger et al., 2002). It has become clear that the two issues are not unrelated (Anderson et al., 2002). However, the relationships between coastal eutrophication and HAB formation, development and maintenance are not yet well understood (Anderson et al., 2002) and are currently the subject of a significant body of ongoing research. The National Science Foundation (NSF), the Office of Naval Research (ONR), the Environmental Protection Agency (EPA), and the National Oceanic and Atmospheric Administration (NOAA), in recognition of the critical nature of our lack of understanding of HABs and their relationships to coastal eutrophication, initiated a national research initiative entitled the Ecology and Oceanography of Harmful Algal Blooms (ECOHAB) in the mid-1990s. The overall goal of ECOHAB is "To develop an understanding of the population dynamics and trophic impacts of harmful algal species which can be used as a basis for minimizing their adverse effects on the economy, public health, and marine ecosystems" (ECOHAB: A National Research Agenda). This research initiative has supported a variety of research programs and provided for the development of regional ECOHAB programs that can address the specific HAB forming species and the associated suite of health, fisheries and social/economic issues appropriate for each region. In addition, the ECOHAB program has focused on three specific elements: the HAB organisms, environmental regulations of blooms, and food web and community interactions.

The Gulf of Mexico is one such region that has experienced substantial blooms of the toxic dinoflagellate *Karenia brevis* (C.C. Davis) G. Hansen & Ø. Moestrup (*K. brevis*; formerly *Gymnodinium breve* Davis) throughout recorded history of the Gulf region (Steidinger et al., 1998). Blooms of this dinoflagellate along the West Florida Shelf have been associated with massive fish kills through the activity of brevetoxins that are produced by the organism. However, there remain significant questions in regard to bloom initiation, maintenance and export of *K. brevis* on the West Florida Shelf. In addition, there is uncertainty as to the sources of inorganic and organic nutrients that support the growth and maintenance of such large blooms in the shelf waters. The ECOHAB: Florida program was supported by the ECOHAB Program to address these questions and to assess how environmental forcing factors impact cellular, behavioral and community processes during different stages of bloom development.

Typically, blooms of *K. brevis* begin to form offshore in oligotrophic waters of the mid-shelf during Fall. As cells grow and divide, the bloom intensifies and can be concentrated or transported by physical features such as density fronts (Walsh et al., 2003). Often these physical mechanisms not only serve to concentrate the bloom organisms but also transport the bloom towards shore, particularly when conditions support downwelling, where they may persist for periods from a few months to as much as 18 months (Walsh et al., 2003). Physical mechanisms, such as entrainment and advection offshore, and prevailing winds that support upwelling conditions may also serve to dissipate the bloom during Winter. This sequence of bloom