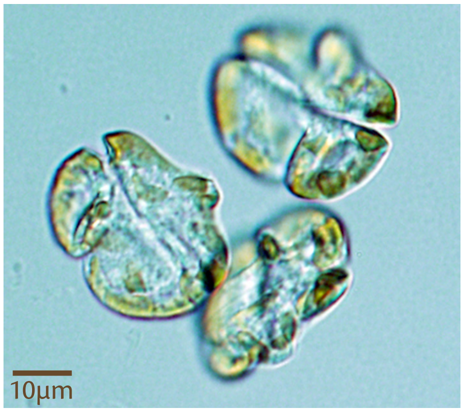
Red Tides of the West Florida Shelf: Science and Management

Native to the Gulf of Mexico, *Karenia brevis* is a dinoflagellate that blooms almost annually off the west coast of Florida. *K. brevis* blooms are not a new phenomenon on the west Florida shelf, as ships' logs suggest bloom-related events (fish kills) dating back to the 1500s. The nutrient sources supporting such long-term, prolific blooms, are multiple and complex. This newsletter outlines conclusions of a five-year study funded by the National Oceanographic and Atmospheric Administration's Ecology of Harmful Algal Bloom Program (NOAA–ECOHAB), in which researchers investigated the sources of nutrients fueling the massive, persistent biomass accumulations of *K. brevis* that occur on the west Florida shelf. This collaborative research effort included biological, chemical, and physical marine scientists. These researchers examined and compared the physical and chemical environment of the west Florida shelf with the physiological characteristics of *K. brevis* during multiple bloom stages (combined initiation and development, maintenance) and in different bloom environments (offshore, coastal, lower estuary, upper estuary).

FLORIDA RED TIDES ARE CAUSED BY THE TOXIC DINOFLAGELLATE *KARENIA BREVIS*



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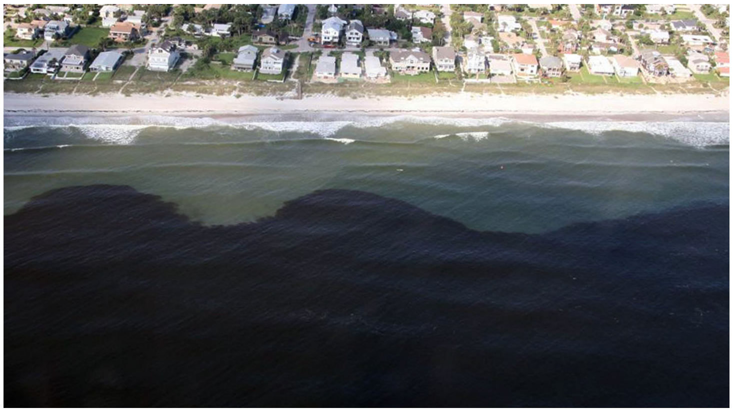
Karenia brevis (Davis) G. Hansen & Moestrup, formerly *Ptychodiscus brevis* and *Gymnodinium breve*, is an unarmored dinoflagellate ranging from 18–45 µm in size. Dinoflagellates are microscopic single-celled organisms. Cells have two flagella that allow for movement within the water column at speeds up to one meter hr $^{-1}$. Like other dinoflagellates, *K. brevis* reproduces asexually by cell division but also has a sexual cycle that may include 'resting' stages. *K. brevis* is a plant-like microalgae, capable of creating its own energy from the sun via photosynthesis but can also use a mix of biological and chemical sources of energy as food. The species is classified as a coastal bloom species; however blooms can occur over a wide range of coastal environments and nutrient conditions. Blooms typically occur in late summer and fall; however they have been documented in all months of the year.

Left: Karenia brevis*, the Florida red tide dinoflagellate.*

KARENIA BREVIS BLOOMS ON THE WEST FLORIDA SHELF ARE NOT A NEW PHENOMENON

K. brevis is native to the Gulf of Mexico ecosystem,and reports suggesting bloom-related events (fish kills) date back to 1528. The organism responsible for red tide was identifed and described in1948 after the largest fish kill in Florida history occurred in 1947. The first nutrient-related *K. brevis* study was conducted in 1948 with the goal of examining the relationship of Caloosahatchee River outflow with bloom events.

Right: A bloom of K. brevis *off the coast of Jacksonville, Florida. When* K. brevis *cells are present in high concentrations, they can discolor water.*



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RED TIDES HAVE LARGE ECOLOGICAL AND ECONOMIC IMPACTS

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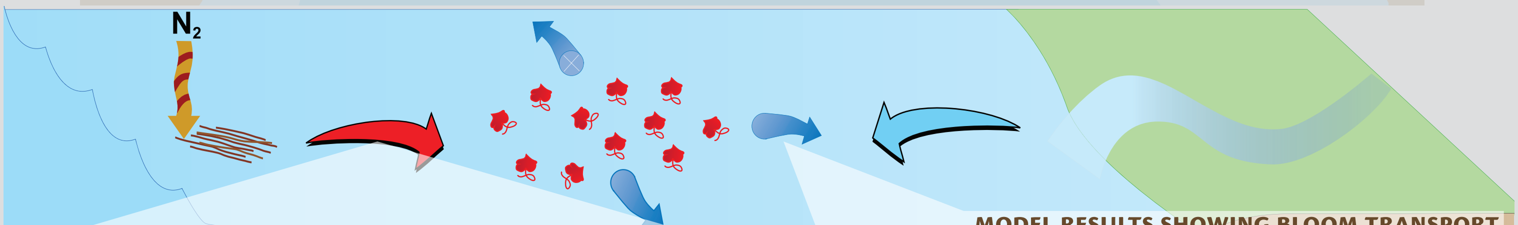
Karenia brevis produces a suite of brevetoxins capable of killing fish, birds, and marine mammals. Toxins can accumulate in filter-feeding shellfish (oysters, clams) tissue and can, if ingested by humans, cause Neurotoxic Shellfish Poisoning (NSP). The State of Florida continuously monitors for *K. brevis*, and commercial shellfish harvesting areas are closed when 5,000 cells L^{-1} of *K. brevis* are detected in the vicinity. There have been no NSP cases from consumption of shellfish from these areas. In addition, when cells are disrupted by winds, breaking waves, or surf, toxins may become aerosolized. This can lead to respiratory irritation in people at beaches and up to three miles inland from the coast, depending on wind conditions. Beach clean-ups, tourism-related losses, medical expenses, and lost work days during red tide events can average over a million dollars lost annually during harmful algal bloom events.

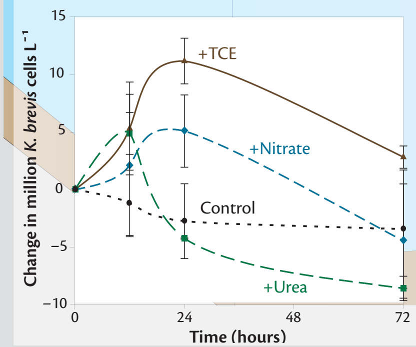
Left: A fish kill caused by a K. brevis *bloom.*

The West Florida Shelf is Prone to Red Tides

Karenia brevis is native to the Gulf of Mexico and blooms have been recorded off of Mexico, Texas, Louisiana, Mississippi, Alabama, and Florida. On the west Florida shelf, blooms of *K. brevis* are common from the area off Clearwater to Fort Myers.

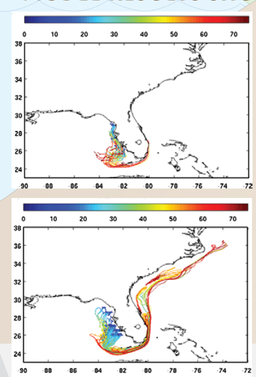


RESPONSE OF *K. BREVIS* TO DIFFERENT NUTRIENT FORMS AND SOURCES



***Karenia brevis* growth is stimulated by urea, nitrate, and TCE (exudates from the co-occurring N_2 fixer *Trichodesmium* spp.).** Points are the average value (± S.D.) of the difference from the initial sample. Positive indicates an increased cell number, negative indicates decreased cell number (Sipler et al., in press).

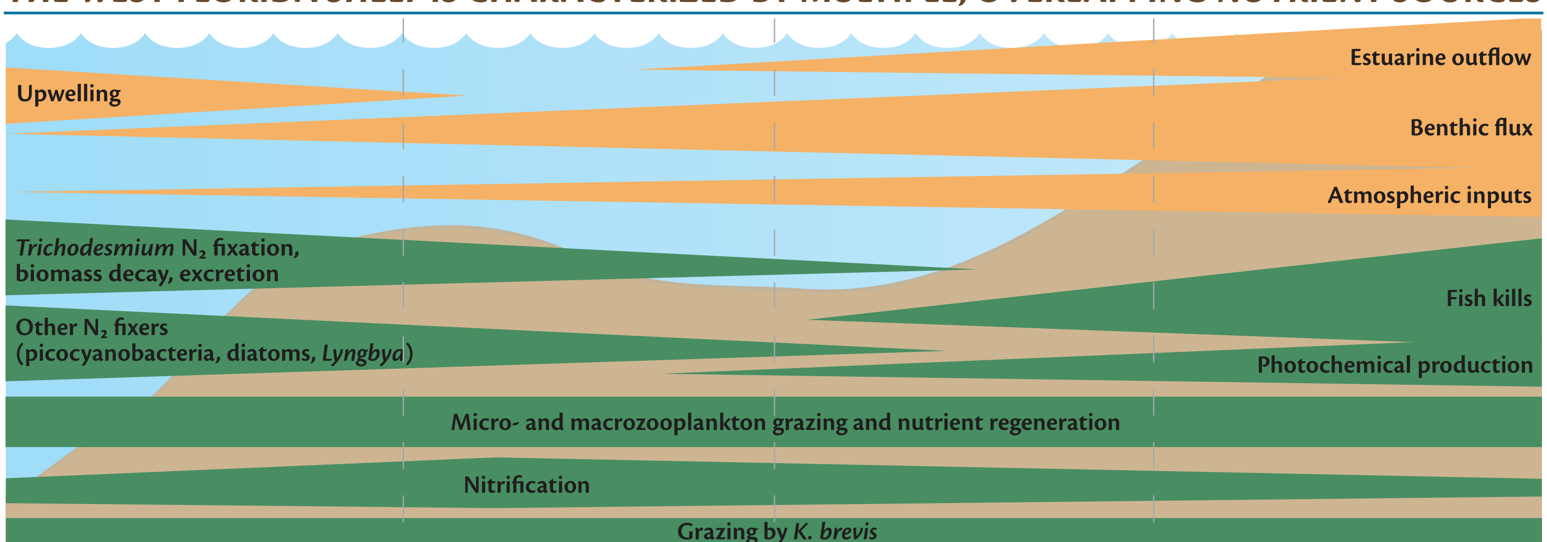
MODEL RESULTS SHOWING BLOOM TRANSPORT



***Karenia brevis* blooms can be transported to the east coast of the US.** Model output showing the paths of surface drifters (which represent water parcels with *K. brevis* blooms present) demonstrate stationary bloom conditions in 2006 (top), and conditions promoting transport to the east Florida coast in 2007 (bottom) (Weisberg, 2011).

Karenia brevis blooms intiate in offshore, low-nutrient waters, where they are able to utilize ammonium produced by the nitrogen-fixing cyanobacteria *Trichodesmium* spp. Cells are concentrated and transported nearshore through physical forcing mechanisms and blooms can be advected north or south via the coastal currrents, Loop Current and Gulf Stream.

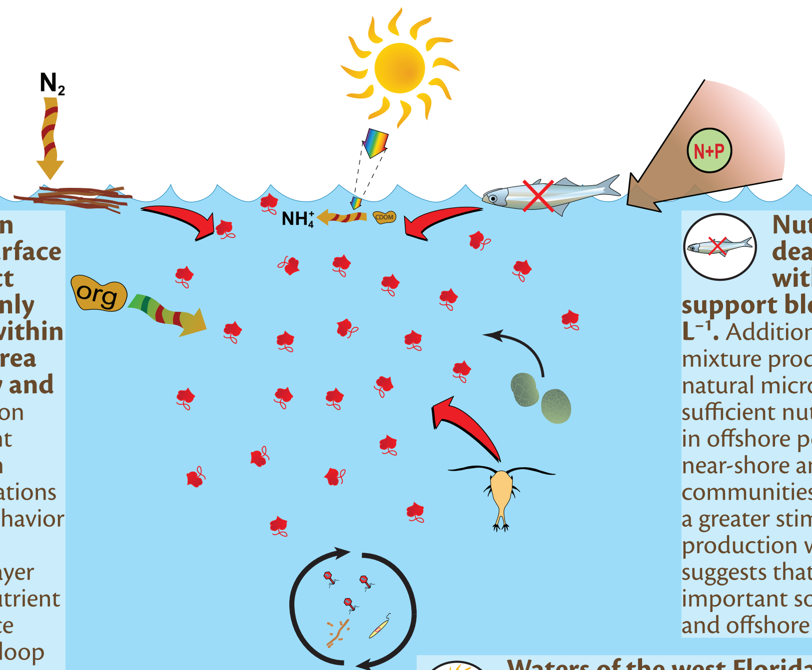
THE WEST FLORIDA SHELF IS CHARACTERIZED BY MULTIPLE, OVERLAPPING NUTRIENT SOURCES



External and *in situ* nutrient sources supplying blooms of *K. brevis* on an offshore–lagoonal gradient on the west Florida shelf. Length of bar/triangle indicates the relative importance of each nutrient over the gradient (offshore, coastal, lower estuary, upper estuary). Width of bar/triangle indicates relative importance of source in comparison to each other.

Karenia brevis is Opportunistic: Utilizing Multiple and Complex Nutrient Sources

Nutrient sources supporting *K. brevis* blooms are multiple, diverse, and complex. The ability of *K. brevis* to utilize a variety of inorganic and organic nitrogen (N) and phosphorus (P) sources allows the species a significant ecological advantage. Known nutrient sources were quantified and evaluated for their relative significance. The largest nutrient sources observed were the decay and recycling of *Trichodesmium* spp. bloom biomass, and nutrient release from zooplankton grazing, followed by the decay of red tide-related dead fish, benthic nutrient flux, photochemical nutrient production, nitrification, and *Trichodesmium* spp. N_2 fixation. These were followed by estuarine inputs and pelagic N_2 fixation. New identified and quantified nutrient sources for blooms included nitrification, photochemical nutrient production, microzooplankton grazing, pelagic N_2 fixation, and *Trichodesmium* biomass decay. Many of these sources alone were sufficient to support observed bloom biomass. Additionally, as *K. brevis* bloom concentrations increased, nutrient cycling by the microbial loop increased in importance.



The surface aggregation layer, a narrow 5 cm surface band where cells collect during daylight hours, is not only an area of concentrated cells within a *K. brevis* bloom but also an area of increased biological activity and nutrient cycling. Vertical migration of *K. brevis* to access deeper nutrient concentrations was not observed in blooms. However, based on observations of a daylight surface aggregation behavior of *K. brevis*, it is hypothesized that migration to a narrow sea surface layer during daylight hours serves as a nutrient acquisition strategy to access surface associated nutrients and microbial loop enhanced nutrient production.

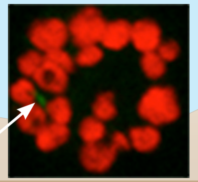
Nutrient release rates from dead, decaying fish fall within the range required to support blooms of at least 10^6 cells L^{-1}. Additions of fish 'goo' (a nutrient mixture produced by decaying fish) to natural microbial populations provided sufficient nutrients to alleviate P limitation in offshore populations. While both near-shore and offshore phytoplankton communities utilized N from additions, a greater stimulation of chlorophyll *a* production was observed offshore. This suggests that decaying fish could provide an important source of N and P in both coastal and offshore habitats.

Waters of the west Florida shelf are generally N-limited and therefore sources of newly available N could play a large role in relieving nutrient limitation. Photochemically produced ammonium (NH_4^+) is created during a chemical reaction involving light. Observed NH_4^+ photoproduction rates were comparable within three *K. brevis* blooms during 2007, 2008, and 2009, but insufficient to support the measured NH_4^+ uptake at all *K. brevis* sites. In addition, separate studies demonstrated that N uptake by the phytoplankton community was dominated by the uptake of NH_4^+, indicating the potential importance of newly available N as a source for *K. brevis*.

The photosynthetic cyanobacteria *Trichodesmium* is capable of fixing atmospheric nitrogen (N) into ammonium, which can then be used by other organisms. *Trichodesmium* spp. and *K. brevis* have historically co-occurred in the Eastern Gulf of Mexico. While release of 'new' N from biological N_2 fixation could have potentially supplied up to 40% of the large 2001 red tide (Mulholland et al., 2006; Mulholland et al., in press), estimates of the total N available within surface populations of observed *Trichodesmium* spp. biomass during cell death suggest that up to 100% of N and P requirements of such large blooms can be met from N_2 fixation sources (Lenes & Heil, 2010).

A 'tuft' of Trichodesmium *spp. as viewed under a compound microscope (Judy O'Neil, UMCES).*

***Synechococcus* spp. is a single-celled cyanobacteria native to the Gulf of Mexico. The ability of *K. brevis* to graze on *Synechococcus* spp. cells has been observed in previous studies, and was investigated. Ingestion rates of *K. brevis* on *Synechococcus* spp. were highly dependent on experimental prey concentrations.** Below a lower feeding threshold (1.86 x10^4 cells mL^{-1} grazing did not occur and above a saturating prey concentration (~1.95 x10^6 cells mL^{-1}) grazing rates did not increase with increasing prey concentrations. Results suggest that grazing may play an important role in maintaining *K. brevis* populations at background, and/or bloom concentrations.



A confocal laser scanning image showing a K. brevis cell (red indicates chloroplasts in periphery of cell) containing a Synechococcus *spp. cell (green) (Leo Procise, ODU).*

Benthic flux is the transport of dissolved nutrients from the sediments into the water column, which can then be utilized by organisms such as *K. brevis*. Based on literature growth rates of *K. brevis* and on cell complement data, the measured sediment flux of nutrients can provide up to 300% of P requirements, and up to 100% of N requirements of 5.0 x 10^4 cells L^{-1} of *K. brevis*.

CONCLUSIONS AND RECOMMENDATIONS

Multiple nutrient sources are available to *K. brevis* blooms but these sources are dynamic and vary with bloom stage and location.

REDUCE controllable nutrient sources through the implementation of best management practices, with the understanding that, given the complexity of *K. brevis* bloom dynamics, no direct impact on *K. brevis* bloom frequency or magnitude may be evident as a result.

Current research and management are limited in their bloom predictive capabilities.

DEVELOP further short-term forecasting and now-casting capabilities. With increasing knowledge and understanding of red tide dynamics and ecology, the need for effective monitoring and predictive capability is also increasing. Continue to provide red tide-related monitoring products that allow for effective targeting of monitoring needs with reduced fiscal and manpower resources for state harmful algal bloom managers (e.g. particle tracking products).

A working hypothesis of bloom initiation has been developed but requires testing and confirmation.

CONTINUE research on the conditions promoting bloom initiation, with the addition of regular 3D surveys of water properties and bio-optics using gliders. Such data is essential for forecasting blooms and their impacts, and developing targeted management strategies.

Specific physical and chemical conditions on the west Florida shelf make it particularly vulnerable to annually reoccurring red tides.

ADAPT to blooms on the west Florida shelf, as they are a chronic, long-term problem. Support, update, and maintain red tide-related mapping, modeling, and monitoring products. Utilize new and existing educational outreach programs to disseminate information and resources.

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Based on NOAA ECOHAB research grant # NA06NOS4780246

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