Gulf and Caribbean Research

Volume 33 | Issue 1

2022

Temporal and Spatial Occurrence of *Karenia brevis* Blooms in the Northcentral Gulf of Mexico

Jonathan Jackson
Mississippi State University, jonathan.jackson@noaa.gov

Yee Lau
Mississippi State University, yee.h.lau@noaa.gov

Paul Mickle
Mississippi State University, pmickle@ngi.msstate.edu

Just Cebrian
Mississippi State University, jcebrian@ngi.msstate.edu

Recommended Citation

Jackson, J., Y. Lau, P. Mickle and J. Cebrian. 2022. Temporal and Spatial Occurrence of *Karenia brevis* Blooms in the Northcentral Gulf of Mexico. Gulf and Caribbean Research 33 (1): SC1-SC6.
Retrieved from https://aquila.usm.edu/gcr/vol33/iss1/5
DOI: https://doi.org/10.18785/gcr.3301.05

GULF AND CARIBBEAN

RESEARCH

Volume 33
2022
ISSN: 2572-1410

Published by

THE UNIVERSITY OF
SOUTHERN MISSISSIPPI

GULF COAST RESEARCH LABORATORY
Ocean Springs, Mississippi

Gulf and Caribbean Research Vol 33, SC1-SC6, 2022
DOI: 10.18785/gcr.3301.5
Manuscript received December 14, 2021; accepted June 28, 2022

SHORT COMMUNICATION

TEMPORAL AND SPATIAL OCCURRENCE OF *KARENIA BREVIS* BLOOMS IN THE NORTHCENTRAL GULF OF MEXICO

Jonathan Jackson,[1,2,*] Yee Lau[1,2], Paul Mickle,[1,2] and Just Cebrian[1,2]
*[1]NOAA's National Centers for Environmental Information, 1021 Balch Blvd, Stennis Space Center, MS, 39529; [2]Northern Gulf Institute, Mississippi State University, 1021 Balch Blvd, Stennis Space Center, MS, 39529; *Corresponding author, email: jonathan.jackson@noaa.gov*

KEY WORDS: harmful algal blooms, algal temporal variability, algal spatial variability, red tide

INTRODUCTION

Harmful algal blooms are known to occur in the Gulf of Mexico (GOM) throughout recorded history (Brand and Compton 2007). Harmful algal blooms in the GOM are commonly caused by the dinoflagellate *Karenia brevis*, which, through the production of brevetoxin, can impact aquatic and terrestrial life (Pierce and Henry 2008, Landsberg et al. 2009). Brevetoxin can be transmitted by ingestion, either directly or through prey consumption, or inhalation of the aerosolized toxin. At population bloom densities, brevetoxin can reach toxic levels and cause detrimental impacts on wildlife and fisheries, which in turn may also cause human intoxication through consumption of contaminated seafood and large economic losses for the seafood industry (Anderson et al. 2000). Blooms of *K. brevis* can also represent a direct risk to human health through toxin inhalation (Flewing et al. 2005, Anderson et al. 2007).

Blooms of *K. brevis* are common along the coast of Texas and the southern Gulf coast of Florida, but less frequent along the Mississippi (MS), Alabama (AL), and Florida (FL) panhandle coasts (Tester and Steidinger 1997, Soto et al. 2018). More frequent *K. brevis* blooms on the southern Gulf coast of Florida may be due to higher nutrient inputs from the mainland (Brand and Compton 2007, Medina et al. 2022), whereas more frequent blooms on the Texas coast may be due to prolonged salinity increases (Tominack et al. 2020). Because of their lower occurrence, *K. brevis* blooms in the northcentral GOM have been less studied, and are less understood, than in other areas in the GOM. Yet, *K. brevis* blooms may still have a significant impact on the fisheries and economy of the northcentral GOM (Anderson et al. 2000).

Here we use public data sets on *K. brevis* blooms collected by the states of MS (Mississippi Department of Marine Resources), AL (Alabama Department of Public Health), and FL (Florida Fish and Wildlife Conservation Commission) to examine the temporal and spatial occurrence of these blooms in the northcentral GOM from the Louisiana (LA)–Mississippi state line to Apalachee Bay in FL over an ~15 year period (October 2005–July 2020). Based on previous reports that have shown *K. brevis* blooms originating in the northeast GOM may migrate westward (Carlson and Clarke 2009, McCulloch et al. 2013, Kamykowski et al. 2013, Waters et al. 2015, Soto et al. 2018), we expect to find evidence of such migration in our study given its spatial and temporal reach. The results contribute to the characterization and understanding of *K. brevis* blooms in this understudied region of the GOM.

MATERIALS AND METHODS

The National Oceanographic and Atmospheric Administration (NOAA) National Centers for Environmental Information's (NCEI) Harmful Algal BloomS Observing System (HABSOS; Hall et al. 2006, NOAA National Centers for Environmental Information 2021) database contains over 180,000 *K. brevis* cell counts obtained by GOM states. Data was generated using state sampling protocols (Alabama Department of Public Health 2016, Mississippi Department of Marine Resources Shellfish Bureau 2016, Florida Fish and Wildlife Conservation Commission 2019, 2020). Briefly, water samples were collected in the field with bottles, fixed with Lugol's Iodine, stored out of sunlight, and transported to the laboratory. In the laboratory, the bottles were gently shaken and a subsample pipetted out of the bottle into a counting chamber. The volume of the subsample varied between 0.1 and 200 ml. The subsample was then allowed to settle for 15–30 minutes. Depending on the concentration of cells in the subsample, the entire chamber or only a section of it was counted. The number of cells counted per subsample varied between 0 and 1,400. Cell density was calculated as cells per liter based on the volume of the subsample and the area of the chamber counted. Upon completion of sample processing, the states submit the data to HABSOS at NCEI, where the database is archived and updated annually. The data set is available at https://www.ncei.noaa.gov/archive/archive-management-system/OAS/bin/prd/jquery/download/120767.5.5.tar.gz (version 5.5).

We use the value of 5,000 cells of *K. brevis* per liter as the threshold to define a population bloom. The justification is that shellfish harvesting closures in GOM waters due to *K. brevis* are triggered at cell counts higher than this value (Interstate Shellfish Sanitation Conference and US Food and Drug Administration 2007). We realize this is a lower bloom threshold than used in many other studies, where bloom thresholds are set at values from which detrimental impacts on wildlife and humans start to occur. However, in an effort to be overly con-

servative and avert any potential risks to humans from consumption of contaminated seafood, the GOM states have set this low bloom threshold value to execute shellfish harvesting closures. Since one of the main intents of this work is to provide agencies and other stakeholders with relevant information to manage their oyster fisheries, we also use this same threshold throughout the paper.

We start our comparison in 2005 because this is the earliest year where *K. brevis* records are available for the 3 states included in this study. Records of *K. brevis* in MS prior to Hurricane Katrina were lost due to the devastation inflicted by the hurricane. The state resumed its monitoring program in 2005 after the hurricane and, throughout the study period, the program has remained as a reactive effort except during in—season shellfish harvesting openings. That is, during in—season shellfish harvesting months, samples for *K. brevis* cell counts were preemptively collected in the harvesting areas on a monthly basis. This monitoring frequency could be increased if warranted by reports and/or observations from citizen scientists or from other state agencies that *K. brevis* blooms as defined by cell densities > 5,000 cells may be forming. However, during off—season shellfish harvesting closures, the state triggered a monitoring effort at a number of stations along its coast only upon reports and/or observations from citizen scientists. These reports of potential *K. brevis* bloom formation came through the phytoplankton monitoring network and from other state agencies through their own environmental monitoring programs (e.g., through measurements of chlorophyll a content and/or total population cell densities). If bloom values >5,000 cells/L were not found, the effort continued for a period of time deemed safe to conclude that there were no blooms forming in coastal MS at that time. If bloom values were detected, the effort continued until bloom values were not detected anymore for a period of time deemed safe to conclude that the bloom had vanished.

The *K. brevis* state monitoring program in FL was started in 1964 and it has evolved over time. In 1995 the state adopted a recurring *K. brevis* monitoring program where cell counts were continuously recorded at a number of locations along its coast regardless of whether blooms levels were observed or not. In AL, the *K. brevis* state monitoring program started in 1996. It remained as a reactive effort similar to the one described for MS until 2015, at which time it became a recurring effort similar to the one described for FL.

Bloom values were compared among states using the Kruskal Wallis (KW) test, followed with post—hoc pairwise Dunn's tests if pertinent when the 3 states were compared, and using the Mann—Whitney (MW) test when 2 states were compared. We used non—parametric testing because both raw and transformed data failed to comply with the assumptions of ANOVA. Normality was evaluated with the Shapiro—Wilk test, and homogeneity of variance with the Levene's test. All tests were done using IBM SPSS Statistics version 27.0.0.0 and considered significant if $p < 0.05$.

Results

To best combine the data sets from the 3 states for an examination of the temporal and spatial variability of *K. brevis* blooms in the northcentral GOM, we graphed the number of samples with bloom values (i.e., >5000 cells per liter) obtained per day with each state's monitoring program across the duration of the study (Figure S1). Blooms were observed in 7 years throughout the ~15—year period covered in the study. Blooms were irregularly distributed in time, with blooms occurring in consecutive years or being spaced out as much as 7 years. In addition, blooms could be ephemeral and restricted to one state,

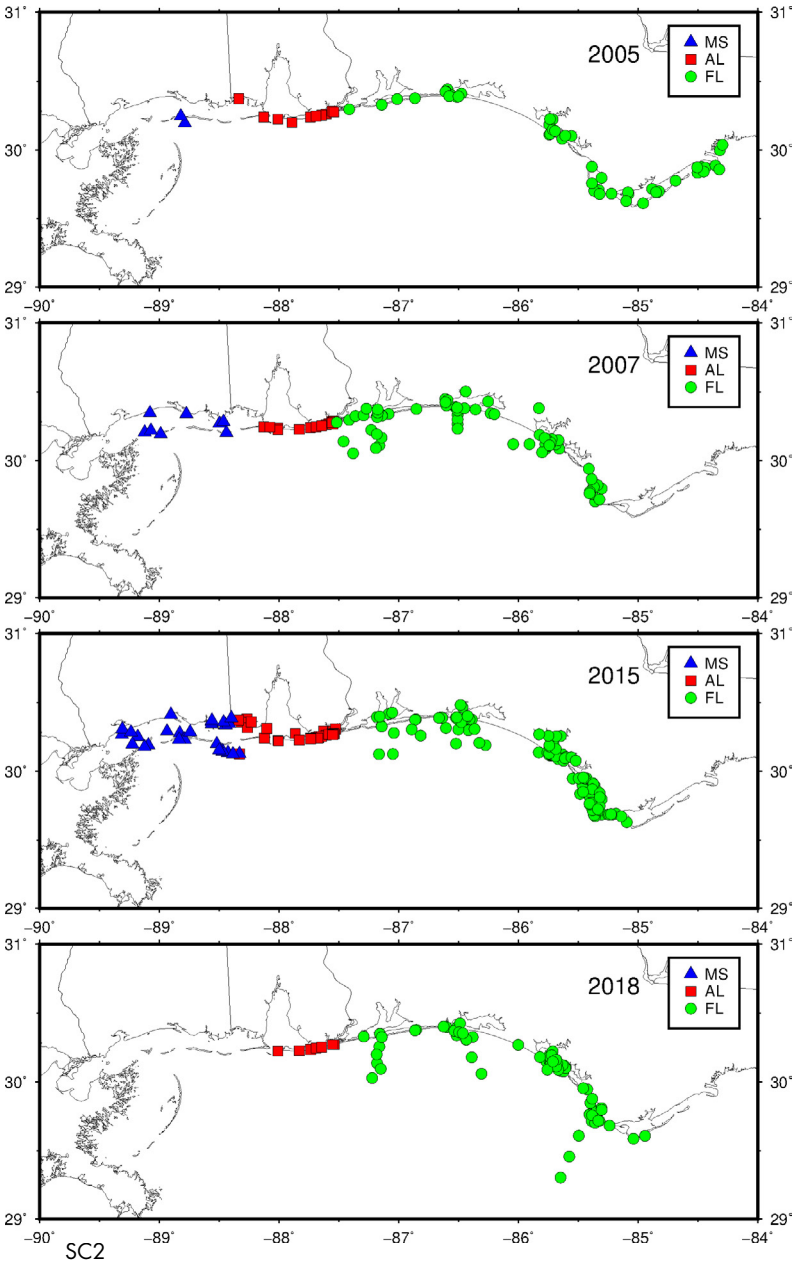

FIGURE 1. *Location of profusive Karenia brevis blooms (defined as >5,000 cells/L) in 2005, 2007, 2015 and 2018 along the northcentral Gulf of Mexico. Solid blue triangles correspond to Mississippi (MS), solid red squares to Alabama (AL), and solid green circles to Florida (FL).*

or profusive and extended through 2 or 3 states (Figure 1). Chronologically from the start of the study period we found profusive blooms in FL and AL in 2005, and in all 3 states in 2007. A bloom–less stretch of 7 years was followed by blooms in 3 consecutive years, i.e., an ephemeral bloom in FL in 2014, profusive blooms in all 3 states in 2015, and an ephemeral bloom in AL in 2016. Finally profusive blooms were seen in FL and AL in 2018, and ephemeral blooms in FL in 2020.

Regardless of the year of occurrence and whether blooms were restricted to one state or extended through 2 or 3 states, blooms occurred in fall/early winter (Figure S1). To further portray the marked season–specific occurrence of the blooms, we computed the number of years in the study period where blooms occurred in a given month for each state (Figure 2). Blooms occurred from October to December in MS and AL, and from September to March in FL.

Bloom cell density ranged from 5,300–14,000,000 cells/L across the 3 states and all years covered in the study. Differences in the magnitude of bloom values among states depended

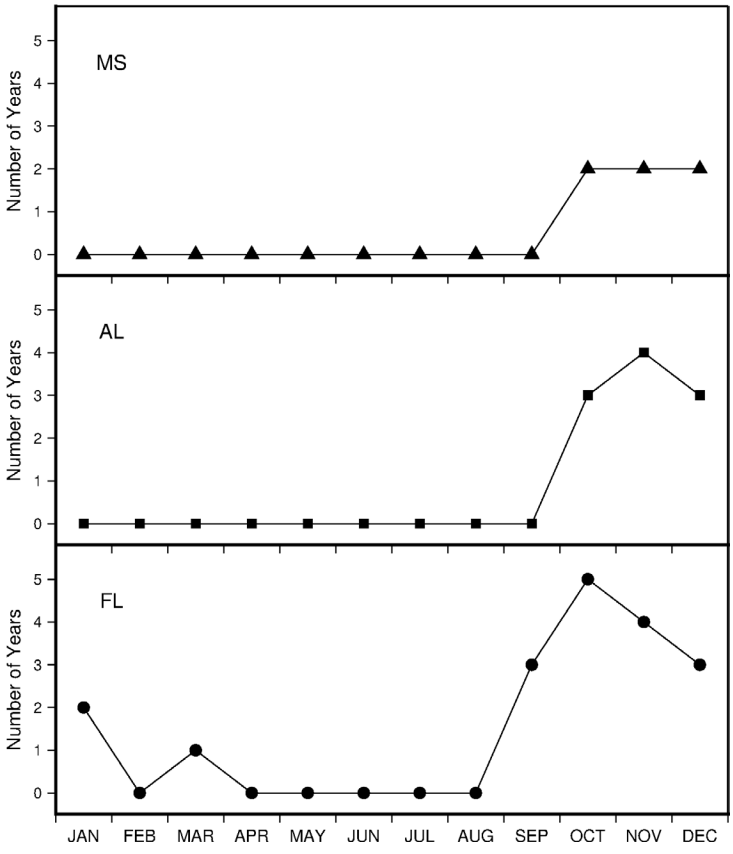

Figure 2. *Number of years in the study period where Karenia brevis blooms occurred in a given month for each state. Solid black triangles correspond to Mississippi (MS), solid black squares to Alabama (AL), and solid black circles to Florida (FL).*

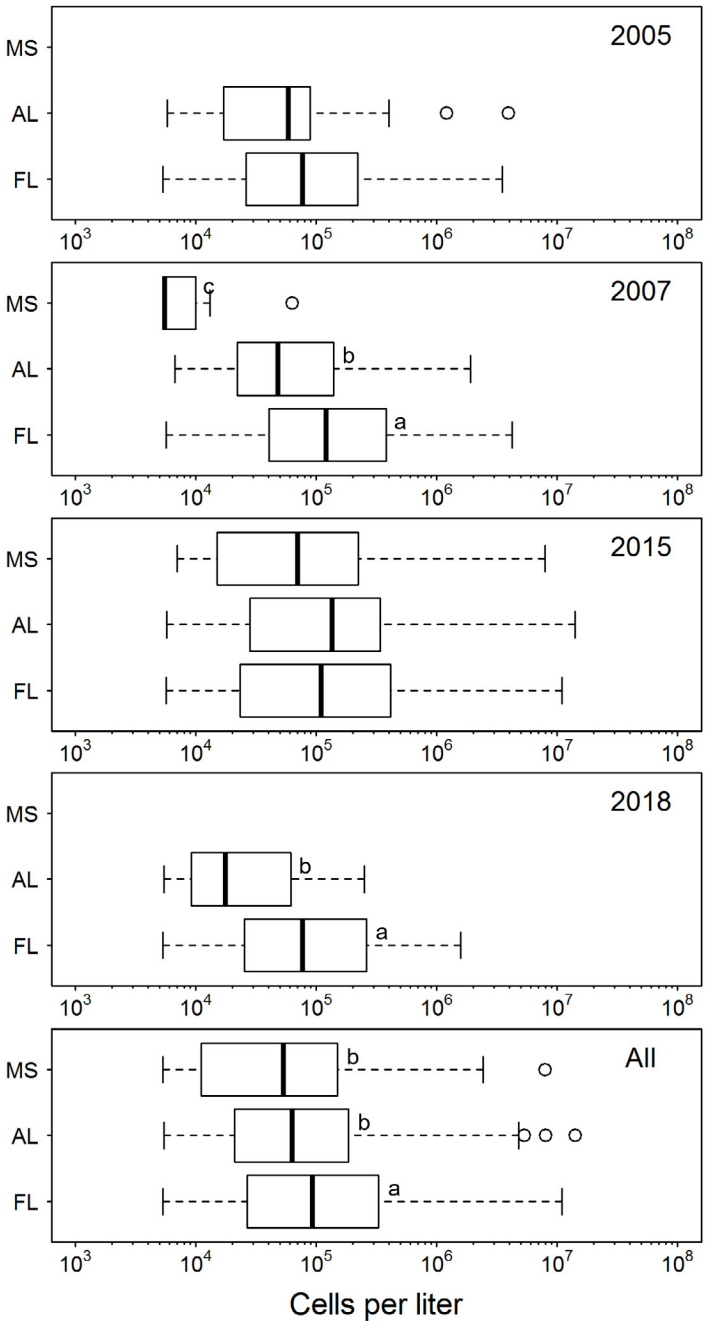

Figure 3. *Box plots comparing Karenia brevis bloom values (i.e., cells/L) among northcentral Gulf of Mexico states for profusive blooms in 2005, 2007, 2015, 2018, and the entire data set (i.e., also including ephemeral blooms). Only 2 bloom values were registered in MS in 2005 and, thus, those values have been removed from the comparison for that year. Each box with a median bar starts in the first quartile (25%) and ends in the third quartile (75%) of the data. Open circles represent outliers. Vertical lines on either side of the box represent the minimum and maximum data values (without counting outliers). Lower case letters indicate significant differences among states.*

on the year considered (Figure 3). We did not find significant differences among states in 2005 ($MW_{42,100}$ = 1.618, p = 0.106) and 2015 ($KW_{47,74,234}$ = 1.75, p = 0.417). In 2007 we found higher values in FL than in AL, which in turn were higher than in MS ($KW_{9,75,103}$ = 30.248, p < 0.001, Dunn's post–hoc tests, MS vs. AL, p = 0.001, MS vs. FL, p <0.001, AL vs. FL,

p = 0.001). In 2018 we found higher values in FL than in AL ($MW_{12,129}$ = 2.693, p = 0.007). For the overall data set we found higher values in FL than in AL and MS, with AL and MS not differing from each other. ($KW_{56,203,566}$ = 13.217, p = 0.001, Dunn's post–hoc tests, MS vs. AL, p = 0.377, MS vs. FL, p = 0.008, AL vs. FL, p = 0.004).

Discussion

Our results help characterize and understand *K. brevis* blooms in the northcentral GOM. In our study area, which extended from the LA–MS state line to Apalachee Bay in FL, blooms occurred irregularly over the period of October 2005 through July 2020. Regardless of whether they were ephemeral or profusive blooms, they occurred in fall/early winter. Similarly, previous studies have shown that *K. brevis* blooms occurred irregularly over the years in the western GOM (i.e., Texas and northeastern Mexico; Magaña et al. 2003, Tominack et al. 2020), and that *K. brevis* blooms tended to occur in fall/winter in southwest Florida (Brand and Compton 2007, Weisburg et al. 2019).

The profusive blooms in 2007, 2015 and 2018 first occurred in FL. We cannot determine if this was also the case for 2005 since our study period started after blooms had first appeared in that year. In 2007, blooms were first reported on 24 September in FL, and on 16 October and 19 November in AL and MS, respectively. In 2015, blooms were first reported on 7 September in FL, and on 13 November and 12 October in AL and MS, respectively. In 2018, blooms were first reported on 4 September in FL and on 8 November in AL. This is consistent with westward migration events of *K. brevis* blooms from areas in the northeast GOM that have been reported in the past, where blooms that originate in central or northern FL are transported westward (Carlson and Clarke 2009, McCulloch et al. 2013, Kamykowski et al. 2013, Waters et al. 2015, Soto et al. 2018). Our results suggest that these migrating blooms may propagate through AL, such as the blooms in 2005 and 2018, and MS, such as the blooms in 2007 and 2015, and as the blooms migrate they can either maintain similar cell concentrations (i.e., 2005 and 2015), or reduce their cell concentrations (i.e., 2007 and 2018). The ephemeral blooms in FL in 2014 and 2020 could represent outskirts of migrating blooms that did not propagate farther into AL and MS or, alternatively, they could be independent of bloom migration events such as the seemingly ephemeral bloom in AL in 2016.

Sampling was recurring in FL regardless of the cell density values throughout the duration of the study. In MS it was reactive, except during in–season oyster harvesting openings, throughout the duration of the study, whereas in AL it was similar to MS until 2015 and then similar to FL through the remainder of the study. These differences in sampling regime among states should not affect the suggestion that *K. brevis* blooms formed in central or northwestern FL and may migrate westward into AL and MS and, as they do so, cell concentrations may be reduced. Indeed, reactive sampling could have resulted in delayed detection of bloom values in AL and MS, but such delay is highly unlikely to be as long as the time elapsed between the date of first bloom detection in FL and the date of first bloom detection in AL or MS. Similarly, by missing incipient bloom values, we may be excluding from the analyses newly formed blooms with cell densities lower than mature blooms in AL and MS, but this would not call into question the significantly lower bloom cell densities in AL and MS than in FL in 2007 and 2018. Additionally, missing incipient blooms should not affect the lack of differences in bloom cell densities among states in 2015, and, if anything, it may result in significantly lower bloom cell densities in AL than in FL in 2005.

Unfortunately, the data set with bloom cell density values does not have sufficient concomitant measurements of environmental values (e.g., riverine flow, turbidity, temperature, salinity, depth, and nutrients) to provide a more robust analysis. These additional data could provide unequivocal evidence that *K. brevis* blooms may indeed migrate from their origin in the northeast GOM into AL and MS, as well as what mechanisms may be responsible for bloom dilution (i.e., decrease in cell density). Thus, more work is needed to robustly test our hypothesis regarding the possible westward migration of *K. brevis* blooms along the northcentral GOM into AL and MS, and possible reduction in cell density as the blooms migrate. Similarly, the data set does not allow for mechanistic analysis of what environmental conditions may cause the blooms. While the data set does allow us to report the blooms occur in fall/late winter in irregular years, it does not allow us to examine reasons for why this is so.

In summary, our results provide a previously unreported analysis of the spatial and temporal occurrence of *K. brevis* blooms in the northcentral GOM, and it suggests blooms originated in the northeast GOM may migrate into AL and MS. Additionally, our data point to ephemeral blooms independent of possible migration events. Nevertheless, more studies are needed for a deeper characterization and understanding of the dynamics of *K. brevis* bloom formation, dispersion, and fate in the northcentral and other regions of the GOM. The data and findings provided in this study may prove useful in informing and conducting future studies. In this regard, we encourage coordination and collaboration among federal and state agencies, academic units, non–governmental organizations, and other stakeholders regarding *K. brevis* monitoring programs. In particular, complementing the *K. brevis* cell density data sets compiled by the states with measurements of additional targeted environmental variables through such partnerships would be very beneficial for our understanding and management of *K. brevis* blooms. For instance, the state of Mississippi has recently shifted from a reactive to a recurring monitoring program similar to those in AL and FL, and this may open new opportunities for coordination and collaboration in the region.

Acknowledgements

We thank the Alabama Department of Public Health, Mississippi Department of Marine Resources, and the Florida Fish and Wildlife Conservation Commission for assistance with data documentation. We also thank J. Webster from the NOAA's National Centers for Environmental Information for reading and providing useful comments on a prior version of the manuscript. We are grateful to C. Hill from the Mississippi State University High Performance Computer Center for providing technical assistance throughout this effort. We are indebted to the Editors and 2 anonymous reviewers for constructive feedback. Funding for this study was provided by the NOAA NCEI Oceanographic and Geophysical Science and Services Division.

Literature Cited

Alabama Department of Public Health. 2016. Alabama HAB Response Plan. Version 01.16.1. Technical Report. Alabama Department of Public Health, Montgomery, AL, USA. 29 p.

Anderson, D., P. Hoagland, Y. Kaoru, and A.W. White. 2000. Estimated Annual Economic Impacts from Harmful Algal Blooms (HABs) in the United States. WHOI–2000–11. Technical Report. Woods Hole Oceanographic Institution, Woods Hole, MA, USA. 96 p.

Anderson, D., D. Lewis, and K. Hilbert. 2007. Integrating Salinity Measurements from Aquarius into the Harmful Algal Blooms Observing System. NASA Solutions Network Formulation Report. National Aeronautics and Space Administration, Stennis Space Center, MS, USA. 5 p. https://ntrs.nasa.gov/api/citations/20100003142/downloads/20100003142.pdf

Brand, L. and A. Compton. 2007. Long–term increase in *Karenia brevis* abundance along the southwest Florida Coast. Harmful Algae 6:232–252. https://doi.org/10.1016/j.hal.2006.08.005

Carlson, D.F. and A.J. Clarke. 2009 Seasonal along–isobath geostrophic flows on the west Florida shelf with application to *Karenia brevis* red tide blooms in Florida's Big Bend. Continental Shelf Research 29:445–455. https://doi.org/10.1016/j.csr.2008.11.003

Flewing, L.J., J.P. Naar, J.P. Abbott, D.G. Baden, N.B Barros, G.D. Bossart, M.D. Bottein, D.G. Hammond, E.M. Haubold, C.A. Heil, M.S. Henry, H.M. Jacocks, T.A. Leighfield, R.H. Pierce, T.D. Pitchford, S.A. Rommel, P.S. Scott, K.A. Steidinger, E.W. Truby, F.M. Van Dolah, and J.H. Landsberg. 2005. Red tides and marine mammal mortalities: Unexpected brevetoxin vectors may account for deaths long after or remote from an algal bloom. Nature 435:755–756. https://doi.org/10.1038/nature435755a.

Florida Fish and Wildlife Conservation Commission. 2019. Collection of Water Column Samples for Microscopic Analysis of Microalgae. Technical Report. Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, St. Petersburg, FL, USA. 1 p.

Florida Fish and Wildlife Conservation Commission. 2020. Microscopic Analysis of Microalgae – KPP Counting (*Karenia brevis, Pseudo–nitzschia* spp., and *Pyrodiniuum bahamense*). Technical Report. Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, St. Petersburg, FL, USA. 4 p.

Hall, C., T. McPherson, B. Spiering, R. Brown, L. Estep, B. Lunde, D. Guest, A. Navard, M. Pagnutti, R. Ryan, and J.P. Spruce. 2006. Verification and Validation of NASA–Supported Enhancements to the Near Real Time Harmful Algal Blooms Observing System (HABSOS). Technical Report. National Aeronautics and Space Administration, Stennis Space Center, MS, USA. 50 p. https://ntrs.nasa.gov/api/citations/20060050036/downloads/20060050036.pdf

Interstate Shellfish Sanitation Conference and US Food and Drug Administration. 2007. Guide for the Control of Molluscan Shellfish 2007 Revision. Technical Report. Interstate Shellfish Sanitation Conference, Columbia, SC, USA. 549 p. https://www.fda.gov/media/117080/download.

Kamykowski, D., K. Grabowski Pridgen, J.M. Morrison, A.A. McCulloch, E.S. Nyadjro, C.A. Thomas, and G.A. Sinclair. 2013. Cold front induced changes on the Florida panhandle shelf during October 2008. Continental Shelf Research 54:52–66. https://doi.org/10.1016/j.csr.2012.12.006

Landsberg, J.H., L.J. Flewelling, and J. Naar. 2009. *Karenia brevis* red tides, brevetoxins in the food web, and impacts on natural resources: Decadal advancements. Harmful Algae 8:598–607. https:// doi.org/10.1016/j.hal.2008.11.010

Magaña, H.A., C. Contreras, and T.A. Villareal. 2003. A historical assessment of *Karenia brevis* in the western Gulf of Mexico. Harmful Algae 2:163–171. https://doi.org/10.1016/S1568–9883(03)00026–X

McCulloch, A.A., D. Kamykowski, J.M. Morrison, C.J. Thomas, and K. Pridgen. 2013. A physical and biological context for *Karenia brevis* seed populations on the northwest Florida shelf during July 2009. Continental Shelf Research 63:94–111. https://doi.org/10.1016/j.csr.2013.05.001

Medina, M., D. Kaplan, E.C. Milbrandt, D. Tomasko, R. Huffaker, and C. Angelini. 2022. Nitrogen–enriched discharges from a highly managed watershed intensify red tide (*Karenia brevis*) blooms in southwest Florida. Science of the Total Environment 827:154149. https://doi.org/10.1016/j.scitotenv.2022.154149

Mississippi Department of Marine Resources Shellfish Bureau. 2016. Marine Biotoxin Contingency Plan, Revised 2016. Mississippi Department of Marine Resources, Shellfish Bureau, Biloxi, MS, USA. 6 p.

NOAA National Centers for Environmental Information. 2021. Harmful Algal Blooms Observing System (HABSOS). Stennis Space Center, MS, USA. https://habsos.noaa.gov (viewed on 8/1/2022)

Pierce, R.H. and M.S. Henry. 2008. Harmful algal toxins of the Florida red tide (*Karenia brevis*): Natural chemical stressors in South Florida coastal ecosystems. Ecotoxicology 17:623–631. https://doi.org/10.1007/s10646–008–0241–x

Soto, I.M., M.K. Cambuzoglu, A.D. Boyette, S.D. Howden, A.M. Shiller, B. Dzwonkowski, L. Hode, P.J. Fitzpatrick, R.A. Arnone, P.F. Mickle, and K. Cressman. 2018. Advection of *Karenia brevis* blooms from the Florida panhandle towards Mississippi coastal waters. Harmful Algae 72:46–64. https://doi.org/10.1016/j.hal.2017.12.008

Tester, P.A. and K.A. Steidinger. 1997. *Gymnodinium breve* red tide blooms: Initiation, transport, and consequences of surface circulation. Limnology and Oceanography 42:1039–1051. https://doi.org/10.4319/lo.1997.42.5_part_2.1039

Tominack, S., K. Coffey, D. Yoskowitz, G. Sutton, and M. Wetz. 2020. An assessment of trends in the frequency and duration of *Karenia brevis* red tide blooms on the south Texas coast (western Gulf of Mexico). PLoS ONE 15:0239309. https://doi.org/10.1371/journal.pone.0239309

Waters, L.G., T.G. Wolcott, D. Kamykowski, and G. Sinclair. 2015. Deep–water seed populations for red tide blooms in the Gulf of Mexico. Marine Ecology Progress Series 129:1–16. https://doi.org/10.3354/meps11272

Weisburg, R.H., L. Yonggang, C. Lembke, C. Hu, K. Hubbard, and M. Garrett. 2019. The coastal ocean circulation influence on the 2018 west Florida shelf *K. brevis* red tide bloom. Journal of Geophysical Research: Oceans 124:2501–2512. https://doi.org/10.1029/2018JC014887