'Hotspots' for HABs in the Gulf of Mexico?

The study of "hotspots" is a relatively new approach for determining factors contributing to HABs. Hotspots are highly localized and regularly recurring bloom events. Data from intensive multi-year monitoring of biotic and abiotic parameters prior to, during, and after hotspot bloom events are then integrated into ocean models to forecast future events. Modeling HAB hotspots is one of the latest target areas for the National Centers for Coastal Ocean Sciences programs (ECOHAB, MERHAB, PCM, CHRP, and NGOMEX). One of these hotspots is the Juan de Fuca Eddy in the Pacific Northwest (http://www.ecohabpnw.org). This cyclonic eddy forms at the each spring between opposing northwest flowing currents and southeast upwelling and topographic jets and, in doing so, entrains nutrients and initiates high density *Pseudo-nitzschia* spp. blooms (Trainer et al. 2009). In California, upwelling jets and coastal land use in two regions, Monterrey and San Pedro, for clues to initiation of *Pseudo-nitzschia* blooms (http://oceandatacenter.ucsc.edu/MBHAB/hotspots/).

Undoubtedly, the west coast of Florida with its quasi-annual, recurrences of *Karenia brevis* blooms is one of the most studied HAB hotspots in the U.S. (refs) The multi-agency collaborative mapping and prediction system, harmful algal bloom operational forecast system (HAB-OFS, http://tidesandcurrents.noaa.gov/hab/) for *K., brevis* in the Gulf of Mexico serves as a model for design of similar systems in U.S. Data from remote sensing monitoring of blooms as well as wind speed/direction, ocean current speed/direction, temperature, light penetrance, barometric pressure, sea level, tide, and salinity data can be used for "hind-casting" identification of previously unrecognized factors.

After assembling data for all harmful algae species observed within the Gulf of Mexico and associated bays & estuaries, either at bloom densities, $\geq 1 \times 10^6$ cells L^{-1} (Smayda, ref) or background densities, typically <1,000 cells L^{-1}, dates and durations of blooms, and the latitudes-longitudes, if given, or approximate positions from text descriptions, no other HAB 'hotspot' phenomena, besides *K. brevis* blooms on the West Florida Shelf, were obvious. However, given the almost 100 year documentation of ever-increasing bloom periodicity and duration of extant HAB species and the first-time observations of new or rare (to the GOM) HAB species, one could convincingly argue that all of Gulf of Mexico, including Cuba, is a hotspot or rather 'test

bed' for introduction and of new HAB taxa and either successful or failed establishment in their adapted life strategy or niche.

Again, consider the recurrence of *K. brevis* blooms on the West Florida Shelf. Despite several decades of studies, the initiation factors for *K. brevis* blooms in the Gulf of Mexico are still poorly understood. However it is largely accepted that they are initiated offshore, seeded by cysts in bottom sediments or water column (Steidinger, 1975). More recent surveys of cyst distributions in sediments from the West Florida Shelf provide additional support (Kang, 2010). *K. brevis* also appears to be strategically adapted for extended bloom durations in oligotrophic, offshore waters through its ability to downward migrate to bottom sediments and acquire organic and inorganic N at the sediment-water interface (Sinclair and Kamykowsi, 2008) even in the dark (Sinclair et al., 2006). And, there is increasing evidence to that *K. brevis* utilizes organic N, fixed by co-occurring cyanobacteria (Havens et al., 2004).

The adaptive life strategy or 'niche' of *K. brevis* places it squarely as a "Type VI—Coastal Entrained Taxa" within Smayda's (2002) "Turbulence-Nutrient Matrix Along an Onshore-Offshore Continuum," a diagonal gradient of eight dinoflagellate life form types (fig. 1).

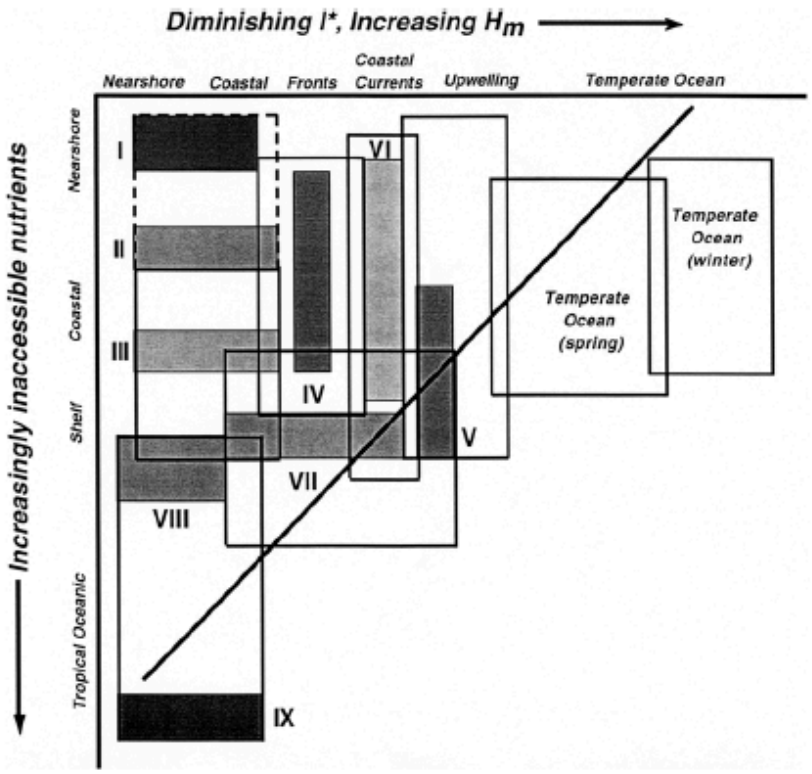

Figure 1. Smayda's (2002) predominant dinoflagellate life forms associated with a nutrient requirement and turbulence tolerance matrix lies between near shore to temperate- or tropical-oceanic habitats. (**NOTE:** Permission has not yet been obtained from publisher for reproduction)

Type I. Gymnodiniods that prefer bays & estuaries and have the highest nutrient requirements (e.g. *Gymnodinium* spp, *Heterocapsa rotundata*);

Type II. Peridinians/*Prorocentroids* that prefer coastal to nearshore and have greater nutrient requirements (e.g. *Heterocapsa triquetra*, *Scrippsiella trochoidea*, *Prorocentrum micans*, *P. minimum*);

Type III. Ceratians that prefer coastal to nearshore and have lower nutrient requirements (e.g. *Ceratium tripos*, *C. fusus*, *C. lineatum*);

Type IV. Frontal Zone taxa that prefer frontal zones near edge of shelf (e.g. *Karenia mikimotoi*, *Alexandrium tamarense*);

Type V. Upwelling Relaxation taxa that prefer upwelling zones i.e. at sharply declining rather than gradual slopes (*Gymnodinium catenatum*, *Ligulodinium polyedrum*);

Type VI. Coastal Current Entrained taxa that prefer region between offshore current and nearshore at the edge of the coastal-shelf boundary (e.g. *Karenia brevis*, *Ceratium* spp., *Pyrodinium bahamense*);

Type VII. Dinophysoids that prefer the continental shelf and frontal zones (e.g. *Dinophysis acuta*, *D. acuminate*)

Type VIII. Tropical oceanic flora (e.g.*Amphisolenia*, *Histionies, Ornithocercus*, *Ceratium* spp.);

Type IX. Tropical shade flora (e.g. *Gambierdiscus* spp., *Pyrocystis noctiluca*, *Pyrocystis pyriformis*)

In the past decade, an alarming rate of first time observations of new HAB species were observed in Florida—

1. 1997 - 2004. First-time blooms of *Pyrodinium bahamense* & *Pseudo-nitzchia spp.* in Indian River Lagoon.

2. August-November 2005 and August-November 2010. First-time bloom of *Peridinium quinquecorne* from southern Sanibel Island and southward to Seagate.

3. September 9 - 29, 2010. First -time blook of *Takayama cf tuberculata* (30×10^6 cells L^{-1}) in coastal waters just off Barefoot Beach and Estero Bay, Collier County. September 22, bloom still at Barefoot Beach, Vanderbilt, and Seagate beaches and background concentrations at Naples Pier 1. By September 29, bloom had migrated to Marco Island Beaches, still medium concentrations at Barefoot Beach, and reduced to background concentrations at Vanderbilt Beach, Naples Pier, and South Marco Beach.

4. February 2011. *Noctiluca scintillans* bloom off Florida panhandle

5. July 5 - August 2, 2011. Recurring bloom of *Takayama tuberculata* plus the diatom species *Hemiaulus* atVanderbilt Beach and Naples, Florida. Present in Collier County—samples taken between 2 and 10. miles offshore of Collier beaches.

6. March 2011 to March 2012. First time bloom of *Pedinophyceae* in Indian River Lagoon. Called the "Super Bloom" of 2011. Extended for 131,000 acres in the Banana River Lagoon and into northern Indian Lagoon and southern Mosquito Lagoon.

7. Early? July 2012. First time blooms of *Aureoumbra lagunensis* in Indian River Lagoon (first time for Florida). First time bloom of *Pyrodinium bahamense* in Mosquito Lagoon and northern Indian River Lagoon.

In Texas, the 2008 Dinophysis spp. bloom in Texas coastal waters was a first-time observation—

In March and April 2008, a rapidly increasing bloom of *Dinophysis spp.,* (predominantly *D. ovum*) was monitored in the "coastal bend" region of Texas (Swanson et al. 2008) in response to early detection by an imaging FlowCytobot (Cambell et al. 2010). This was the first observance of a *Dinophysis* spp. bloom in Texas coastal waters. Cell density patterns indicated that the bloom initiated in the nearshore and then migrated through passes in barrier islands. Highest densities reached >3,000 cells per ml in a small semi-enclosed harbor. Shellfish harvesting grounds were temporarily closed for several weeks in three nearby bays after oysters were found to contain up to 68.1 ug okadaic ccid (OA) per 100 g tissue. The Texas Parks and Wildlife Department also collected samples from four other stretches along the coast having

multiple inlets through barrier islands and determined that the bloom was restricted to the coastal bend region. Two years later in early April 2010, Alabama closed its shellfish harvesting areas because *Dinophysis acuminata* were detected at 3,800 cells L^{-1} in Grand Bay (Raines 2010). According to Lisa Cambell (2010), bloom began offshore and moved into bays through the passes. (my note--but in coast of France seem to begin within the bays. Is it possible that once established, cysts are then seeded in bays?)

Increased observations of *Pseudo-nitzchia* blooms 2007 to 2011 in Mobile Bay.
Plus a hot spot in Mobile Bay determined to be linked to nutrient rich groundwater discharges.
Alabama Department of Public Health (Novoveska et al. ????). collected biweekly samples for phytoplankton analysis at four sites along the Alabama coast from 1999 to 2008. Thirty-seven genera and potentially 114 species were identified and included 22 potential HAB species. Bloom qualifying cell densities (10^6 L^{-1}) of *Prorocentrum minimum* were present in winter and spring samples collected in 2003, 2005, 2007, 2009, and 2011. The only other HAB in 2007 was *Karlodinium veneficum*. *Karenia brevis* cell counts approached bloom densities in October to December with average monthly densities of 2,500 to 30,000 cells per L. Highest average monthly densities for *Alexandrium monilatum* (3,000 to 4,000 cells per L) occurred in August and September. *Pseudo-nitzchia* spp., blooms at three sites on the Fort Meyer Peninsula, were found to occur in response to nitrogen rich discharges from surface and, in particular, groundwater (Liefer et al. 2009).

Pseudo-nitzchia bloom durations and recurrences increasing—

1. Mississippi River Delta, Louisiana, 1969-1990. Six blooms of Pseudo-nitzchia. And 18 from 1990 to 1999 (Dortch, 1999)

2. South Carolina., 2010. Major blooms of *Pseudo-nitzchia* occurring brackish stormwater retention ponds. (Also first time bloom of Pfiesteria)

[Pfiesteria-like organisms isolated from Mobile Bay (Burkholder and Glasgow 1997)]

Increased periodicity and duration of *K. brevis* in Florida and Texas—

From Brande 2010

Location	Date	Reported mortality	Density (Cells L-1)	Salinity	Temperature (C)	Reference
Indian River and Sarasota, FL	August-September 1951	Finfish	n.a.	18-32	30-34	Howell (1953)
Offats Bayou, Galveston, TX	Summer 1949	Finfish, shrimp, crabs	n.a.	n.a.	n.a.	Connell and Cross (1950)
Fort Myers to Naples, FL	1966	Finfish - *Caranx* spp., *Strongylura marina, Lagodon rhomboids*	n.a.	>32	>29	Williams and Ingle (1972)
Galveston, TXa	1971-1972	Finfish, shellfish, annelids, coelenterates, crustaceans, echinoderms	1.88 xlO6 "massive bloom"	30-34	29-32	Wardle etal. (1975)
Indian River, FL	July 1977	n.a.	8.9 xlO5	32.0	31.5-32	Norris (1983)
Melbourne Beach, FL	July 1977	n.a.	1.7 xlO6	30.5	29.5	Norris (1983)
Port St. John, FL	September 1977	Finfish (thousands)	Bloom	n.a.	n.a.	Norris (1983)
Mississippi Sound (MS-LA)	August 1979	No deaths	1.65 xlO7	24-26	30-31	Perry et al. (1979)
Mobile Bay, AL	August 1979	Finfish	n.a.	n.a.	n.a.	Perry et al. (1979)
Pensacola Bay, FL	August 1979	Finfish	3.18 xlO7	14	28	Perry et al. (1979)
Indian River, FL	September 1979	n.a.	<1 xlO3	16-21	24.5-30	Norris (1983)
Gulf of Cariaco, Venezuela	January-February, April-May 1984; January 1985	n.a.	0.1 to4xl04	n.a.	n.a.	Ferraz-Reyes etal. (1985)
Coastal MS	1998	Zooplankton, ichthyoplankton	n.a.	n.a.	n.a.	ICES (1999)
York River, VA	September 2007	Veined rapa whelks *(Rapana venosa)*	4.0 xlO7	22.4-22.8	27-28	Harding et al. (2009)

(Marine Pollution Bulletin, Vol. 6 (1):5 Following passage of Hurricane Carmen, Sept. 7 & 8 september, 1974, samples collected off Panama City on Sept. 12th contained 170,000 to 3,800,000 K. brevis. Bloom extended from Panama City to Pensacola}

In Texas-- historic

- **1528,** time of Spanish Explorers (Cabeza de Vaca)

- **Summers 1936-1941**, Anecdotal from local residents-Offatts Bayou "dense, red slick" indicative of at least 1 x 10^6 cells L^{-1} Samples taken though out bayou (Gunter 1942)

- **Since 1947**, *K. brevis* was associated with massive fish kills in near ***west coast of southern Florida*** (Wilson & Ray 1956)

- **1948 to 1950**, USFWS maintained lab in Sarasota Fl and collected samples from large areas of the adjacent Gulf waters but no *K. brevis* found (Wilson & Ray 1956).

- **mid-July to September 10, 1949**, *Gonyaulax* spp. blooms in Offatts Bayou from (Connell and Cross 1950)

- **November 1952**, *K. brevis* bloom occurred south-southwest of Sanibel Island (by USFWS M/V Alaska)

- **September 1953 to January 1955**, *K. brevis* consistently found along Florida west coast, and sporadically thereafter until 1956.

- **1953 to 1955**, samples taken along coast from Galveston, TX to Florida. No *K. brevis* observed.

- **September 1955** , Offatts Bayou in *Gonyaulax monilata* 500 to 1,000 cells per ml (Gates and Wilson, 1960)

- **September 1955,** Mouth of Rio Grande to ten miles north of Port Isabel (20 square mile area) 50 to 500 cells per ml. No *K. brevis* in samples from Laguna Madre (Wilson and Ray 1956).

- **September 15-27,** 1955 Rio Grande to 45 miles south along beach of Tamaulipas. Aerial observation of fish kills at 40 miles south of Rio Grande. September 16, 1955 aerial observation from Playa Washington observed massive fish kills for 21 miles of beach. Water sample collected 36 miles south of mouth of Rio Grande had 22,000 cells per ml of *K. brevis*. Anecdotal info from fishermen and airplane pilots stated 120 miles of coastline in Tamaulipas affected (Wilson and Ray 1956) *Gulf Fishery Investigations, USFWS, Galveston, TX*

From published and grey literature (reports, letters, maps) for HABs in the GOM.
The Florida Fish and Wildlife Conservation Commission's Fish and Wildlife Research Institute offered the most comprehensive (1954 to present) database (web address).
Alabama Department of Health (ref)

	Florida	Alabama	Mississippi	Louisiana	Texas
Dinophyceae					
Karenia brevis	1954-2013		X	X	X
Gyrodinium estuariale	X				
Pyrodinium bahamense	X				
Karlodinium veneficum		2007		X	
Dinophysis spp.				X	2008
Prorocentrum spp.				X	
Prorocentrum rhathymum	X				
Prorocentrum minimum		2003 2005 2007 2009 2011	X		
Heterocapsa spp.				X	
Gamberdiscus spp.					
Bacillariophyceae					
Pseudo-nitzschia spp.		X	X	X	
Thalassiosira spp.	X			X	
Rhizosoleniaceae	X			X	
Cyanophyceae					
Trichodesmium	X				
Lyngbya majuscula				X	
Anabaena spp.				X	
Microcystis				X	
Cylindrospermopsis raciborskii				X	
Pelagophyceae					
Aureococcus anophagefferens					X
Aureoumbra lagunensis					X

Pyrodinium bahamense- Tampa Bay, also in Puerto Rico
Pyrodinium bahamense var. compressum-Roy (1977)
Kota Kinabalu, Malaysia, restricted to the Indo-Pacific
occur in June–July and December–January-Adam et. Al (2011)
Paralytic shellfish poisoning-Ting, Wong (1989)

Prorocentrum minimum-
GOM 1979 (from Sierra-Betran 2005)
Yucatan 2001, 2003
Pacific coast of Mexico 1980
In Gulf of California since 1985
Sinaloa 1990, 1991, 1992 (may/july, aug/oct) 1993 (feb/mar)
San Ignacio 1998
Ballenas 1998
Mazatlan 1999
Pacific Coast 2000
Hermosillo Son 2003
Chiapas 2002-2003
La Paz 2003 mostly associated with heavy rains or large source of N

Found in ship ballast water from manzanillo bay- P. minimum Associated with urban wastewater discharges (Cortes-Altamirano & Agraz-Hernandez 1994)

Florida-St. Joseph Bay, Tampa Bay, Perdido Bay, southwest Florida
Alabama-Mouth of Mobile Bay, Perdido Bay
Mississippi

Papers reporting blooms:
1995 2
1996 1
1997 2
2005 3
2007 7
2008 4
2009 2
2010 4
2011 4
2012/13 8

Growth requirements for first time and recurring HABs

Karlodinium veneficum—Gymnodinoid "naked" dinoflagellate (ref for describer) typically occuring in shallow, stratified coastal ecosystems, mixotrophs, background densities 10^2-10^3 cells per ml, and bloom densities 10^4-10^5 cells per ml. Produces "karlotoxins" with hemolytic, icthyotoxic, and cytoxic properties. First observed in Walvis Bay (Namibia, Africa) as a bloom occurring in the upper meter of highly anoxic water. *K. veneficum* is frequently associated with fish kills. Grows at temperatures between 7-24°C and salinities of 10-34 psu. Responsible for

30,000 to 50,000 fish kill occurring from September 26 to 29, 2005 in Chesapeake Bay and blooms of increasing cell density followed for next three years (Place et al. 2012).

Prymnesium parvum & P. saltans. Haptophyte. FW strains are apparently restricted to one site in Germany with high sulfate and chloride concentrations. Most marine species have clear tendencies to bloom in brackish water embayments and estuaries. Salinity is primary factor controlling distribution – in culture died at salinities less than 1.12 ppt but grew well from 5.6 to 22.5 ppt

From Brand 2012

Karenia brevis-salinity 5 to 24 PSU, K. brevis has a compensation point around 6–8 mmol m_2 s_1 and saturation around 35–120 mmol photon m_2 s_1. All Karenia species have chlorophylls a and c; and have fucoxanthin, 190-butanoyloxyfucoxanthin, 190-hexanoyloxyfucoxanthin, and 19-hexanoyloxyparacentrone 3-acetate (gyroxanthindiester) as accessory pigments instead of peridinin (Steidinger et al., 2008a). K. brevis and K. mikimotoi also have gyroxanthin (Richardson and Pinckney, 2004).

While K. brevis appears well adapted to low light levels, it appears to use the photoprotective xanthophyll cycle pigments diadinoxanthin and diatoxanthin to tolerate high light intensity when it accumulates at the surface during the day (Evens et al., 2001).

Studies with field populations of K. brevis show that it can use nitrate, ammonia, urea, glutamate, and dissolved organic matter from Trichodesmium (Bronk et al., 2004). Sinclair et al. (2009) have shown that K. brevis takes up ammonia and urea at night as well as day, which could be important in obtaining nutrients during diel vertical migration. Baden and Mende (1979) showed that K. brevis can use glycine, valine, and methionine. Shimizu et al. (1995) found that urea and glycine added to cultures of K. brevis stimulates a shift to a more heterotrophic mode, and increased biomass and brevetoxin amount 2–4 fold. Mulholland et al. (2004, 2006) have shown that K. brevis can utilize dissolved organic matter that has been excreted by Trichodesmium. Vargo and Shanley (1985) have shown that K. brevis uses organic

P. minimum is a toxic species; it produces venerupin (**hepatotoxin**) which has **caused shellfish poisoning resulting in gastrointestinal illnesses in humans and a number of deaths**. This species is **also responsible for shellfish kills** in Japan and the **Gulf of Mexico,** Florida (Nakazima, 1965,Nakazima, 1968, Okaichi and Imatomi, 1979, Tangen, 1983, Shimizu, 1987, Smith, 1975, Steidinger and Tangen, 1996)

Heil et. Al (2005) distributed geographically in temperate and subtropical waters, Japan; France; Norway; Netherlands; New York, USA, also Mediterranean coast of France-Heil et. Al (2005)
high temperatures, incident irradiances, low to moderate salinities in coastal and estuarine environments (often characterized as eutrophic), high amount of physiological flexibility-Heil et. Al (2005)
harmful to humans via shellfish poisoning, relationship with increasing eutrophication-Heil et. Al (2005)
Detected in Ballast Water Yes-Yoshida et. Al (1996)

Pseudo-Nitschia cosmopolitan in coastal waters (found in both coastal and open water)
Salinity tolerance appears to be species specific (Thessen et al. 2005)
Coast of Texas & Louisiana 1 to 35 psu, Alabama- variable from fresh to 35
Occurs year round in Alabama-Mobile Bay and Perdidio Bay (Liefer 2012)
euryhaline, eurythermal
Toxigenic species are typically coastal

temps Sea of Japan 12-20 deg C
China Sea 12-2

References

Contreras, Cindy. 2001. Redtide (*Gymnodinium breve*) Studies Along The Texas Coast..Texas Park and Wildlife Departmment. MARFIN NA96FM0341MF. **In house**

*Wilson, W. B., and S. M. Ray. 1956. The occurrence of Gymnodinium brevis in the western Gulf of Mexico. Ecology 37 (2):388.

Zein-Eldin, Z. P. 1961. Plankton pigments in East Lagoon, Galveston, Texas. Transactions of the American Fisheries Society 90 (1):32- 41.

Finucane, J. H., and A. Dragovich. 1959. Counts of red tide organisms, Gymnodinium breve, and associated oceanographic data from Florida west coast, 1954-57. U.S. Fish and Wildlife Service, Special Scientific Report- -Fisheries No. 289, 220 p.

Dragovich, A., J. H. Finucane, J. A. Kelley, and B. Z. May. 1963. Counts of red-tide organisms, Gymnodinium breve, and associated oceanographic data from Florida west coast, 1960-1961. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 455, 40 p.

Dragovich, A. 1963. Hydrology and plankton of coastal waters at Naples, Florida. Journal of the Florida Academy of Sciences 26 (1):22-47.

Galtsoff, P. S. 1948. Red tide; progress report on the investigations of the cause of the mortality of fish along the west coast of Florida. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 46, 44 p.

*Gates, J. A., and W. B. Wilson. 1960. The toxicity of Gonyaulax monilata Howell to Mugil cephalus. Limnology and Oceanography 5 (2):171-174.

Graham, H. W. 1954. Dinoflagellates of the Gulf of Mexico. Fishery Bulletin, U.S. 89 (55):223-226.

*Gunter, G. 1942. Offatts Bayou, a locality with recurrent summer mortality of marine organisms. American Midland Naturalist 28(3): 631-633.

Howell, J. F. 1953. Gonyaulax monilata, sp. Nov., the causative dinoflagellate of a red tide on the east coast of Florida in August- September 1951. Transactions of the American Microscopial Society 72 (2):153- 156.

Hudson, J. H., D. M. Allen, and T. J. Costello. 1970. The flora and fauna of a Florida Bay. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 604, 14 p.

King, J. E. 1950. A preliminary report on the plankton of the west coast of Florida. Quarterly Journal of the Florida Academy of Science 12 (2):109-137.

**Ray, S. M., and W. B. Wilson. 1957. Effects of unialgal and bacteria-free cultures of Gymnodinium brevis on fish and notes on related studies with bacteria. Fishery Bulletin, U.S. 57 (123):469-496.

Ray, S. M., and W. B. Wilson. 1957. The effects of unialgal and bacteria-free cultures of Gymnodinium brevis on fish and notes on related studies with bacteria. U.S. Fish and Wildlife Service, Special Scientific Report-- Fisheries No. 211, 50 p.

Rounsefell, G. A., and J. E. Evans. 1958. Large-scale experimental test of cooper sulfate as a control for the Florida red tide. U.S. Fish and Wildlife Service, Special Scientific Report-- Fisheries No. 270, 57 p.

Starr, T. J., D. Martinez, and W. Fosberg. 1957. The vitamin B12 activity of mullet and shark serum. Limnology and Oceanography 2 (2):111-113.

Starr, T. J., M. E. Jones, and D. Martinez. 1957. The production of vitamin B12-active substances by marine bacteria. Limnology and Oceanography 2 (2):114-119.

Starr, T. J. 1958. Notes on a toxin from Gymnodinium breve. Texas Reports on Biology and Medicine 16 (4):500-507.

Starr, T. J. 1959. A bacteriological technique for the isolation of marine diatoms. Texas Reports on Biology and Medicine 17:624-625.

Starr, T. J., and F. Sanders. 1959. Some ecological aspects of vitamin B12-active substances. Texas Reports on Biology and Medicine 17 (1):49-59.

Stevenson, R. E. 1969. Space photos detect changing currents along the Texas coast. Ocean Industry 4:38-39.

Stevenson, R. E., and D. F. Leipper. 1967. Influence of the hurricane on the structure of the thermocline. In: Proceedings of the Hurricane Symposium, October 10-11, 1966. Part I - pp. 158-172; Part III - pp.189-199.

Connell, C. H. and Cross, J.B. 1950 Mass mortality of fish associated with the protozoan Gonyaulax in the Gulf of Mexico. Science, 112(2909):359-363.

Howell, J. F. 1953. Gonyaulax monilata, sp. nov., the causative dinoflagellate of a red tide on the east coast of Florida in August-September, 1951. Trans. Am. Microsc. Soc. 72(2):153-156.

Williams, J., and Ingle, R.M. 1972. Ecological notes on Gonyaulax monilata (Dinophyceae) blooms along the West Coast of Florida. Marine Research Laboratory, Fla. Dept. Nat. Res. Leflet Series, Vol 1-Phytoplankton, Part 1(Dinoflagellates) No. 5. 12 pp.

Gates, J. A. and Wilson, W.B. 1960. The toxicity of Gonyaulax monilata Howell to Mugil cephalus. Limnol. Oceanogr. 5(2):171-174.

Marvin, K.T. 1965. Operation and maintenance of salt water laboratories. U.S. Fish Wild. Serv. Circ. No. 230:84-86.

Stumpf, R.P., Culver, M.E., Tester, P.A., Tomlinson, M., Kirkpatrick, G.J., Pederson, B.A., Truby, E., Ransibrahmanakul, V., Soracco, M., 2003. Monitoring Karenia brevis blooms in the Gulf of Mexico using satellite ocean color imagery and other data. Harmful Algae 2, 147–160.

Evans, G., Jones, L., 2001. Economic Impact of the, 2000 Red Tide on Galveston County, Texas: A Case Study. Texas Parks and Wildlife Department, pp. 9–35.

Buskey, E.J., Stewart, S., Peterson, J., Collumb, C., 1996. Current status and historical trends of brown tide and red tide phytoplankton blooms in the Corpus Christi Bay National Estuary program study area. In: Corpus Christi Bay National Estuary Program, CCBNEP-07. p. 85.

Buskey, E.J., Liu, H., Collumb, C., Bersano, J.G.F., 2001. The decline and recovery of a persistent Texas brown tide algal bloom in the Laguna Madre (Texas, USA). Estuaries 24, 337–346.

Jacobson, D.M., Andersen, R.A., 1994. The discovery of mixotrophy in photosynthetic species Dinophysis (Dinophyceae): light and electron microscopical observations of food vacuoles in Dinophysis acuminata, D. norvegica, and two heterotrophic dinophysoid dinoflagellates. Phycologia 33, 97–110.

Marshall, H., Egerton, T., Stem, T., Hicks, J., McNally, J., Kokocinski, M., 2002. Extended bloom concentrations of the toxic dinoflagellate Dinophysis acuminata in Virginia estuaries during late winter through early spring, 2002. In: Steidinger, K.A., Landsberg, J.H., Tomas, C.R., Vargo, G.A. (Eds.), Xth HAB International Conference, St. Pete Beach, FL, USA, pp. 364–366

Tango, P., Butler, W., Lacouture, R., Goshorn, D., Magnien, R., Michael, B., Hall, S., Browhawn, K., Wittman, R., Beatty, W., 2002. An Unprecedented Bloom of Dinophysis acuminata in Chesapeake Bay. In: Steidinger, K.A., Landsberg, J.H., Tomas, C.R., Vargo, G.A. (Eds.), Xth HAB International Conference, St. Pete Beach, FL, USA, pp. 358–360.

Smayda, T.J., 1990. Novel and nuisance phytoplankton blooms in the sea: evidence for a global epidemic. In: Grane´ li, E., Sundstro¨m, B., Edler, L., Anderson, D. (Eds.), Toxic Marine Phytoplankton. Elsevier Science, New York, pp. 29–41.

Cortes-Altamirano R, Agraz-Hernandez C (1994) Presencia de *Prorocentrum nlinjrnu~n* (Pav) Schiller estanques para cultivo de camaron. Cienc Mar UAS 13:ll-16

Novoveska, L., Smith, W. L. Dorsey, C. P., and MacIntyre, H.L. ???? Seasonal and interannual changes in dinoflagellates community composition in near-shore Alabama waters (powerpoint slides)

Raines, B. 2010 Gulf Coast Oyster Reefs May be Home to Emerging Infection Threat, www.al.com accessed 11/13/2012.

Review of HAB Observation Data Resources

NOAA Harmful Algal Bloom Operational Forecast System (HAB-OFS) add web address

Data Contributors:

1. Florida Fish and Wildlife Research Institute
   HAB Events
   Florida Red Tide Current Status
   Other Florida HAB Events
   HAB Archive
   Historical Database
   1. "Looking at the Florida Red Tide Historical Database" Electronic HAB database contains detailed description of historical data including dates, measured parameters, methods for sampling and analyses. *Karenia brevis* data expressed as "# samples containing ≥ 100,000 cells per liter were collected in response to bloom events occurring between 1954 and 1997 and include some offshore transects. Between 1998 and 2002, K. brevis data were collected during 1 to 3 week cruises and from permanent sampling stations. Nutrients, chlorophyll, and dissolved oxygen measurements were included. Data availability: