NOAA Technical Report NOS CO-OPS 066

Assessment of the Eastern Gulf of Mexico Harmful Algal Bloom Operational Forecast System (GOMX HAB-OFS):

A Comparative Analysis of Forecast Skill and Utilization from October 1, 2004 to April 30, 2008

July 2013

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U.S. DEPARTMENT OF COMMERCE
National Ocean Service
Center for Operational Oceanographic Products and Services

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A Comparative Analysis of Forecast Skill and Utilization from October 1, 2004 to April 30, 2008

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Table of Contents

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

1.1 Background

Blooms of a toxic dinoflagellate, *Karenia brevis*, commonly referred to as "red tide", occur nearly every year on the Gulf coast of Florida, typically between August and December, and are reportedly the most common harmful algal bloom (HAB) occurring in the eastern Gulf of Mexico (Stumpf, et al., 2003). Numerous fish kills and various marine bird and mammal deaths have been linked to *K. brevis* blooms, and "very low" levels (≥5,000μg/L) of *K. brevis* prompt the closure of shellfish beds to prevent Neurotoxic Shellfish Poisoning (NSP) in humans (Tomlinson, et al. 2004). Under certain wind conditions and wave action, the cells of *K. brevis* can lyse releasing toxins into the water, where the toxins are incorporated into the marine aerosol. Inhaling the toxin causes respiratory distress, especially for people with chronic respiratory illnesses such as asthma (Kirkpatrick, et al., 2004). Winds can carry the toxic aerosols from nearshore surface blooms to distances at least 4.2 km from the beach, prompting necessary advisories at afflicted beaches (Kirkpatrick, et al., 2010).

In order to assist coastal managers in mitigating damages due to HABs, a new ecological forecast system for the Gulf of Mexico was developed through a multi-office NOAA effort. In October 2004, this ecological forecast system was transitioned from research to operational status along the coast of Florida, creating the Gulf of Mexico HAB Operational Forecast System (GOMX HAB-OFS). In 2010, the coast of Texas was also transitioned to operations.

Operational GOMX HAB-OFS bulletins are produced twice weekly during active bloom events (once weekly during inactive bloom status) and provide information concerning the possible presence or confirmed identification of new blooms, in addition to monitoring existing blooms and providing forecasts of spatial bloom extents, movement, and intensification conditions (see Appendix I, II, and III for example bulletins). The bulletins also report daily coastal respiratory irritation forecasts that are publicly available via the Internet at http://tidesandcurrents.noaa.gov/hab.

As a result of the forecasts in the bulletins, advance cautionary notice can be issued to protect beachgoers from respiratory illness; necessary mitigation actions, such as closing shellfish beds, can be initiated before a bloom becomes a coastal hazard; and mass marine animal casualties can be minimized through advance response. The bulletins identify potential areas of harmful algal blooms using satellite imagery. By doing so, the bulletins provide advance notice to appropriate state, county and local agricultural and health service departments to initiate sampling programs and confirm the identity of any anomalously high chlorophyll features present in the imagery. If a feature is found to contain *K. brevis* at a concentration level capable of causing human NSP when ingested, shellfish harvesting is prohibited in the region of the bloom and shellfish bed closures are listed on regional hotlines and via the Internet at http://www.floridaaquaculture.com and http://www.dshs.state.tx.us/seafood/redtide.shtm. The bulletins also indicate potential geographic extents of presently confirmed blooms to allow for more effective field sampling. This, in turn, assists in confirming the extent and severity of a toxic bloom, aids technological development of forecasting methods, and enhances scientific knowledge of the HAB species, *K. brevis*.

1.2 Objective

This report provides an evaluation of the HAB-OFS products issued for Florida during the bloom years from May 1, 2005 to April 30, 2008, with a re-analysis of previously published data for October 1, 2004 to April 30, 2005 to allow comparison across all years (Fisher, et al., 2006). A bloom year (BY) refers to the time period from May 1, YYYY to April 30, YYYY, where BY2005-2006 spans the period from May 1, 2005 to April 30, 2006 and so on. This time period was selected to capture the typical initiation and termination period of *K. brevis* blooms in the Gulf of Mexico enabling interannual comparisons. The analysis includes an assessment of bulletin utilization, early warning capability and forecast quality (i.e. accuracy, reliability and skill). The results of this assessment will be used to guide enhancements to the operational forecast system with the goals of improving forecast quality through increased scientific understanding and the refinement of forecast models. Some of the recommendations may also be applicable to the HAB-OFS in the Western Gulf of Mexico (Texas), which was transitioned to operations in 2010.

2. METHODS

2.1 Operations

On October 1, 2004, the Center for Operational Oceanographic Products and Services (CO-OPS) transitioned a new ecological forecast system for harmful algal blooms (HABs) in the Gulf of Mexico, known as the Gulf of Mexico Harmful Algal Bloom Operational Forecast System (GOMX HAB-OFS), from research to operational status. This was part of a NOAA collaborative effort with the National Centers for Coastal Ocean Science (NCCOS-science and research), the Coastal Services Center (CSC-technology development and public outreach), and the National Environmental Satellite, Data and Information Service (NESDIS/CoastWatch Program-satellite ocean color imagery). Under the system's previous research status, bulletins were issued only as employee resources allowed and bloom occurrence dictated. The operational status enabled regular dissemination of forecast products to accommodate user requirements. In 2008, all remaining technological and outreach activities formerly conducted by CSC were transferred to CO-OPS. Operations discussed in this report are relevant to the years from BY2005-2008 and may vary from the current operational methods and procedures used as of the date of publication. However, modifications to the HAB-OFS since 2008 have been minor so the conclusions of this assessment report remain relevant.

The GOMX HAB-OFS employs a combination of automated processing and manual analyses using a web-based interface. During the BY2005-2008 assessment period, Sea-viewing Wide Field-of-view Sensor (SeaWiFS) satellite ocean color imagery (provided by NOAA's CoastWatch Program) was processed using a chlorophyll algorithm. Daily chlorophyll images were analyzed in conjunction with chlorophyll anomaly imagery highlighting regions of above-average elevated chlorophyll (as determined through a 60-day running mean) to determine the potential presence or existing boundaries of harmful algal blooms containing the species *Karenia brevis* (Stumpf, et al., 2003). Moderate Resolution Imaging Spectroradiometer (MODIS) ocean color imagery was processed using an identical procedure and served as a backup imagery source when SeaWiFS imagery was unavailable due to technical issues. The forecast system also incorporated analyses of the following data for bloom confirmation: hindcast and forecast winds available through the National Data Buoy Center (NDBC), the North American Mesoscale (NAM) model, and the National Weather Service (NWS); a wind transport model developed by NCCOS; and *in situ K. brevis* cell count data from several organizations including the Florida Fish and Wildlife Research Institute (FWRI) and Mote Marine Laboratory (MML). In 2006, daily respiratory impacts, dead fish, and discolored water reports became available at many beaches in southwest Florida through the establishment of Mote Marine Laboratory's lifeguard reporting system and were incorporated in subsequent bloom analyses and assessments. These resources, coupled with scientific expertise, were synthesized to analyze data and forecast potential for *K. brevis* bloom transport, spatial extent, intensification, and associated respiratory impacts. To produce these forecasts, the HAB-OFS analysts rely mainly upon mental integration methods, applying established scientific rules and heuristic and numerical models that NCCOS scientists developed and tested (Stumpf, et al., 2003; Tomlinson, et al., 2004; Stumpf, Litaker, Lanerolle, & Tester, 2008). To ensure quality control, each bulletin was written by a primary analyst and reviewed by a second analyst. Additional information about the HAB-OFS bulletin contributors and the data they provide is available in Appendix IV, the HAB Bulletin Guide at http://tidesandcurrents.noaa.gov/hab/habfs_bulletin_guide.pdf and at http://tidesandcurrents.noaa.gov/hab/contributors.html.

Operational HAB forecasts were communicated through two main products that served as decision support tools.

1) The **HAB bulletin** provided a detailed scientific analysis of satellite ocean color imagery, water samples and health reports, meteorological and oceanographic data, and included all relevant forecasts. The bulletin was disseminated via email to registered coastal resource managers, academics, and public health officials with an email subject line indicating the relevant geographic region (see Figure 2 for map of regions and Figure 3 for the geographic distribution of subscribers). The subject line also indicated the priority level of the bulletin for consideration by managers: low, medium, or high (see Table 1).
2) The **public conditions reports** provided information about the presence or absence of a HAB of *K. brevis* including a general description of the geographic region affected, forecasts of associated respiratory impacts, and any recent observations of respiratory impacts, dead fish or discolored water. The conditions reports were available on the HAB-OFS website at http://tidesandcurrents.noaa.gov/hab immediately following bulletin dissemination. These reports were also made available through the Aquatic Toxins Hotline maintained by the Florida Department of Health.

Both products were routinely updated for the southwest Florida region twice weekly during HAB events and once weekly during inactive periods. Products for northwest and east Florida were only updated when HAB events occurred in those regions (see Figure 2 for the map of regions). The dissemination of unscheduled supplemental bulletins or conditions updates was also necessary when new data was received that indicated an increase in bloom extent, intensity, or the level of associated respiratory impacts forecasted.

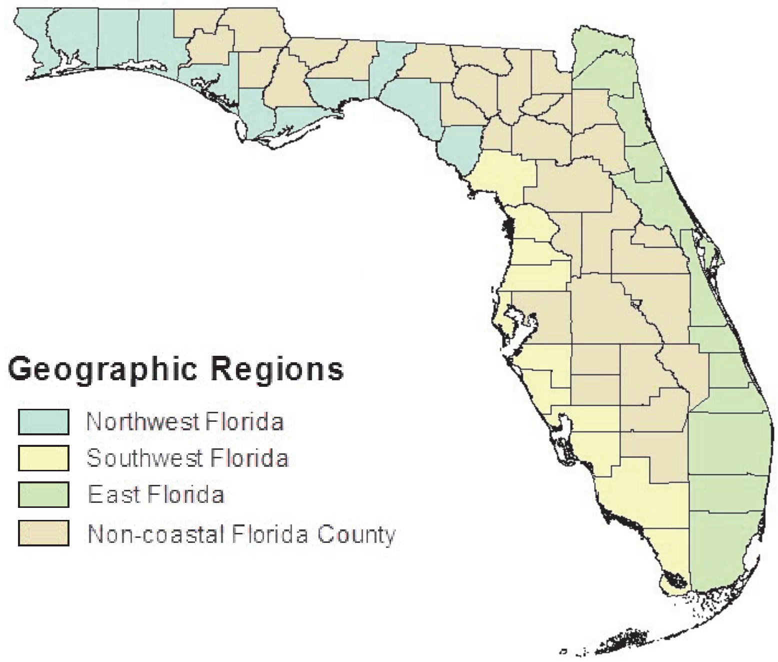


Figure 2. Map of Florida highlighting the three geographic regions for which HAB-OFS bulletins are disseminated. The northwest region spans the coastal counties from Escambia through Dixie, the southwest region spans from Levy through Monroe (including the Florida Keys), and the eastern region spans from Nassau through Miami-Dade.

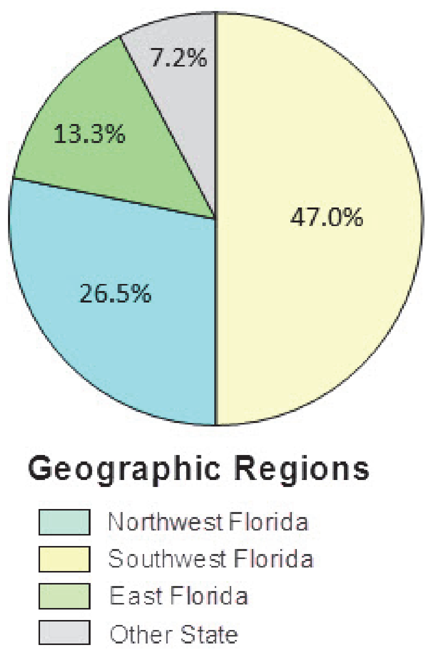


Figure 3. Distribution of Florida bulletin subscribers among the three geographic regions for which HAB bulletins were disseminated from March 2002 to May 2008. Although the HAB-OFS did not issue operational bulletins until October 2004, users subscribed to the demonstration bulletins disseminated by NCCOS as early as March 2002.

Operational status continued to deliver on-call analyst response to public inquiries and bulletin subscription requests. The GOMX HAB-OFS utilized one central telephone number and email distribution address for responding to information requests from the general public and bulletin subscribers. Frequently inquiries pertained to the present and future bloom conditions or potential impacts at specific locations and times to enable event planning. Inquiries received by the HAB-OFS also sought general background information regarding *K. brevis* blooms and their occurrence, and requests to be added to the bulletin distribution list. Occasionally, the HAB-OFS also received inquiries from members of the public who were experiencing symptoms that might be associated with exposure to *K. brevis*.

The first operational year of the HAB-OFS (BY2004-2005) proved successful as evidenced by the high percentage of weekly bulletin utilization (90%) and its demonstrated early warning capability with two harmful and two non-harmful algal blooms accurately identified and 90% of the total forecast component forecasts confirmed correct (Fisher, et al., 2006). Maintaining and improving upon these successes required sustained operational status during the 2005 to 2008 bloom years, including the ongoing support and training of five to six analysts, continued adherence to standard operating procedures, maintenance of consistent analytical methods, and the perpetual refinement of tools and methods made possible by a continuing research to operations collaboration.

Table 1. Priority levels assigned to bulletins indicating the corresponding level of action or response that resource managers might deem necessary based on the status of a harmful algal bloom of *Karenia brevis*.

PRIORITY LEVEL	DESCRIPTION
Low	• Inactive bloom • Resource managers may decide that no new action is necessary
Medium	• Active bloom, but no change in bloom conditions since previous bulletin • Resource managers may or may not decide that new action is necessary
High	• Active bloom, with recent changes in bloom conditions. Examples: o New bloom identified o Change in bloom extent (i.e. new or increase in coastal area impacted) o Bloom intensification (i.e. higher bloom concentrations detected) o Increases in the levels of forecasted respiratory impact levels • Resource managers may decide that immediate action is necessary

2.2 Forecast Component Definitions

The HAB-OFS provides predictions for four different bloom forecast components: transport, spatial extent, intensification, and potential level of respiratory impacts (see Table 2). Transport is defined as the direction a bloom is likely to migrate. Change in bloom extent is forecasted when a bloom is expected to expand beyond its current boundary and into a new county. Extent is typically defined by whole or half county with an approximate 20 mile uncertainty. Intensification is the expected change (increase or decrease) in alongshore algal cell concentrations due to the potential for upwelling or downwelling conditions (Stumpf, Litaker, Lanerolle, & Tester, 2008). Although impacts from a bloom include adverse coastal conditions like the presence of dead fish and discolored water, the only impact associated with *K. brevis* blooms that is currently forecasted by the HAB-OFS is the potential for coastal respiratory irritation. Respiratory irritation impacts are forecasted in levels ranging from “very low” to “high” (in addition to “none” or “not expected”) based on wind direction and speed, as well as the nearby algal cell concentrations identified in water samples (see Table 3 for cell concentration categories). The “very low” respiratory impact level affects only people with severe or chronic respiratory conditions. Similarly, the “low” respiratory impact level affects people who are otherwise healthy, but are more sensitive to *K. brevis* aerosols. The “moderate” respiratory impact level indicates that the general public may potentially notice mild respiratory symptoms, while the “high” respiratory impact level is likely to affect most of the general public with adverse respiratory symptoms (NOAA, 2013). Refer to Table 4 for more information about the respiratory impact levels. Due to limited spatial and temporal observations, these forecasts are made for each half-county and only for coastal regions because respiratory irritation impact levels are not well understood in open water regions (Stumpf, et al., 2009).

Environmental variations in geographic regions influence the forecasts that can be made and the analytical methods employed to develop the forecasts. For example, during initial bloom development, bloom intensification conditions in eastern Florida appear to be caused by downwelling winds rather than upwelling winds, as is the case in other Florida regions (Stumpf, Litaker, Lanerolle, & Tester, 2008). An example of the variation in regional forecast capabilities is the inability to forecast bloom intensification in the Florida Keys region, as it is done in mainland areas of southwest Florida and northwest Florida.

Table 2. Definitions of forecast components.

FORECAST COMPONENT	DEFINITION	CATEGORIES	FORECAST BASED ON	EXAMPLE STATEMENT
Transport	Direction bloom is likely to migrate in relation to the coast	• North • South • East • West • No Change	• Forecasted winds • Local ocean currents • Coriolis effect • Ekman transport	*"Southward transport of the bloom is expected through Friday."*
Extent	Expansion of bloom/ identified feature into a new county	• Increase • Decrease • No Change	• Forecasted winds • Local ocean currents • Coriolis effect • Ekman transport	*"Bloom extent may expand to the south as far as Manatee County through Tuesday."*
Intensification	Expected change in bloom concentration	• Increase • Decrease • No Change	• Forecasted winds • Upwelling/ downwelling favorable conditions • *K. brevis* cell concentrations over the past 10 days	*"Intensification of the bloom is expected over the weekend."*
Respiratory Impacts	Potential level of respiratory irritation caused by the bloom (see Table 4)	• Very low • Low • Moderate • High • None	• Forecasted wind speed and direction • Highest *K. brevis* concentration within most recent 10 days • Bloom proximity to shore • Validated reports of respiratory irritation at the coast associated with a bloom	*"Moderate impacts are possible in southern Pinellas County through Wednesday."*

Table 3. The categories assigned to *Karenia brevis* cell concentrations identified from water samples by state, county and local organizations in Florida.

CATEGORY	CELL CONCENTRATION (CELLS/L)
Not Present	0
Present (or Background)	1000 cells or less
Very Low a	>1000 to <5000
Very Low b	5000 to 10,000
Low a	>10,000 to <50,000
Low b	50,000 to 100,000
Medium	>100,000 to 1,000,000
High	>1,000,000

Table 4. The level of respiratory impacts forecasted and the corresponding population potentially affected.

	AFFECTED POPULATION			
RESPIRATORY IMPACT LEVEL	**None**	**Chronic Respiratory Conditions**	**Sensitive**	**General Public**
None	X			
Very Low		X		
Low		X	X	
Moderate		X	X	X
High		X	X	X

2.3 Skill Assessment

2.3.1 Overview of Procedure

Bulletin forecasts were recorded and evaluated by the primary analyst each week. Bulletin utilization and the forecast quality (i.e. accuracy, reliability and skill) were assessed using the observational evidence available following the dissemination of each bulletin. All bulletin forecasts and assessments were subsequently reviewed and verified by additional analysts prior to the production of this report.

Bulletin utilization was recorded as "confirmed" in the database when there was reliable evidence that the bulletin was used. Evidence of bulletin usage came from sources such as: media and public health reports that referenced bulletin information, indication that sample collection was directed in an area specifically identified in the bulletin to contain a possible or confirmed bloom, and responses or inquiries based on bulletin content. When there was insufficient evidence, bulletin utilization was recorded as "unconfirmed". Utilization assessment was conducted for both individual bulletins and weekly usage.

Similarly, bulletin forecast components were evaluated using evidence from a variety of sources (see Table 5). Transport and extent forecasts were verified based on clear evidence of bloom movement in satellite imagery and/or a geographic shift in the position of *in situ K. brevis* concentration data over the specified time period. Intensification forecasts were verified based on evidence that chlorophyll levels in imagery or *in situ K. brevis* concentrations had increased, decreased or remained stable in the forecasted region. Forecasts of respiratory impacts were verified based on observational data recorded during the specified time period and disseminated by state agencies and research institutions. Sources of observed respiratory impact data used for verification included public health reports and emails from reputable sources. Since 2006, assessments were also based on daily beach conditions reports provided by Mote Marine Laboratory's Beach Conditions Reporting System for the Gulf Coast of Florida, which included a record of the level of respiratory impacts observed each day by trained beach reporters (Kirkpatrick B. , et al., 2008). The definitions of the respiratory impact levels are outlined in Table 6 (Kirkpatrick & Currier, 2010). Observed respiratory impacts were categorized and forecasts were then assessed using Table 7.

Bulletin forecasts were considered "confirmed" when reliable evidence indicated that the forecasted conditions/events had been observed during the specified forecast period. When evidence indicated that the observed conditions/events were different from those that were predicted, the forecast was recorded as "false" in the database. When the necessary observational evidence was not available, forecast quality could not be analyzed further, and it was categorized as "unconfirmed". With regards to respiratory impacts, when beach conditions reports provided by Mote Marine Lab recorded a respiratory impact of "none", the observation could not definitively confirm that no respiratory irritation was experienced throughout the entire half-county forecast region, due to the patchy nature of blooms. Therefore, forecasts were assessed as "unconfirmed" when respiratory impacts of "none" were reported from beaches in the forecast region.

This assessment data was then grouped together by both U.S. government fiscal year and bloom year. Fiscal year (October 1, YYYY to September 30, YYYY) was used to compare changes that may have occurred from one budget year to the next. However, *K. brevis* blooms more frequently develop between August and December, sometimes spanning two or more fiscal years, potentially skewing the results of statistical analyses. Thus, to avoid this issue, a more ecologically meaningful 365 day time span was chosen to represent a bloom year (BY). The time period from May 1, YYYY to April 30, YYYY was selected to best capture the typical seasonal cycle of *K. brevis* blooms in the Gulf of Mexico, from the initiation phase through termination. This minimized the bias in the evaluation results that might have been due to variations in cell concentrations over the course of a bloom's life cycle, enabling a comparison between years. Assessment statistics and graphs for bloom year are detailed throughout this report.

Table 5. Data and resources used to assess each forecast component included in a bulletin.

FORECAST COMPONENT	CATEGORIES	ASSESSED BASED ON
Transport	• North • South • East • West • No Change	• Visible movement of feature in satellite imagery • In situ samples confirm cell concentrations in new location • Reports of *K. brevis* induced respiratory irritation in a new location
Extent	• Increase • Decrease • No Change	• Visible movement of feature in satellite imagery to new half county region • In situ samples confirm cell concentrations in new half county region • Reports of *K. brevis* induced respiratory irritation in a new location
Intensification	• Increase • Decrease • No Change	• Localized change in chlorophyll levels visible in satellite imagery • In situ samples confirm change in cell concentrations in the forecast region
Impacts	• Very low • Low • Moderate • High • None	• Reports of observed respiratory irritation (see Table 7)

Table 6. Definitions of the levels of observed respiratory impacts as assessed by trained beach reporters for the Mote Marine Laboratory Beach Conditions Reporting System for the Gulf Coast of Florida **(Kirkpatrick & Currier, 2010)**.

Level of Respiratory Irritation	Observations during 30 second Sample
None	No coughing/sneezing heard
Slight	A few coughs/sneezes heard
Moderate	A cough/sneeze heard every ~5 seconds
High	Coughing/sneezing heard almost continuously

Table 7. Reports of observed respiratory impacts were used to validate the corresponding level of respiratory impact forecasted for that region according to this chart. Due to the patchy nature of blooms, when respiratory impacts of "none" were reported, the observations could not definitively confirm that no respiratory irritation was experienced throughout the half-county forecast region. Therefore, forecasts were assessed as "unconfirmed" when respiratory impacts of "none" were reported from beaches in the forecast region.

Highest Level of Respiratory Impact Observed	Highest Level of Respiratory Impact Forecasted					
	No forecast and/or no bloom	None	Very low	Low	Moderate	High
No reports *(no data received)*	N/A	Unconfirmed	Unconfirmed	Unconfirmed	Unconfirmed	Unconfirmed
None *(no symptoms observed in region)*	N/A	Unconfirmed	Unconfirmed	Unconfirmed	Unconfirmed	Unconfirmed
Very Low *(only individuals with chronic respiratory conditions)*	FALSE	FALSE	CONFIRMED	FALSE	FALSE	FALSE
Slight *(only sensitive individuals & those with chronic respiratory conditions)*	FALSE	Unconfirmed	Unconfirmed	CONFIRMED	FALSE	FALSE
Moderate *(general public may notice mild symptoms)*	FALSE	FALSE	FALSE	FALSE	CONFIRMED	CONFIRMED
High *(general public may notice adverse symptoms)*	FALSE	FALSE	FALSE	FALSE	CONFIRMED	CONFIRMED

2.3.2 Modification to HAB-OFS Forecast Models and Skill Assessment Procedures

Following its first operational year from October 1, 2004 to September 30, 2005, the HAB-OFS made several procedural modifications from BY2005-2008 to improve upon the accuracy of HAB forecast models (see Table 8). There were also changes made to the methods used to assess the quality of forecasts (see Table9). During the preparation of this report, to ensure that assessment results from BY2005-2008 were directly comparable, all archived forecast assessment data was checked again and updated using a consistent method, as described in section 2.3.1.

Modifications to skill assessment procedures were primarily made to the respiratory impact forecasts and assessments. Originally, the bulletins included a "beach impact" forecast component that consisted of a prediction of potential respiratory impacts and fish kills. It was decided in BY2006-2007 that since originating locations and causes of dead fish and discolored water at the coast could not be immediately substantiated, observations of dead fish or discolored water alone could no longer be used to validate the presence of a harmful algal bloom and respiratory impact forecasts. Consequently, beach impact forecast validations were restricted to observed respiratory impacts only. Thus, to maintain consistency in this report, respiratory impact forecasts were only assessed using observations of respiratory irritation for validation (see Table 2 for forecast component definitions and Table 7 for the method that observations were used to assess the forecast). In addition, when several cell concentration categories were identified in a region, early bulletins stated a range of the possible respiratory impact levels based on these varying concentrations (i.e. "low" to "high" impacts possible). In BY2006-2007, the highest forecast in that range was given based simply on the highest concentration and highest wind speed over the time period. For consistency in this report, only the highest potential respiratory impact forecast for a region was assessed.

Table 8. Changes to the forecast models from October 2004 to May 2008.

Bloom Year	Effective Date	Description of Change
Respiratory Impact Forecast		
BY2006-2007	8/15/06	Beach impact forecasts were restricted to only respiratory irritation. Fish kills were no longer forecasted.
BY2006-2007	8/15/06	When forecasting impacts for a region with varying concentrations, the highest level of potential impact was forecasted (based on highest concentration observed, predicted wind direction and highest wind speed) for that region.
BY2006-2007	10/10/06	When developing forecasts, cell concentrations provided over the most recent 10 days are to be considered (formerly 1 week).
Intensification Forecast		
BY2007-2008	1/8/08	On the east coast of Florida, intensification was no longer forecast because no correlation was found between upwelling and intensification.

Table 9. Changes that impacted the assessment of bulletin forecast components from October 2004 to May 2008.

Bloom Year	Effective Date	Description of Change
Respiratory Impact Forecast		
BY2005-2006	4/18/06	If no respiratory impacts were observed, the corresponding respiratory impact forecasts were marked “unconfirmed”.
BY2005-2006	5/2/06	Fish kills alone were no longer considered confirmation of beach impacts without being accompanied by reports of respiratory irritation. Discolored water was not considered confirmation of beach impacts.
BY2006-2007	12/1/06	In bulletins issued during both active and inactive bloom periods, a “no expected impacts” forecast statement was included for regions unaffected by a bloom.
BY2007-2008	6/3/08	During an inactive bloom period, “no expected impacts” statement should be recorded as “N/A” and not assessed. If impacts are reported, change to none and mark false, make note in comments.
BY2007-2008	3/25/08	New Impact Skill SOP introduced for assessment of impact forecasts on or after 10/1/07.

2.3.3 Statistical Analysis

In order to assess the level of success, verify the forecasts, and continually improve the HAB-OFS, forecast quality and bulletin utilization were evaluated regularly.

2.3.3.1 Capability of Assessing Bulletin Utilization and Forecast Components

Before beginning a more extensive evaluation of forecast quality and utilization, the number of bulletins that were capable of being assessed was examined and compared to the number that could not be assessed. As described in the Skill Assessment section (2.3) and Table 5, the assessment of bulletin utilization and forecast components was limited by the availability of post-bulletin evidence. When there was insufficient evidence for further assessment, assessment entries were recorded as “unconfirmed”. Assessment capability varied, especially between the types of forecast components (i.e. transport, intensification, extent and respiratory impacts). Reliance on reports of field observations made assessment difficult in some cases. In order to evaluate the assessment capability, we compared the percent of assessable bulletins for each forecast component and utilization.

2.3.3.2 Forecast Frequency

Although all bulletins included at least one forecast, some components were forecasted more often than others. This is a direct result of the bloom conditions during the forecast period. For example, the development of an intensification forecast relied upon the presence of a coastal bloom, whereas a transport forecast could be developed for either an active bloom or unconfirmed feature appearing in imagery. It could also indicate that some components were easier to forecast than others using established forecast system rules guided by existing scientific knowledge. The frequency that each component was forecast was estimated by calculating the proportion of bulletins that included each of the individual components.

2.3.3.3 Forecast Verification and Skill Assessment

Forecast quality was estimated for each of the following forecast components: bloom transport (transport), changes in the spatial extent of blooms (extent), bloom intensification (intensification), and the daily potential level of respiratory impacts at the coast (impacts). Statistics were compared between bloom years (5/1/YYYY to 4/30/YYYY) and geographic regions.

Since there is no single statistic that can characterize the quality of a forecast, several different verification measures were calculated (Doswell, Davies-Jones and Keller 1990). All of the forecasts included in the HAB bulletins were binary, i.e. the predicted event was observed to either occur or not occur. Contingency tables were created showing the frequency of "yes" and "no" matched forecasts and observations (see Table 10). In reference to Table 10, there are two types of correct forecasts, indicated by the letters A and D, and two types of false forecasts, indicated by the letters B and C. The letter A represents the number of "hits" or the number of events that were forecasted and also observed. D represents the number of "correct rejections" or the number of times an event was correctly forecast to not occur. B represents the number of "false alarms" or the number of events that were forecasted, but not observed. C represents the number of "misses" or the number of events that were not forecasted, but were observed. The total number of forecasts is represented by N.

Table 10. Example of a 2 x 2 contingency table. The first table shows the types of correct forecasts (hit and correct rejection) and false forecasts (false alarm and miss). The second table shows the same categories represented by letters A through D with N as the total number of events forecasted and/or observed.

		EVENT OBSERVED?		
		Yes	**No**	**Marginal Total**
EVENT FORECAST?	**Yes**	*Hit*	*False Alarm*	*Forecast*
	No	*Miss*	*Correct Rejection*	*Not Forecast*
	Marginal Total	*Observed*	*Not Observed*	*Sum Total*

		EVENT OBSERVED?		
		Yes	**No**	**Marginal Total**
EVENT FORECAST?	**Yes**	*A*	*B*	*A+B*
	No	*C*	*D*	*C+D*
	Marginal Total	*A+C*	*B+D*	*A+B+C+D=N*

There are numerous categorical statistics that can be used to assess forecast quality. The statistics selected for this report include those commonly used for the verification of binary meteorological forecasts and are appropriate for the verification of rare events like harmful algal blooms. Three basic attributes of forecasts were measured: reliability, accuracy, and skill.

The reliability of binary forecasts is often measured by calculating the bias, a statistic that demonstrates whether there are consistent differences between the frequency of observed events and the frequency of event forecasts which would indicate a tendency towards over- or under-forecasting. When events are often predicted, but not observed they are said to be over-forecast. The term under-forecasting describes when forecasts are consistently not issued for events that are observed (Thornes & Stephenson, 2001). The frequency of event forecasts are compared to the frequency of observed events. With respect to the 2 x 2 contingency table (Table 10):

$$BIAS = (A+B)/(A+C) \qquad \text{[range: 0 to } \infty\text{]} \qquad (1)$$

where a score of one indicates no bias, while a score greater than one indicates that the forecast system over-forecasts the event. A score of less than one suggests that the forecast system under-forecasts the event (Nurmi, 2005).

Forecast accuracy was measured through the use of four different statistics: proportion correct, probability of detection (or hit rate), false alarm ratio, and threat score (or critical success index). Proportion correct (PC) is measured by the number of correct forecasts compared to the total number of forecasts. With respect to the 2 x 2 contingency table (Table 10):

$$PC = (A+D)/N \qquad \text{[range: 0 to 1]} \qquad (2)$$

where a perfect score equals one or 100% (Nurmi, 2005). Probability of detection (POD), or hit rate, measures the proportion of observed events that were correctly forecast. With respect to the 2 x 2 contingency table (Table 10):

$$POD = A/(A+C) \qquad \text{[range: 0 to 1]} \qquad (3)$$

where one is a perfect score (Nurmi, 2005). Since the POD could be artificially inflated by producing excessive “no” forecasts, it should be considered along with a statistic sensitive to the number of false alarms generated by the forecast system. The false alarm ratio (FAR) is a verification measure of categorical forecast performance that compares the number of false alarms to the total number of forecasts. With respect to the 2 x 2 contingency table (Table 10):

$$FAR = B/(A+B) \qquad \text{[range: 1 to 0]} \qquad (4)$$

where zero is a perfect score (Nurmi, 2005). The threat score (TS) is commonly used to measure the performance of rare event forecasts. It is a measure for the event being forecast after removing the number of times the event was correctly forecasted to not occur. With respect to the 2 x 2 contingency table (Table 10):

$$TS = A/(A+B+C) \qquad \text{[range: 0 to 1]} \qquad (5)$$

where a perfect score is one (Nurmi, 2005).

Forecast skill is often estimated using a skill score that compares the variation in the accuracy of a forecast with an estimate of the forecast results that could be due solely to chance, climatology, or persistence. The Heidke skill score (HSS) was selected for this assessment because it is commonly used to assess rare event forecasts, such as tornadoes and flash floods (Doswell, Davies-Jones, & Keller, 1990). It is a skill corrected verification measure of categorical forecast performance that references the proportion of correct forecasts relative to the number of correct forecasts that could be made by random chance (NOAA/Space Weather Prediction Center, 2007). With respect to the 2 x 2 contingency table (Table 10), the Heidke skill score is calculated as:

$$HSS = 2(AD-BC)/\{(A+C)(C+D)+(A+B)(B+D)\} \quad \text{[range: } -\infty \text{ to } 1] \qquad (6)$$

where a perfect score is one or 100%. A score of zero indicates that the forecast is no better than random chance at predicting the event (i.e. no forecast skill) (Nurmi, 2005).

2.3.3.4 Bulletin Utilization

A successful forecast system is one that not only produces accurate forecasts, but also one that is well-used by its intended audience(s). Bulletin utilization was confirmed based on evidence from sources that included sampling response to cited bloom regions, media or public health reports identifying bulletin information, and written/ phoned responses or inquiries based on bulletin analyses. The proportion of bulletins that were confirmed as utilized was then calculated for each fiscal year, bloom year, and priority level. Since some sources used to confirm bulletin utilization issue reports on a weekly basis, weekly utilization of the bulletin was also calculated recognizing that more than one bulletin disseminated within a weekly period may have been utilized by the confirmation source.

3. RESULTS

3.1 Summary of *Karenia brevis* Events

From the time the Harmful Algal Bloom Operational Forecast System (HAB-OFS) was transitioned to operations on October 1, 2004 to the end of the fourth bloom year (BY) on April 30, 2008, a total of 398 bulletins and 30 supplemental bulletins and/or conditions updates were issued, containing 435 forecasts (see Table 11). Figure 4 shows that during this time, the HAB-OFS provided early warning of nine separate *Karenia brevis* events (69.2%), while four other *K. brevis* events were first identified by water samples collected in the field by organizations in Florida (see Appendix IV). These *K. brevis* events included newly formed blooms, *K. brevis* concentrations below developed bloom levels (<50,000 cells/L), and the reemergence of concentrations of previously identified blooms that had been thought to have dissipated offshore. The exact number of blooms and their duration was difficult to ascertain because water sample data may have been unavailable at times, especially when a bloom dissipated in offshore or remote locations that were difficult to access routinely. In addition, if there were gaps in satellite imagery or sample data, cells from one bloom might have been transported undetected to a new location. This might have been interpreted as the formation of a new bloom, since genetic data was not available to indicate the origin of the new bloom population and its relatedness to bloom populations occurring during the same time period that were seemingly isolated by geographic distance. Due to this uncertainty, the following data should be considered to be rough estimates of the number of bloom events. However, the data still illustrate the variability of *K. brevis* events between bloom years. The longest lasting bloom was approximately 293 days in duration in BY2006-2007, while BY2007-2008 had six bloom events with an average duration of approximately 62.83 days (see Table 12). Maps of the monthly *K. brevis* samples collected during BY2004-2008 are shown in Figure 5 to Figure 15.

Table 11. The number of HAB-OFS products issued during the 2004 to 2008 bloom years. Scheduled bulletins are issued every Monday throughout the year for southwest Florida, where *K. brevis* blooms occur most frequently, and every Monday and Thursday during a bloom in each of the bulletin regions (southwest, northwest or east Florida). Supplemental bulletins and conditions updates are issued when data is received that indicates a new bloom or an increase in bloom extent, intensity, or the associated respiratory impacts forecasted.

Bloom Year	# of HAB-OFS Products Issued	
	# of Scheduled Bulletins	*# of Supplemental/ Conditions Updates*
10/1/04 to 4/30/05	61	2
5/1/05 to 4/30/06	131	3
5/1/06 to 4/30/07	96	7
5/1/07 to 4/30/08	110	18

Table 12. Estimates of the number, bulletin region impacted and average duration (in days) of *Karenia brevis* bloom events detected during the 2004 to 2008 bloom years.

Bloom Year	# of *K. brevis* Events Detected	Bulletin Region			Avg. Bloom Duration (in days)
		SW FL	*NW FL*	*East FL*	
10/1/04 to 4/30/05	2	X			250
5/1/05 to 4/30/06	4	X	X		82.5
5/1/06 to 4/30/07	1	X			293
5/1/07 to 4/30/08	6	X	X	X	62.83

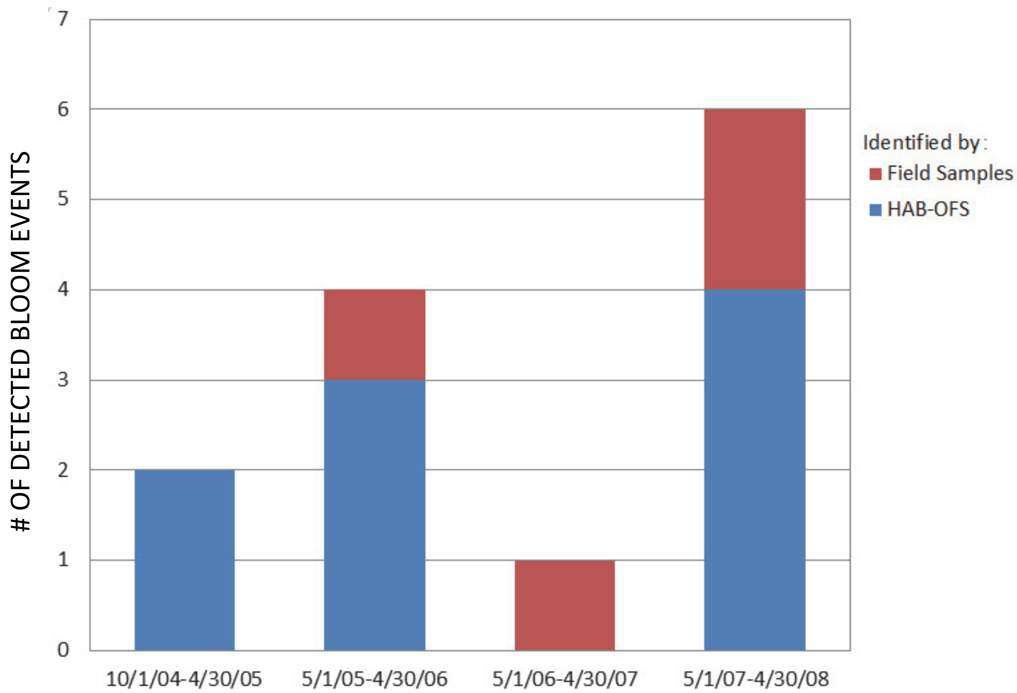


Figure 4. The number of *Karenia brevis* events detected by HAB-OFS satellite imagery or samples collected in the field during the 2004 to 2008 bloom years.

3.1.1 Bloom Year: 2004-2005

Two blooms, both detected first by satellite imagery, occurred during BY2004-2005. Maps of the monthly *K. brevis* samples collected during this period are shown in Figure 5 and Figure 6, along with a key to cell concentration categories. Descriptions of these blooms are published in the Annual Report of the Gulf of Mexico HAB-OFS (Fisher, et al., 2006) and can be found in Appendix V.

3.1.2 Bloom Year: 2005-2006

There were four blooms during BY2005-2006. Of these, three of the blooms were first detected by satellite imagery, while one bloom was first detected by samples collected in the field by Florida organizations (see Appendix IV). A total of 122 bulletins and 3 supplemental bulletins were disseminated during the four blooms. Maps of the monthly *K. brevis* samples collected during this period are shown in Figure 7, Figure 8 and Figure 9, along with a key to cell concentration categories.

The first bloom of BY2005-2006 was detected in northwest Florida from samples collected on September 1, 2005. This bloom summary was published in the Annual Report of the Gulf of Mexico HAB-OFS (Fisher, et al., 2006) and can be found in Appendix V.

The second bloom of BY2005-2006 was detected via satellite imagery 10 miles offshore southwest Florida between Sarasota Bay and Captiva Island on November 3, 2005 by operational HAB analysts, and was confirmed by sampling reports the following week. It is possible that the resuspension and strong upwelling conditions produced by Hurricane Wilma the last week of October promoted the formation of the bloom and its westward expansion. By the end of November, the bloom had grown in size, with patches of varying concentrations stretching along- and offshore from Pinellas to Collier County. The bloom lingered in southwest Florida through the middle of December, but finally became increasingly patchy and had completely dissipated by February 27, 2006.

The third bloom of BY2005-2006 was detected via satellite imagery south of Key West, Florida on November 25, 2005 by operational HAB analysts and was confirmed by sampling reports by the end of the month. Subsequent satellite imagery also revealed that the bloom was present alongshore the gulfside of the Lower Keys, which was also confirmed by follow-up sampling. At its peak, the bloom had up to "medium" cell concentrations (100,000 to <1,000,000 cells/L) and stretched over 60 miles, from Marathon, Florida to offshore of Key West. The last water samples with bloom concentrations were collected on January 3 and 4, 2006.

The fourth bloom of BY2005-2006 was detected via satellite imagery about 20 miles north of Sugarloaf Key, Florida on January 30, 2006 by operational HAB analysts and was confirmed by sampling reports within the same week. According to imagery analysis, it appears the feature originated off the coast of northern Monroe County and migrated southwest towards the Lower Keys. The bloom was short-lived, and by February 13, the chlorophyll concentrations had decreased dramatically. Patches of chlorophyll continued to be tracked in imagery until March 6, when samples reported no *K. brevis* present in the Keys.

3.1.3 Bloom Year: 2006-2007

The only bloom of BY2006-2007 was first detected via sampling offshore southwest Florida, east of Sanibel Island, on June 16, but did not reach bloom concentrations until June 29 near the mouth of San Carlos Bay. During July, offshore winds produced upwelling conditions which intensified the bloom and led to its expansion into Lee, Charlotte, and southern Sarasota counties, causing respiratory irritation and fish-kill events. The *K. brevis* cell concentrations continued to increase, becoming a developed bloom that stretched from Pinellas to Collier counties by the end of August. Tropical Storm Ernesto made landfall in southeast Florida around August 30, further increasing the extent and intensity of the bloom. Throughout September and October multiple samples of up to "high" concentrations (>1,000,000 cells/L) were collected along- and offshore the southwest Florida coastline, from northern Pinellas to northern Monroe counties. Concentration levels fluctuated over the next few months, causing varying levels of respiratory irritation and fish kills, before the bloom eventually dissipated from late March to April. One patch from this bloom transported from northern Monroe to the gulfside of the Lower Keys, where it proceeded to transport westward over the next few months. By April 3, no *K. brevis* was present in any samples along the southwest Florida coast, or in the Keys. During this bloom, NOAA issued a total of 86 bulletins and an additional 7 supplemental bulletins. Maps of the monthly *K. brevis* samples collected during this period are shown in Figure 10, Figure 11 and Figure 12, along with a key to cell concentration categories.

3.1.4 Bloom Year: 2007-2008

BY2007-2008 was unique because NOAA HAB analysts issued forecasts for blooms in east, northwest and southwest Florida. Although blooms outside of southwest Florida are less common, the blooms in east Florida and northwest Florida/Alabama/Mississippi were more intense than those in southwest Florida during BY2007-2008, causing reports of respiratory irritation, fish kills, and discolored water. During the same time period, there were four bloom events along the southwest Florida coast, consisting of the formation of three blooms and the reemergence of another. However, the bloom events were much milder in terms of the levels of reported impacts. From October 2007 to April 2008, patchy and intermittent bloom level concentrations primarily affected Lee to Monroe counties. During these bloom events, NOAA issued a total of 80 bulletins, 8 supplemental bulletins and 10 conditions updates. Maps of the monthly *K. brevis* samples collected during this period are shown in Figure 13, Figure 14 and Figure 15, along with a key to cell concentration categories.

On September 24, 2007, the Nassau County Health Department (NCHD) began receiving reports of respiratory irritation from beach workers alongshore Amelia Island, on the east coast of Florida. Samples collected by the NCHD/Disease Control and Prevention Services Division confirmed the presence of *K. brevis* at “medium” concentrations at the coast. In response, NOAA HAB analysts issued a supplemental bulletin reporting the identification of the first bloom of BY2007-2008. Between late September and mid-November, the bloom gradually expanded southward causing reports of respiratory irritation, fish kills and discolored water. By December 31, 2007 HAB analysts were reporting that the bloom extended from southern Volusia to northern Palm Beach County. However, soon thereafter, the bloom extent decreased and as of January 24, 2008, the bloom had completely dissipated.

In late September, NOAA HAB analysts also detected in satellite imagery a new bloom developing along the Panhandle of northwest Florida. Initial samples of *K. brevis* indicated “very low” concentrations (>1000 to 10,000 cells/L), but soon after further sampling revealed multiple “medium” concentrations of *K. brevis* south of Walton and Bay counties along with reports of respiratory irritation, fish kills and discolored water. From October 1, 2007 to December 13, 2007, the bloom slowly spread westward into Alabama and Mississippi. Satellite imagery indicated that the bloom existed as a series of unconsolidated patches of *K. brevis* with varying chlorophyll concentrations. Although not as cohesive as the bloom along the east Florida coast, patches of the bloom in northwest Florida did contain up to “medium” and “high” concentrations. HAB analysts reported a significant abatement of the bloom as of December 31, when it was present alongshore only Okaloosa County, FL and Baldwin County, AL. By January 14, 2008 the bloom had completely dissipated and bulletin dissemination for northwest Florida ceased.

The third bloom of BY2007-2008 was first detected by satellite imagery on October 15. Samples collected that day indicated up to “very low” concentrations (>1000 to 10,000 cells/L) of *K. brevis* identified alongshore southern Lee and northern Collier counties. Offshore sampling on

October 19 indicated “very low” *K. brevis* concentrations offshore from Pinellas to Lee counties and up to “high” concentrations offshore Collier County. However, alongshore southwest Florida, the bloom lingered in “low” concentrations (>10,000 to <100,000 cells/L). On October 29, the first respiratory impacts of this bloom were reported along southern Lee County where sampling at that time indicated “low” concentrations of *K. brevis*. Over the next few weeks, the bloom transported south to Collier County, where it dissipated by November 19. However, the bloom was again detected via satellite imagery north of the Lower Keys on November 29, where it was confirmed by samples.

On December 10, the NOAA HAB team released a bulletin to announce the reemergence of the bloom after successfully predicting intensification and transport in Collier County and the Lower Keys. During the next week, imagery showed the feature of high chlorophyll associated with the “low” concentrations of *K. brevis* to be moving south. Following this, sampling from December 17-20 showed that *K. brevis* was no longer present alongshore southwest Florida from Pinellas to Collier County or offshore the Lower Florida Keys.

The fourth bloom of BY2007-2008 was first detected on February 12 when sampling southwest of Pavilion Key, in northern Monroe County, detected “very low” to “medium” concentrations of *K. brevis*. A supplemental bulletin was issued to announce the start of the bloom. Over the next week, two patches of elevated chlorophyll were visible in satellite imagery offshore Monroe County and were confirmed to contain “low” *K. brevis* concentrations shortly afterwards. On March 5, sampling indicated the first presence of *K. brevis* offshore of the Florida Keys when two samples identified “very low” concentrations 15 miles northwest of Key West. Additional sampling indicated that there was no *K. brevis* present in any samples collected within 10 miles offshore. On March 15, HAB analysts reported that the bloom had temporarily subsided, though a patch of elevated chlorophyll remained visible in the imagery 2.2 miles offshore northern Monroe County.

The fifth and last bloom of BY2007-2008 was short-lived, and may have actually been part of the same “bloom system” as the fourth bloom. “Very low” to “low” concentrations of *K. brevis* continued to linger offshore Pavilion Key in Monroe County throughout March and into April. In early April, bloom concentrations were once again identified in central Collier County, with “very low” concentrations identified alongshore South Marco Beach. Only one day later, *K. brevis* concentrations ranging from 1,000-4,999 cells/L were identified in the bay regions of northern Sarasota. Follow-up sampling in all regions indicated diminishing *K. brevis* concentrations ranging from “not present” to “background” (0 to 1000 cells/L). By May 1, there was no indication of a harmful algal bloom along the coast of southwest Florida. While elevated chlorophyll (5-10 μ/L) features were reported and tracked throughout this time, the satellite imagery may have detected the numerous species of non-harmful algae species collected in coastal waters throughout this period. No respiratory irritation, fish kills or discolored water was reported throughout the duration of this bloom.

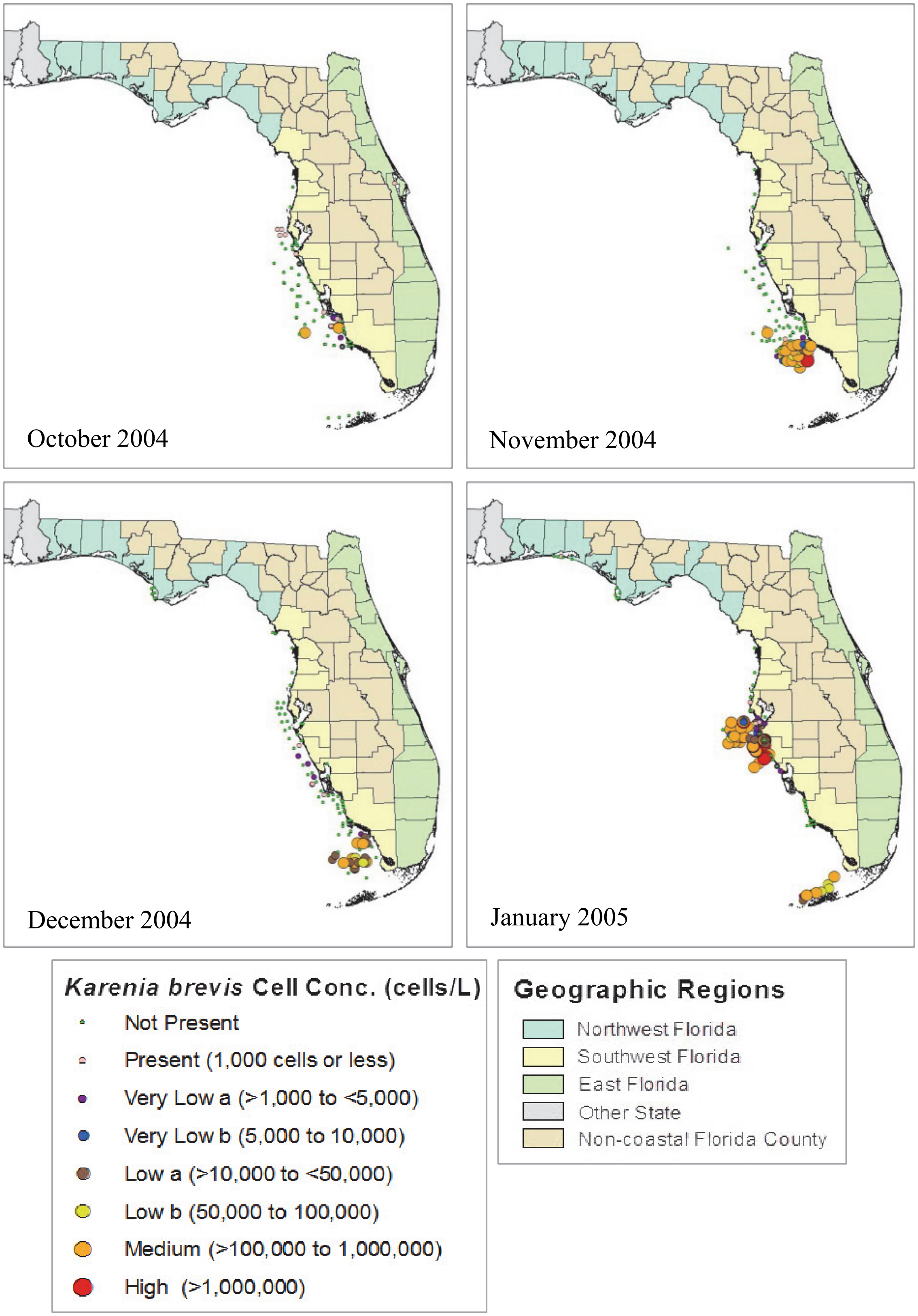


Figure 5. Monthly *Karenia brevis* samples collected during October through January in the 2004-2005 bloom year.

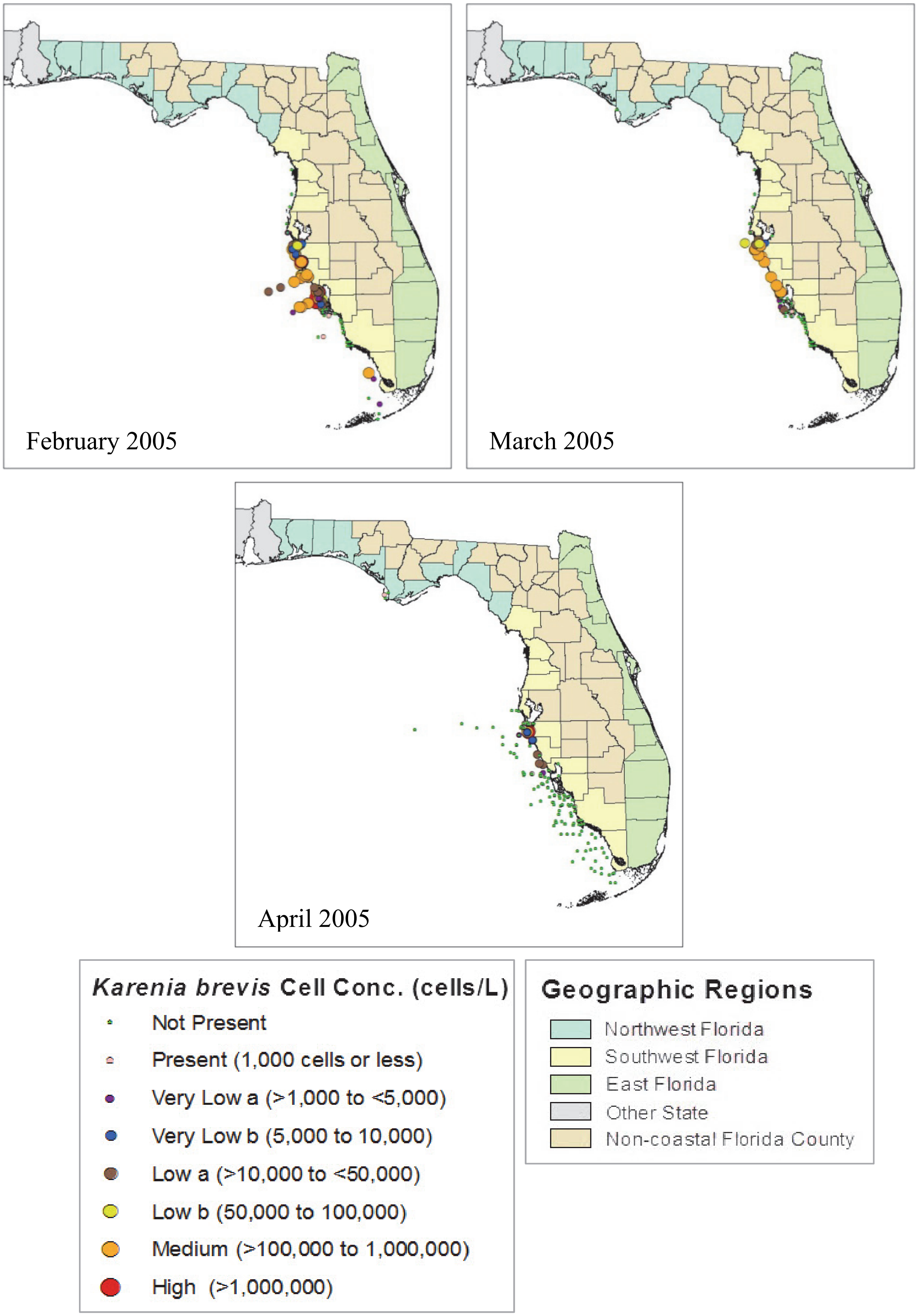


Figure 6. Monthly *Karenia brevis* samples collected during February through April in the 2004-2005 bloom year.

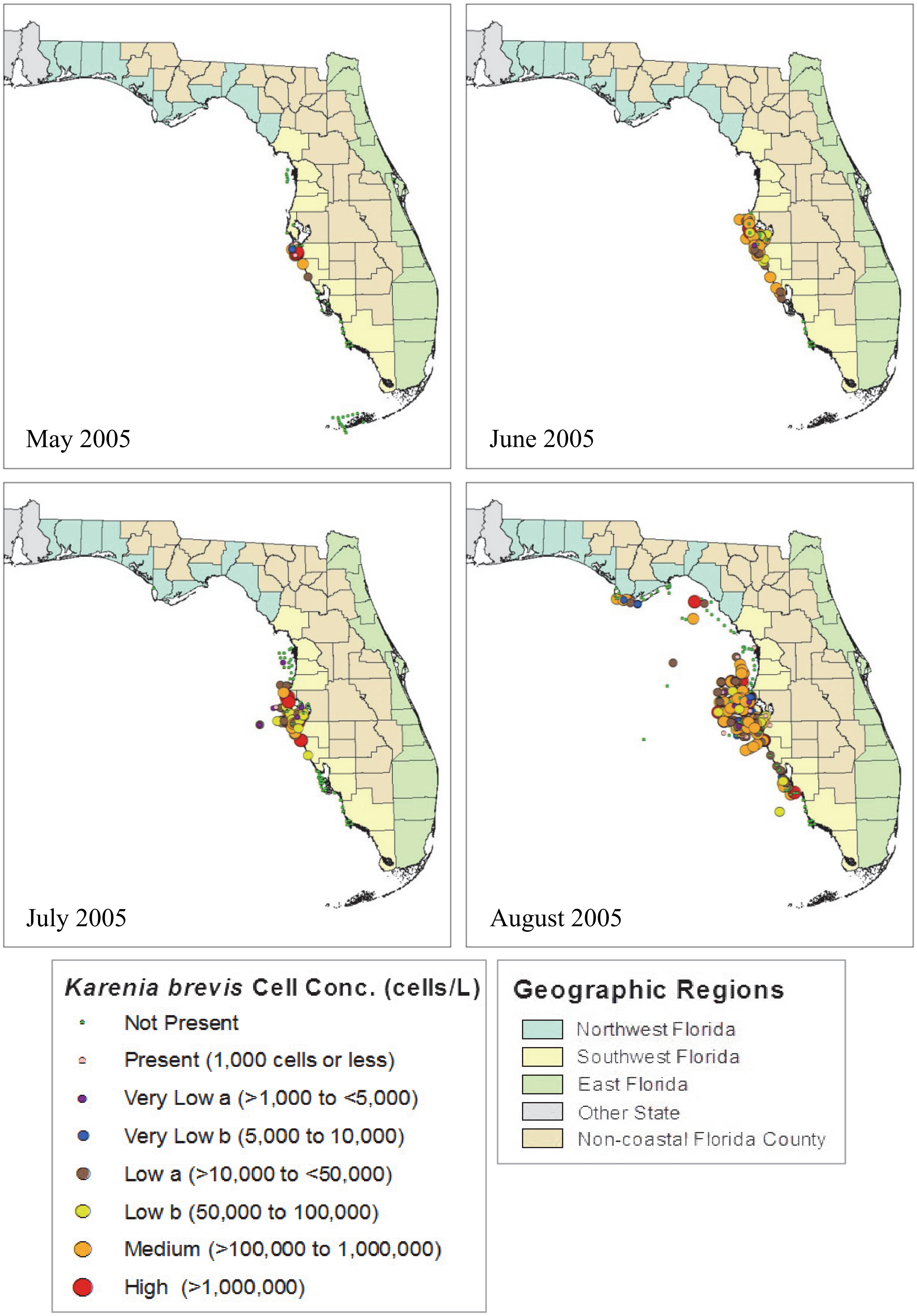


Figure 7. Monthly *Karenia brevis* samples collected during May through August in the 2005-2006 bloom year.

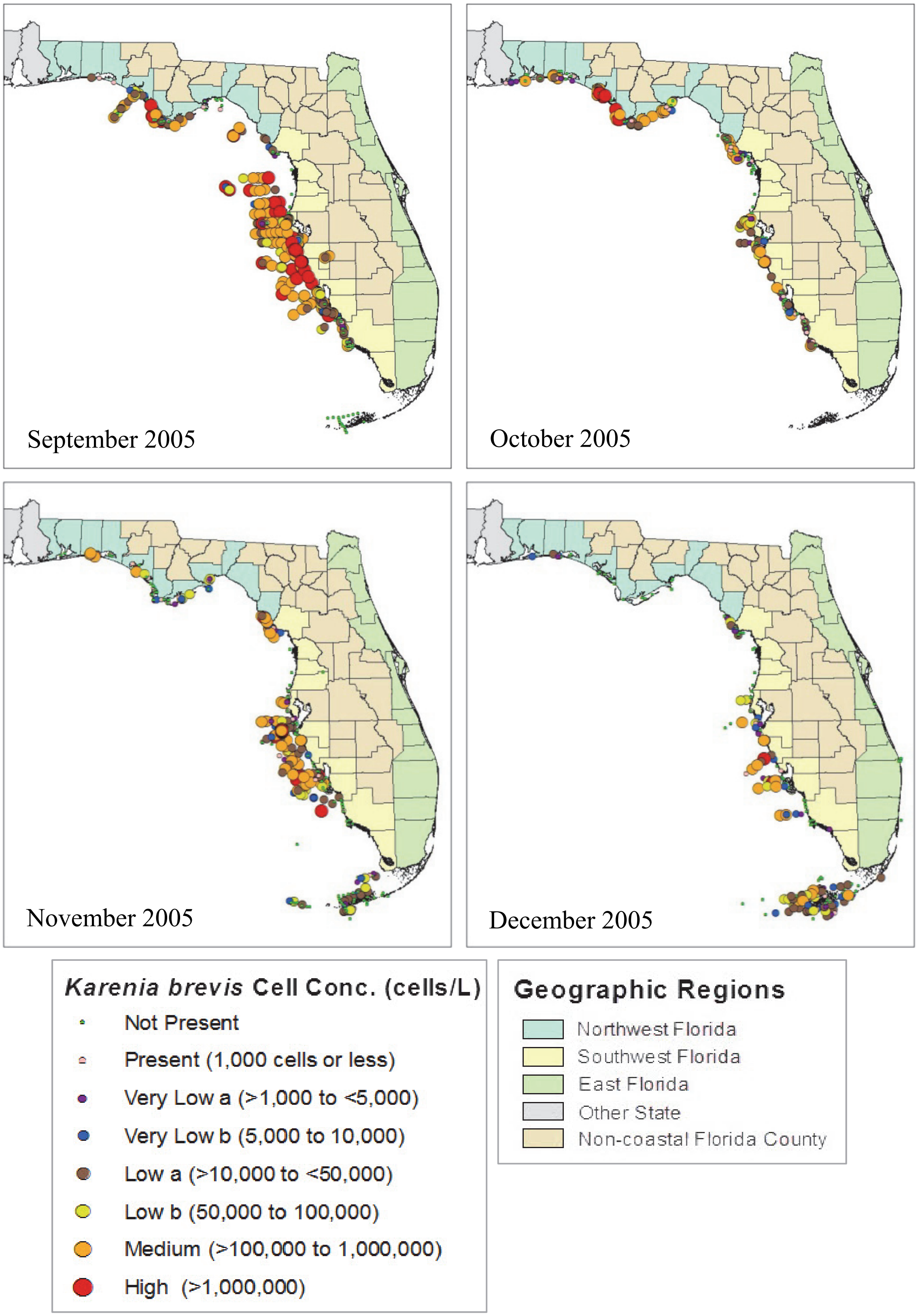


Figure 8. Monthly *Karenia brevis* samples collected during September through December in the 2005-2006 bloom year.

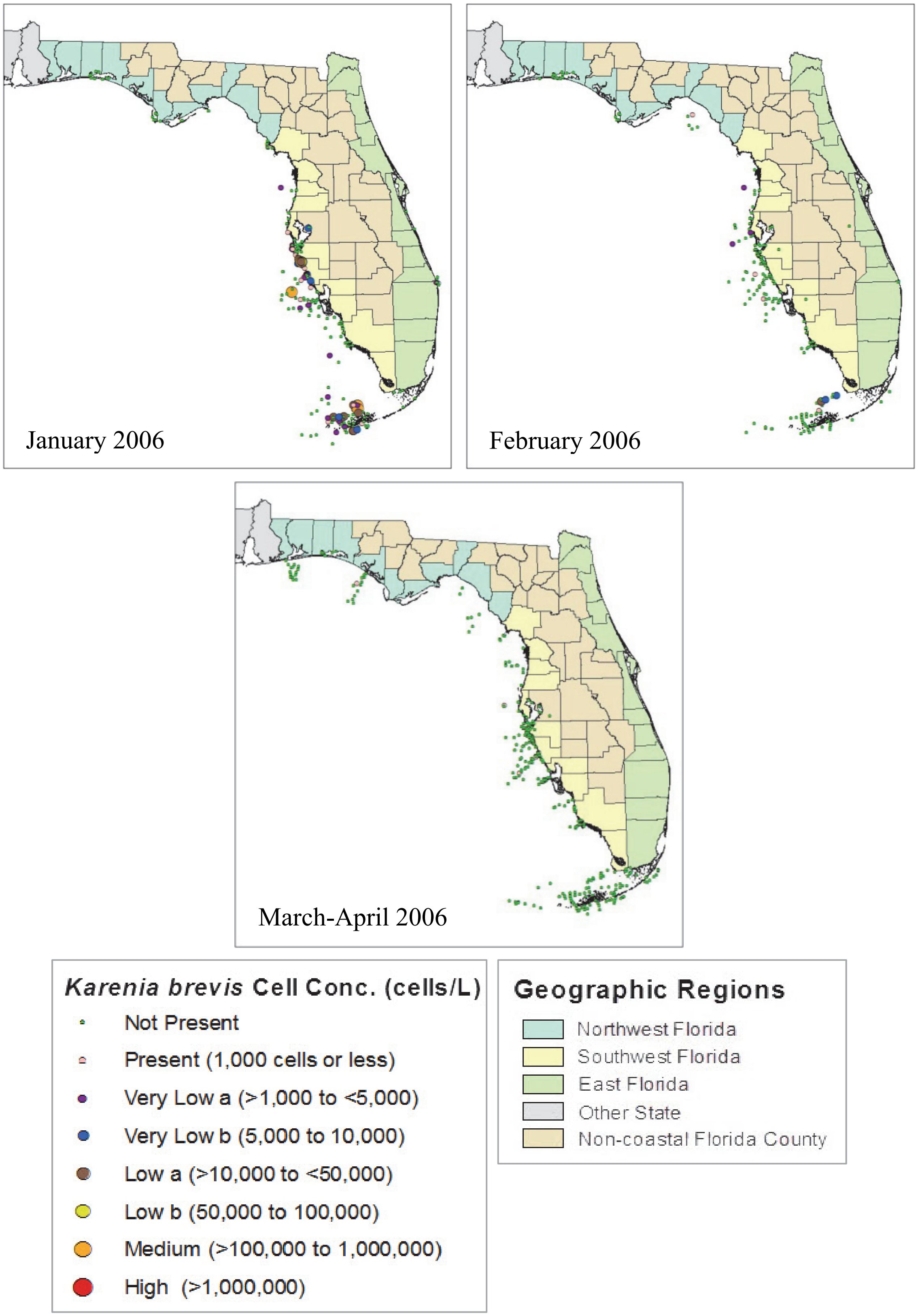


Figure 9. Monthly *Karenia brevis* samples collected during January through April in the 2005-2006 bloom year.

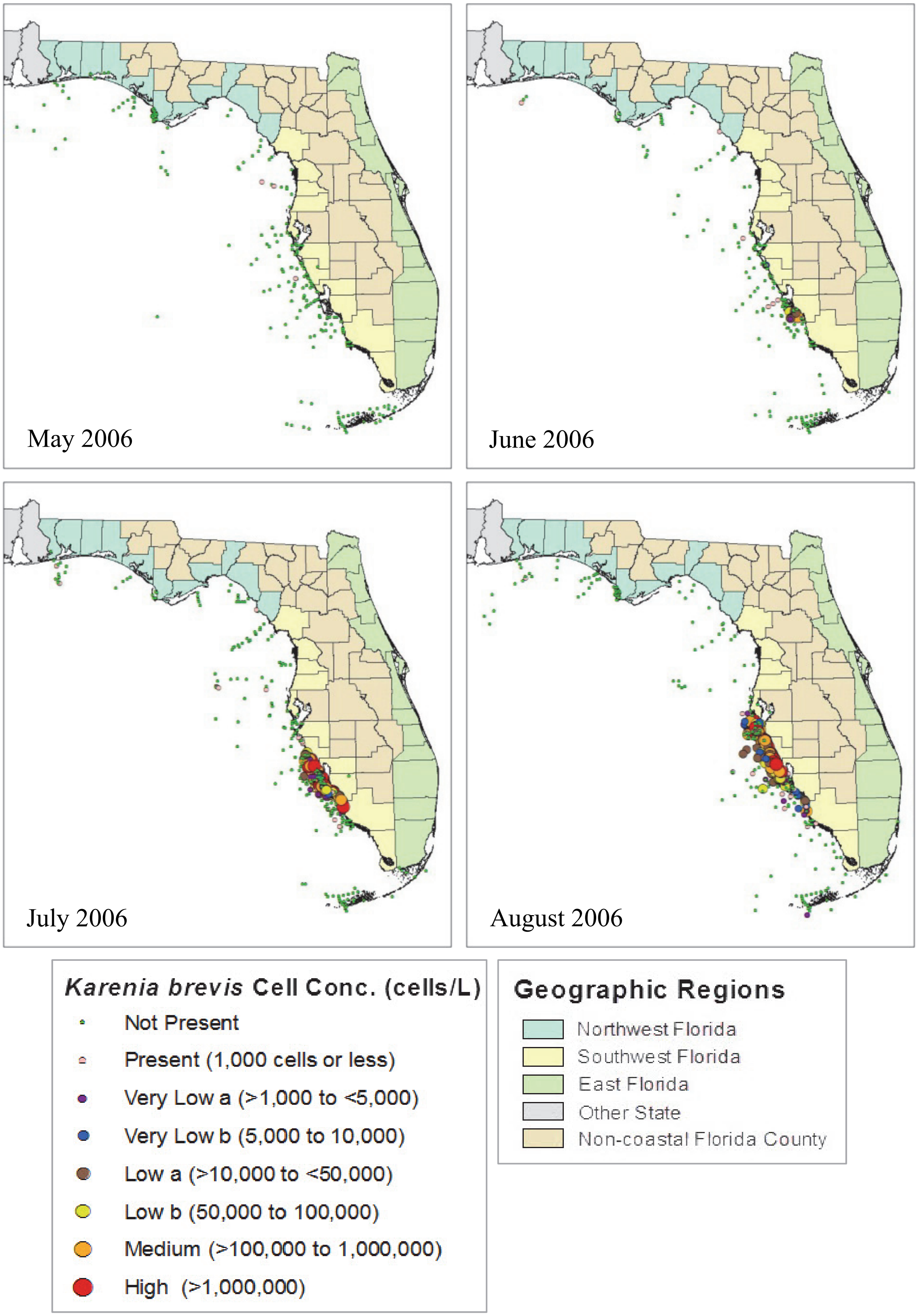


Figure 10. Monthly *Karenia brevis* samples collected during May through August in the 2006-2007 bloom year.

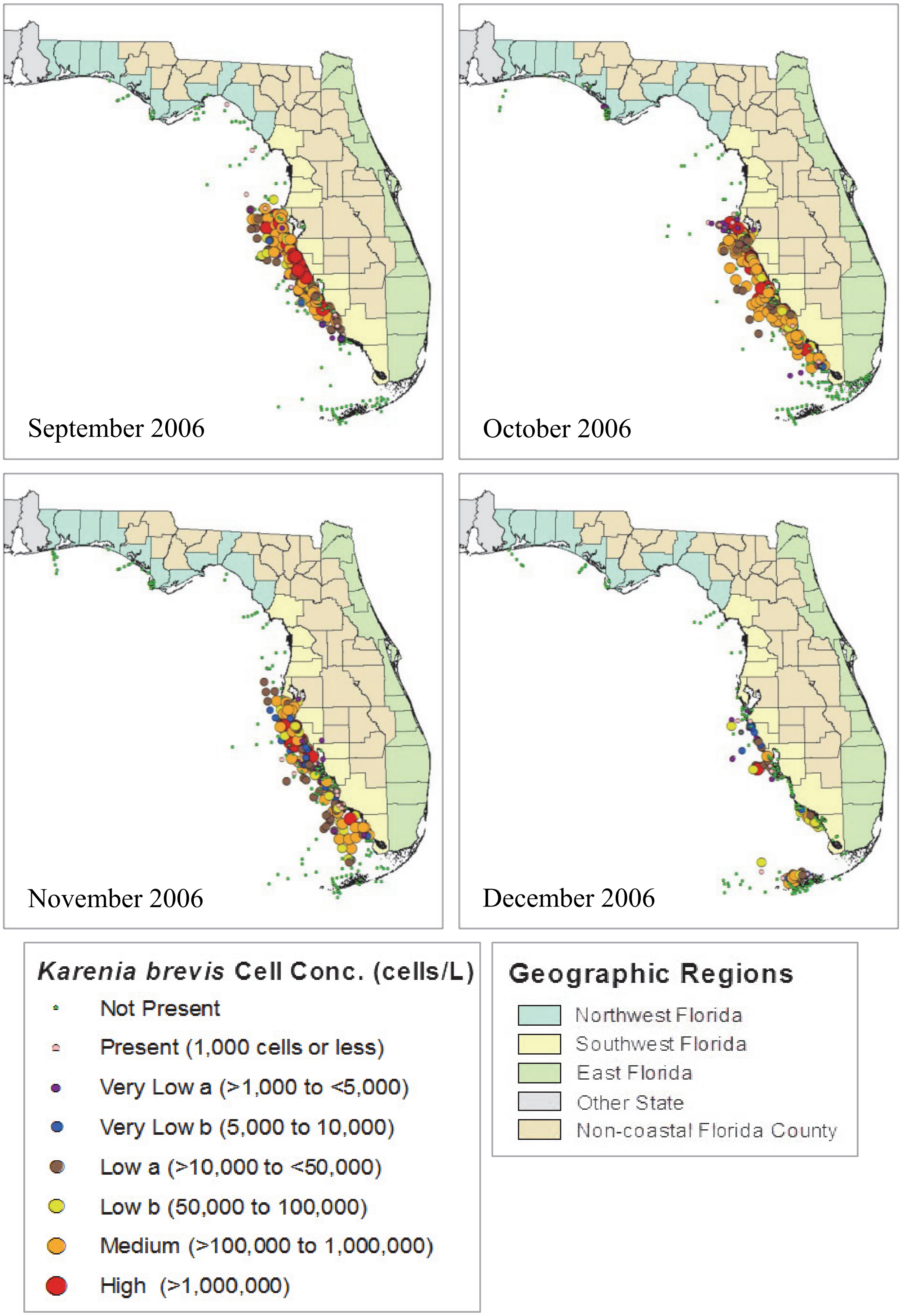


Figure 11. Monthly *Karenia brevis* samples collected during September through December in the 2006-2007 bloom year.

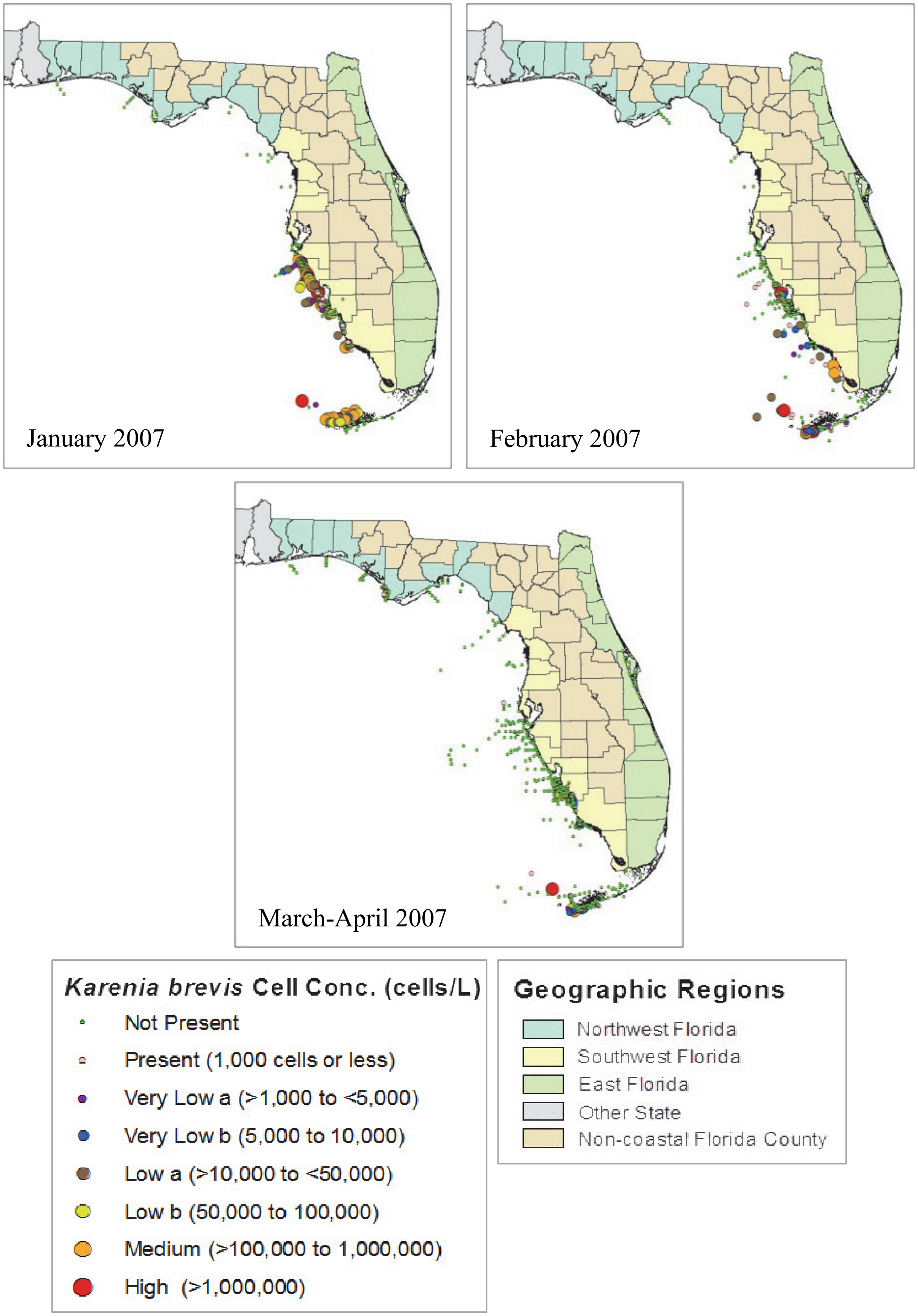


Figure 12. Monthly *Karenia brevis* samples collected during January through April in the 2006-2007 bloom year.

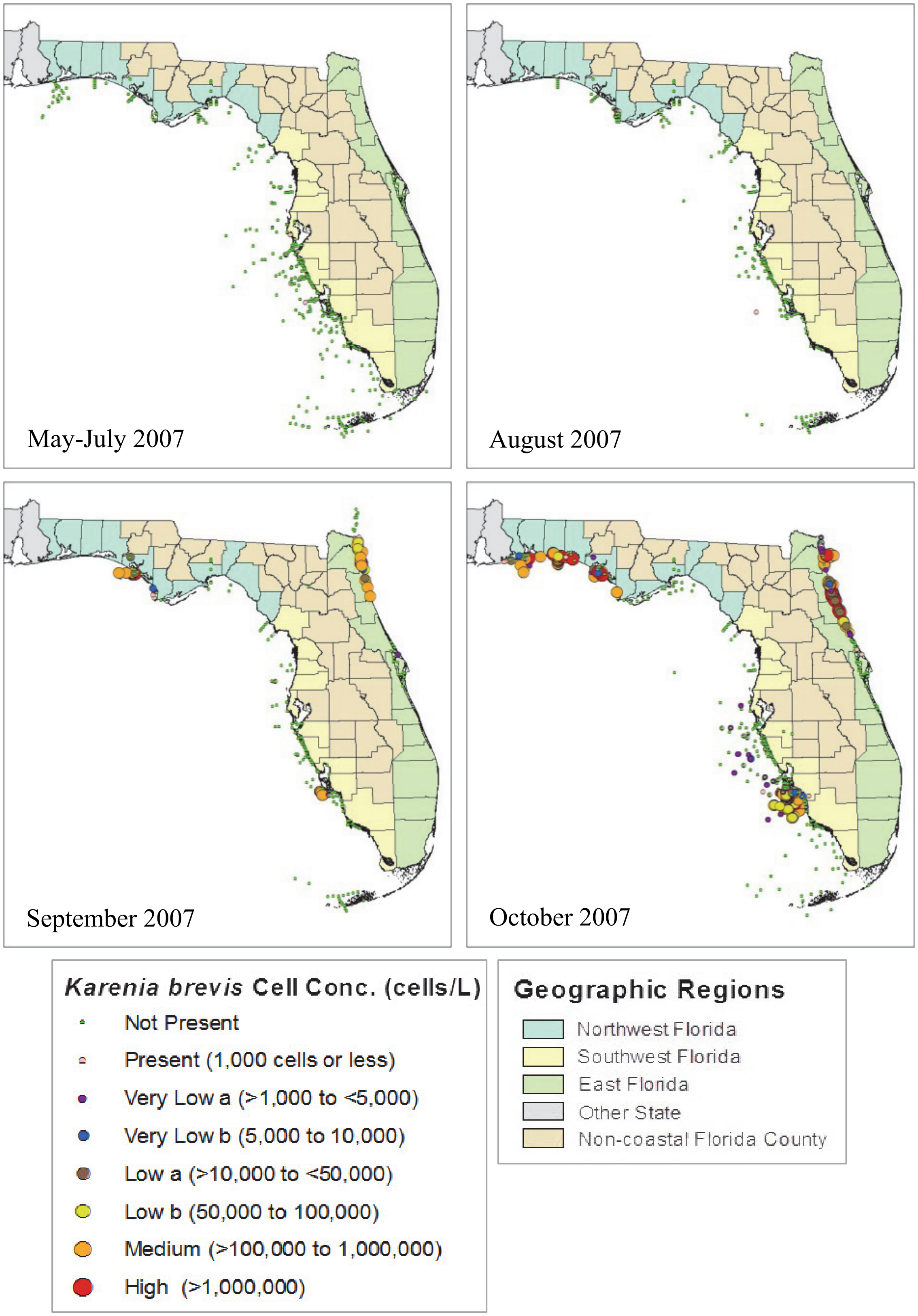


Figure 13. Monthly *Karenia brevis* samples collected during May through October in the 2007-2008 bloom year.

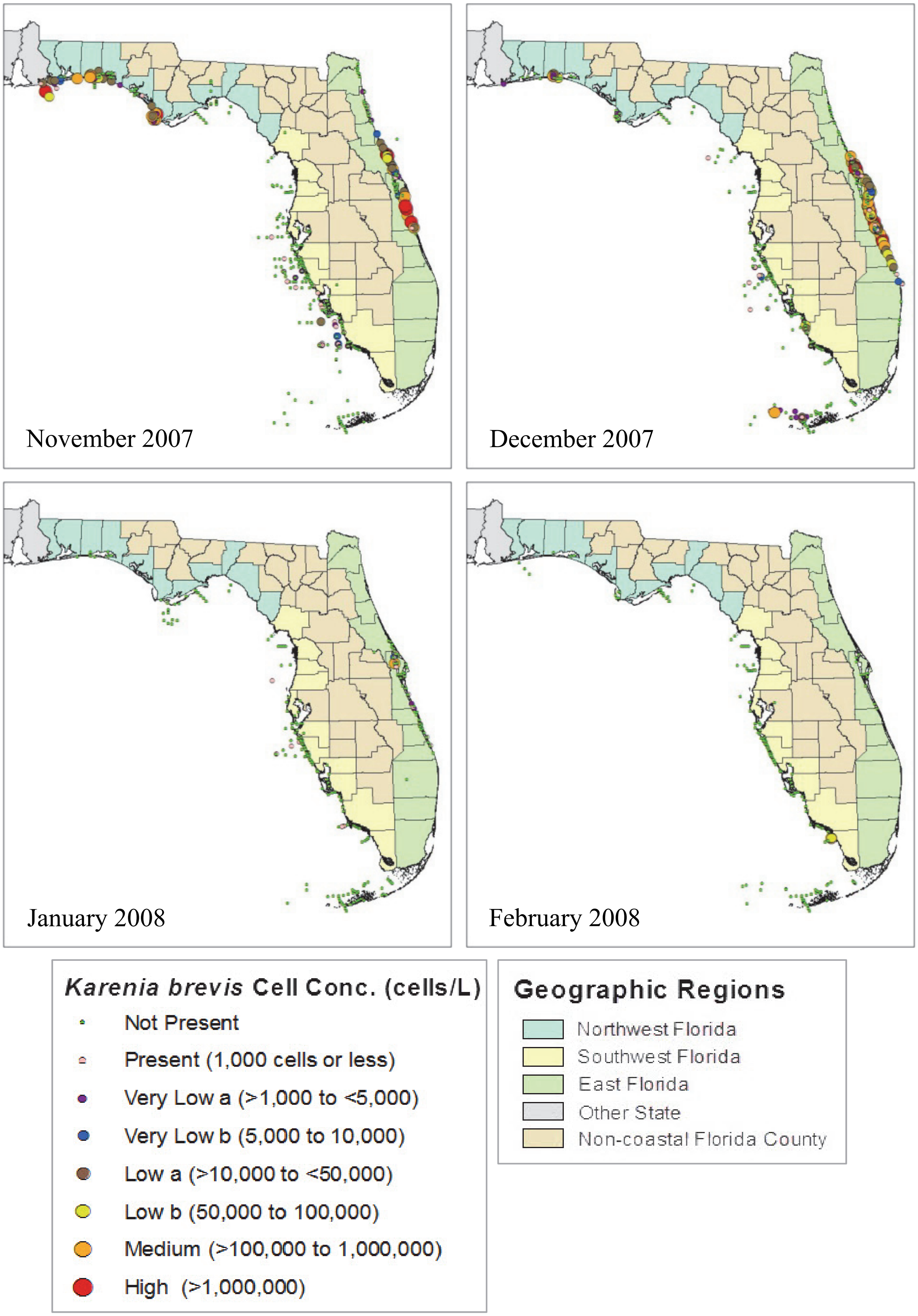


Figure 14. Monthly *Karenia brevis* samples collected during November through February in the 2007-2008 bloom year.

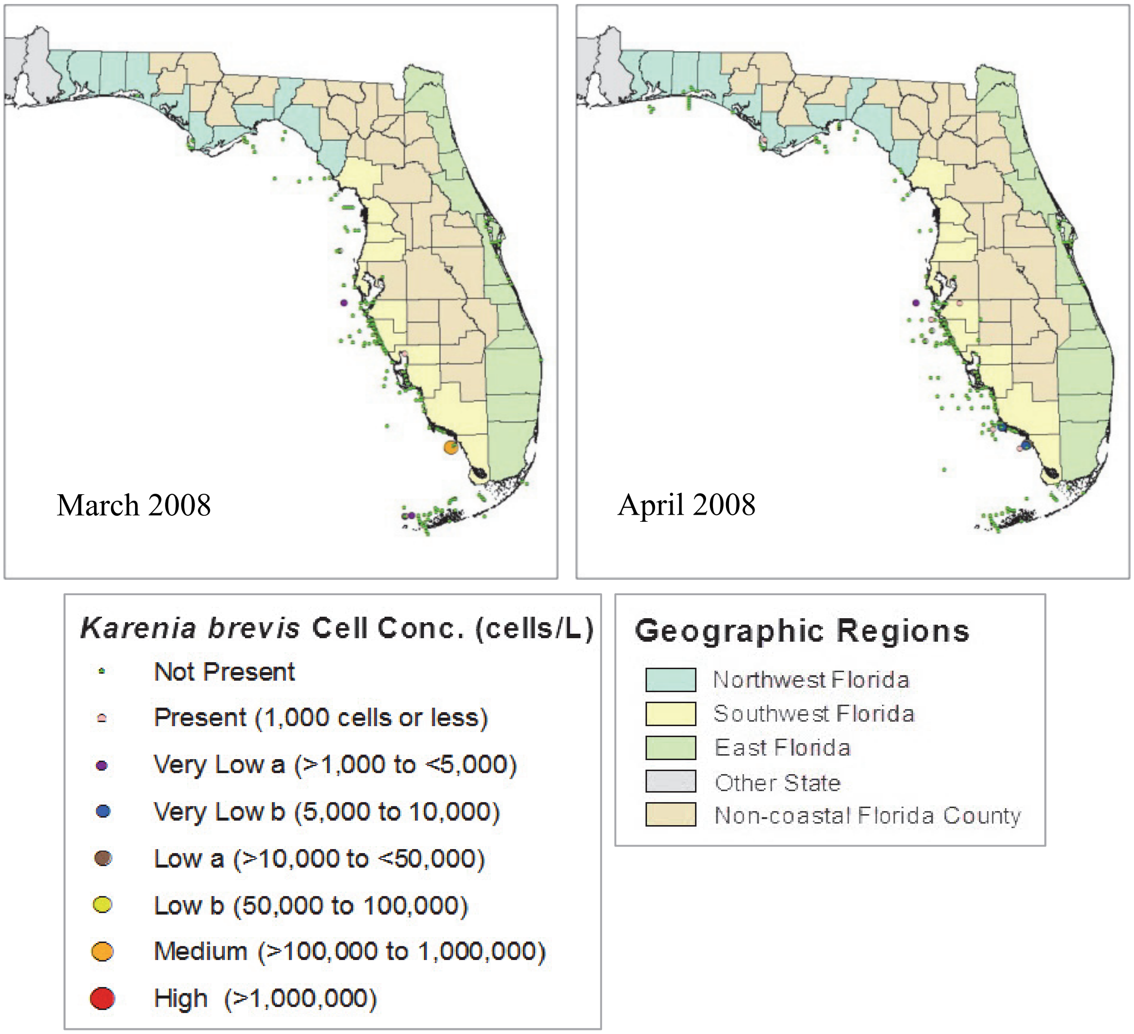


Figure 15. Monthly *Karenia brevis* samples collected during March through April in the 2007-2008 bloom year.

3.2 Bulletin Utilization

Confirmation of use was dependent upon the availability of supporting evidence indicating that bulletin content was used by another source such as a state or county agency, research institution, or public media entity. Both overall and weekly utilization was calculated. Overall the proportion of total bulletins with confirmed utilization was consistently higher than 64% during BY2004-2008 (64-79%). During BY2004-2008, the proportion of weeks where at least one bulletin was confirmed utilized was consistently 83% or higher (83-96%) (see Figure 16).

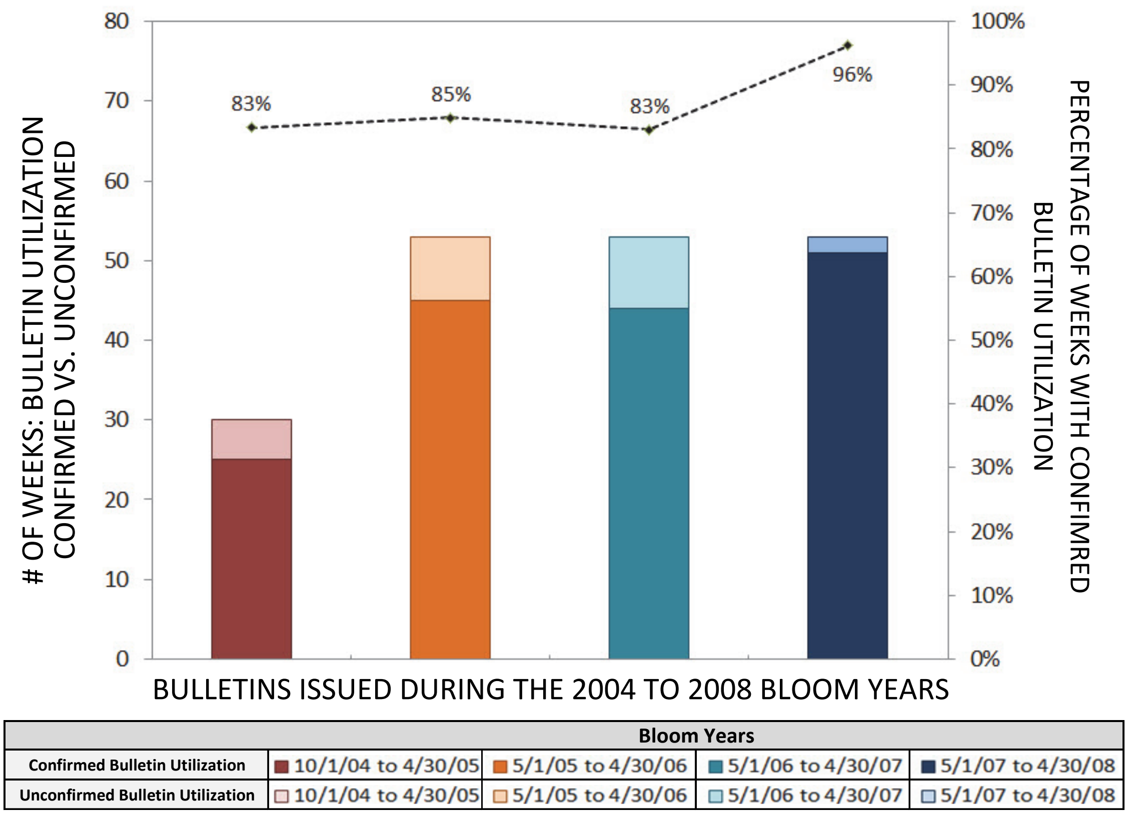
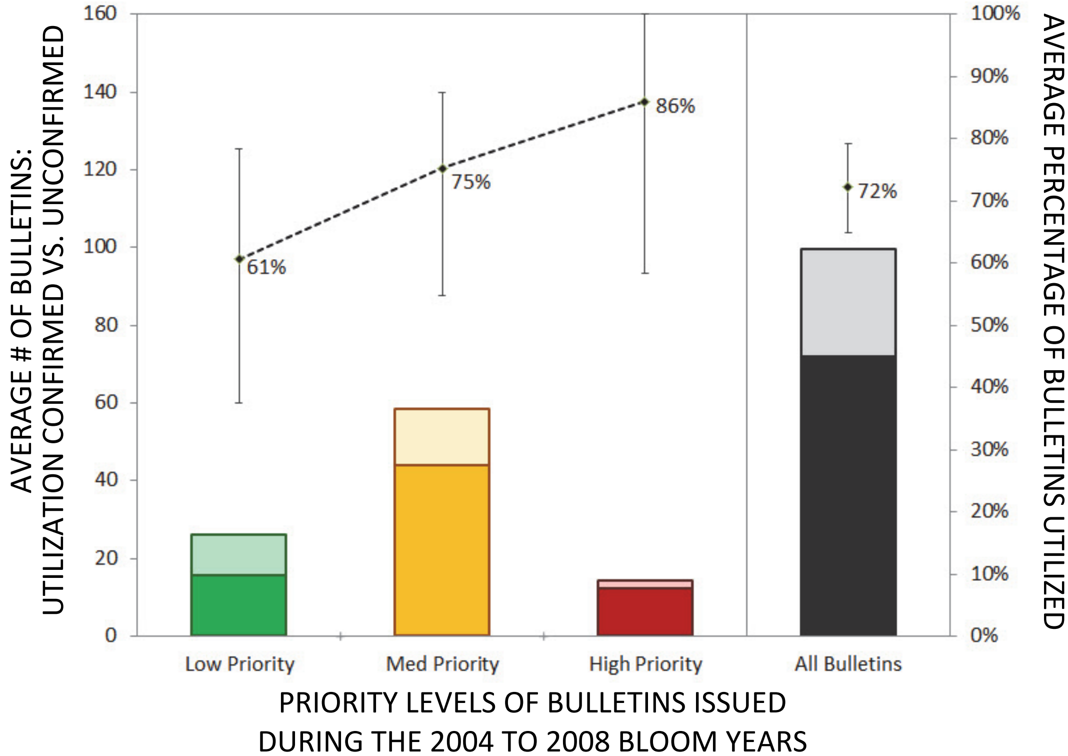


Figure 16. Number of weeks with confirmed bulletin utilization and percentage of weeks with at least one bulletin utilized during the 2004 to 2008 bloom years.

3.2.1 Priority Level

A priority level (low, medium or high) was assigned to each bulletin based on bloom activity and the corresponding level of action or response that resource managers might deem necessary. Utilization of each bulletin varied according to the priority level assigned to the bulletin. During BY2004-2008, medium and high priority bulletins were confirmed utilized greater than 54% of the time (medium=54-87.5% and high=58-100%). On average, 75% of medium priority bulletins and 86% of high priority bulletins were confirmed utilized. The utilization of low priority bulletins varied, dropping to only 37% in BY2006-2007, but rising as high as 78% in BY2007-2008; on average 61% of low priority bulletins were confirmed utilized. Figure 17 shows that during BY2004-2008, an average of 72% of all bulletins were confirmed utilized.

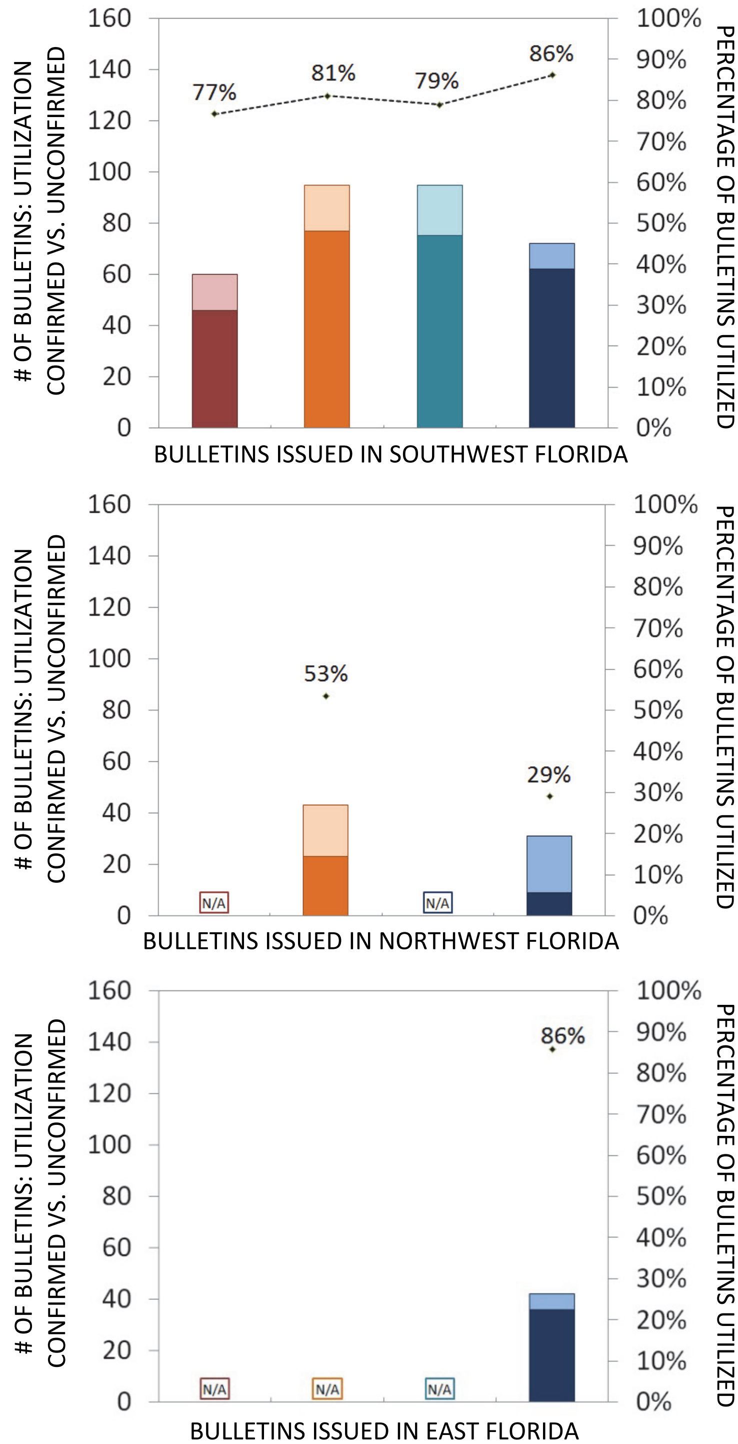


	Bloom Years			
Confirmed Bulletin Utilization	Low Priority	Medium Priority	High Priority	Total Bulletins
Unconfirmed Bulletin Utilization	Low Priority	Medium Priority	High Priority	Total Bulletins

Figure 17. Average number of bulletins with utilization confirmed for each priority level and average percentage of bulletins utilized over the 2004 to 2008 bloom years. A priority level is assigned to each bulletin based on the need for management response.

3.2.2 Region

Figure 18 shows that bulletin utilization varied somewhat by geographic region. Bulletins issued for southwest Florida consistently had the highest confirmed utilization (76.6-86%), with the highest utilization in BY2007-2008 and the lowest in BY2004-2005. Utilization was also high (86%) for bulletins issued for east Florida during the bloom in BY2007-2008. By contrast, confirmed utilization was much lower (29-53%) for bulletins issued during the blooms in northwest Florida in BY2005-2006 and BY2007-2008.



	Bloom Years			
Confirmed Bulletin Utilization	10/1/04 to 4/30/05	5/1/05 to 4/30/06	5/1/06 to 4/30/07	5/1/07 to 4/30/08
Unconfirmed Bulletin Utilization	10/1/04 to 4/30/05	5/1/05 to 4/30/06	5/1/06 to 4/30/07	5/1/07 to 4/30/08

Figure 18. Confirmed bulletin utilization in each geographic region during the 2004 to 2008 bloom years. *Note*: Values of N/A indicate that no bulletins were issued for that geographic region during that bloom year.

3.3 Forecast Frequency

Although all bulletins included at least one forecast, some components (see Table 2) were forecasted more often than others because of bloom conditions and/or forecast system rules that restricted the ability to forecast some components. The frequency that each component was forecast was estimated by calculating the number of individual components compared to the total number of bulletins issued during the bloom year. Since some bulletins might contain multiple forecasts of the same component type (i.e. impacts), each forecast component was evaluated separately.

Figure 19 shows that during BY2004-2008, of the four forecast components, impact forecasts were included in the bulletins most frequently (91-100% of bulletins), followed by forecasts of transport (51-92% of bulletins), intensification (32-46% of bulletins) and extent (1-23% of bulletins). From BY2004-2008, the frequency of impact forecasts increased and as of May 2005, all bulletins included one or more impact forecasts so that the proportion of individual impact forecasts per bulletin was equal to or greater than one (1-3.97). From BY2004-2007, the majority (80-92%) of bulletins included a transport forecast, but this decreased sharply in BY2007-2008 when only 52% of bulletins contained a transport forecast. From BY2004-2008, the frequency of intensification forecasts consistently ranged between 32-46.5%. Extent was consistently the least frequently forecasted component. From BY2004-2006, extent forecasts were included in 19-23.5% of the bulletins. The frequency of extent forecasts decreased further in subsequent years, and by BY2007-2008 only 0.9% of bulletins included this type of forecast.

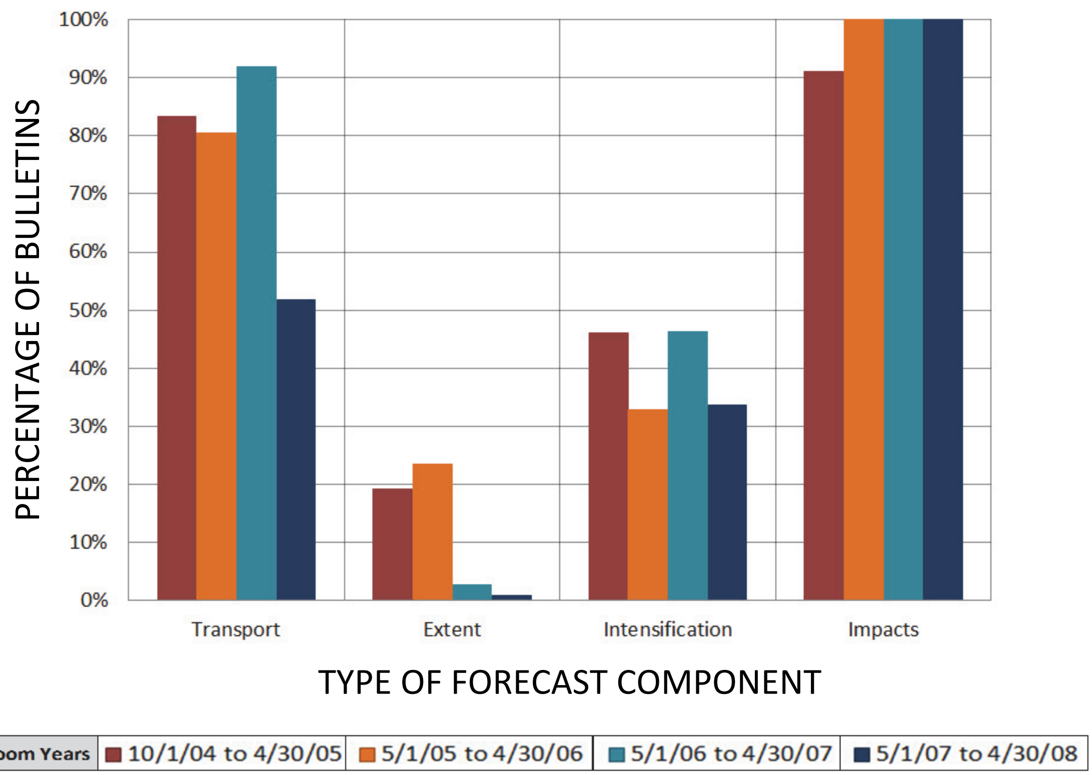


Figure 19. Frequency of forecast components in each bulletin issued during the 2004 to 2008 bloom years.

Note: During the 2005 to 2008 bloom years, the proportion of individual impact forecasts per bulletin was equal to or greater than one (1-3.97) because some bulletins were issued with more than one impact forecast.

3.4 Capability of Assessing the Forecast Components

The assessment of forecast components was dependent on the availability of reliable observational data from reputable government, scientific and academic sources. When the necessary observational evidence was not available, forecast quality could not be assessed and the forecast was categorized as "unconfirmed". Since the observational evidence required for validation was not always available, the assessment capability varied (see Figure 20).

From BY2004-2007, the majority (51.5-69%) of transport forecasts could be assessed. However, this decreased sharply to only 29.8% of transport forecasts in BY2007-2008. From BY2004-2008, the proportion of assessable extent forecasts varied greatly (0-100%) because the forecasts were issued infrequently (1-35 per bloom year). The majority (59-76%) of intensification forecasts made from BY2004-2008 were assessable. Although impact forecasts were made with increasing frequency from BY2004-2008, especially from BY2006-2008, the assessment of these forecasts remained difficult. Since validation of these forecasts relied on the availability of field observations, the proportion of assessable forecasts was fairly low (10-54%). During BY2005-2006, the highest proportion of assessable impact forecasts (54%) were issued, while the lowest proportion (10%) were issued during BY2007-2008.

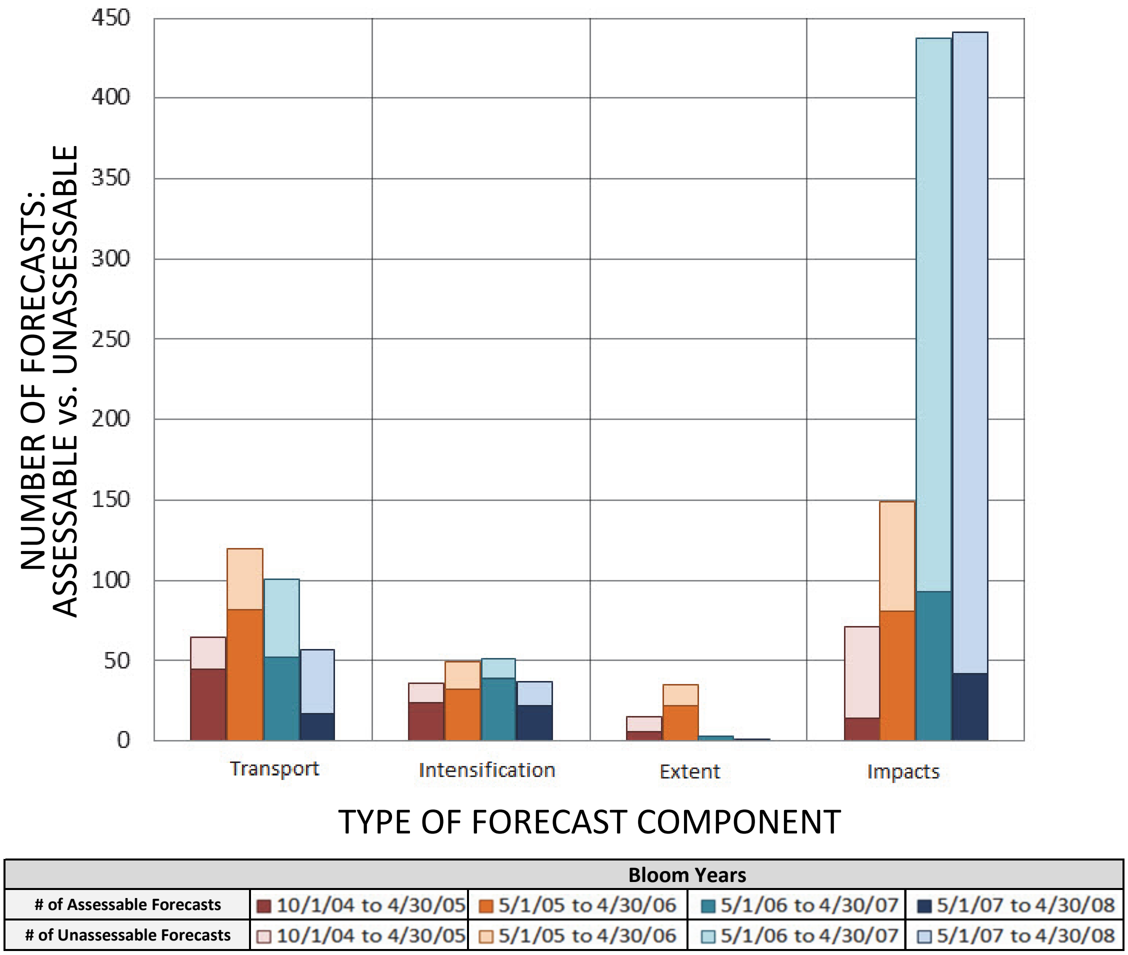


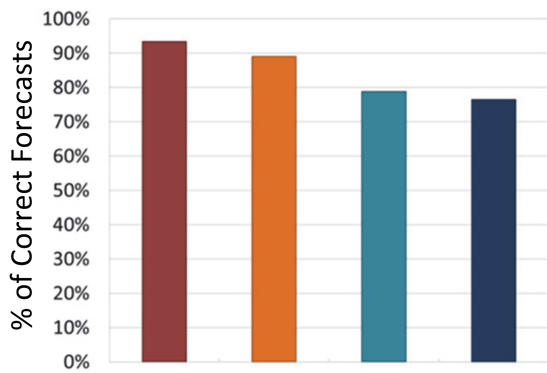
Figure 20. Number of assessable and unassessable forecast components for each bloom year from 2004 to 2008. The assessment of forecast components was dependent on the availability of reliable observational data from reputable government, scientific and academic sources.

3.5 Forecast Accuracy

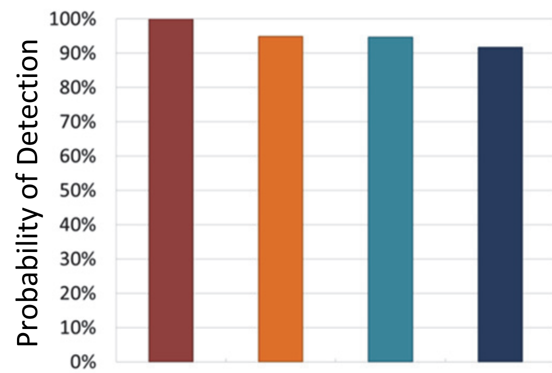
Forecast accuracy was estimated for each of the four forecast components: transport, extent, intensification, and respiratory impacts. Accuracy was also estimated for the individual respiratory impact levels: "no impact", "very low", "low", "medium" and "high". The four different statistics used to estimate forecast accuracy were proportion correct, probability of detection, threat score, and false alarm ratio (see Section 2.3.3.3 for definitions).

3.5.1 Transport

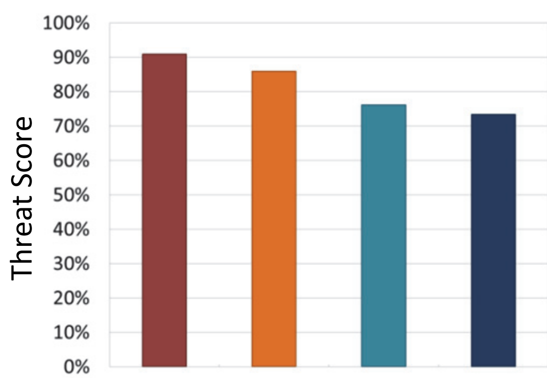
Figure 21 shows that during BY2004-2008, overall, transport forecasts issued for any of the geographic regions were consistently accurate, with a high proportion correct (76-93%), high probability of detection (0.92-1), and high threat scores (0.73-0.91), and relatively low false alarm ratios (0.09-0.21). Transport forecasts for southwest and northwest Florida were the most accurate. Of the transport forecasts issued for southwest Florida, there were a consistently high proportion correct (72-93%), high probability of detection (0.93-1.0), and high threat scores (0.67- 0.91), and relatively low false alarm ratios (0.07-0.33). For forecasts in northwest Florida, there was also a consistently high proportion correct (84-100%), high probability of detection (1.0), high threat scores (0.8-1.0), and relatively low false alarm ratios (0-0.2). Transport forecasts made for the bloom in east Florida during BY2007-2008 were slightly less accurate with a lower proportion correct (66.7%), probability of detection (0.67), and threat score (0.67). The false alarm ratio for east Florida forecasts was perfect (0) meaning transport was always observed when it was forecasted.



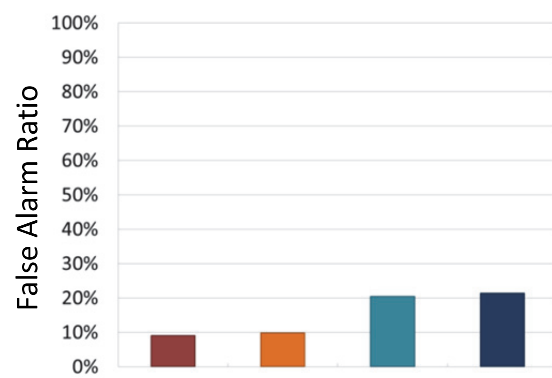
a) Proportion correct: the number of correct transport forecasts compared to the total number of transport forecasts issued.



b) Probability of detection: the proportion of observed bloom transport events that were correctly forecast.



c) Threat score: Measure of forecasted transport events, after removing the correct rejections.



d) False alarm ratio: the number of false alarms compared to the total number of transport forecasts issued.

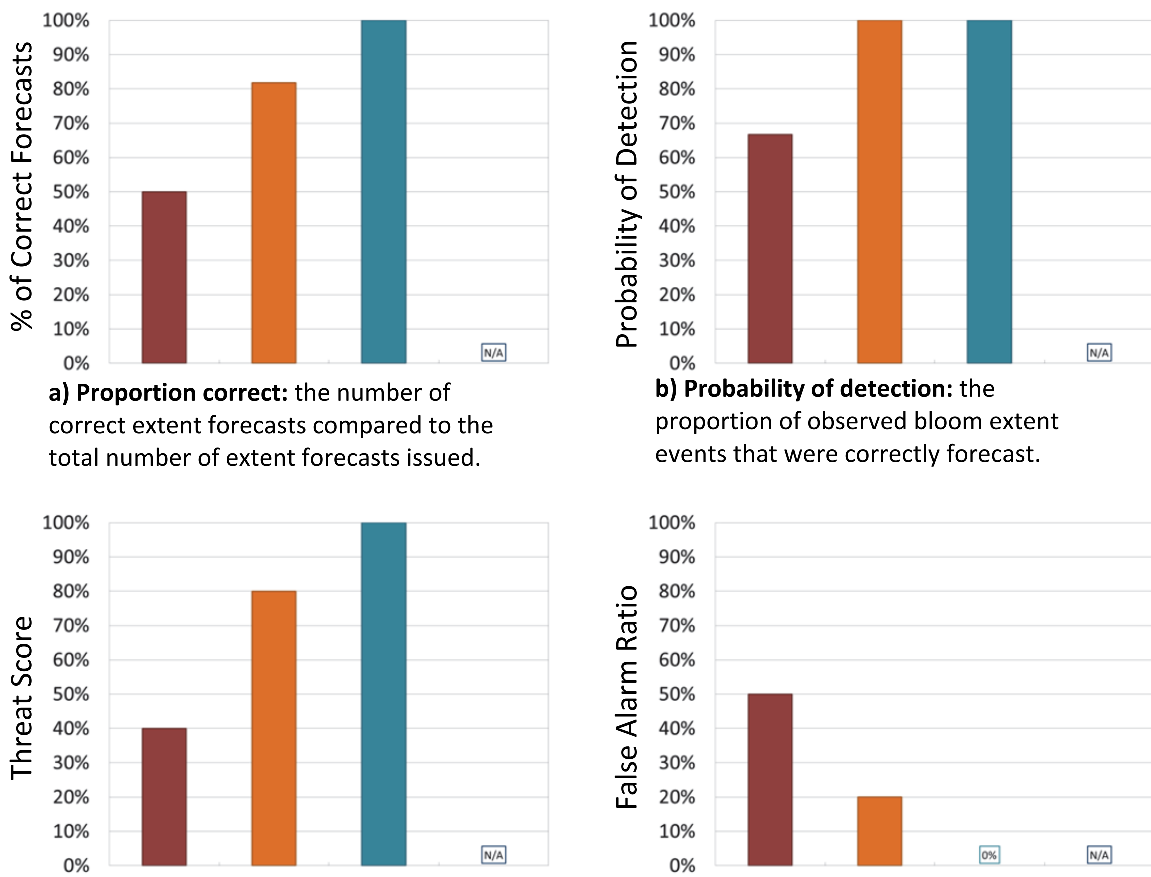
Number of Assessable Forecasts (n) for each Bloom Year				
Bloom Years	10/1/04 to 4/30/05	5/1/05 to 4/30/06	5/1/06 to 4/30/07	5/1/07 to 4/30/08
n	45	82	52	17

Figure 21. Accuracy of transport forecasts issued during the 2004 to 2008 bloom years.

3.5.2 Extent

Extent forecasts were the least frequently issued and were not issued at all in BY2007-2008. For all regions, the extent forecasts issued during BY2005-2007 were more accurate than those issued during BY2004-2005 (see Figure 22). Within BY2004-2007, there were increases in the proportion correct (50-100%), probability of detection (0.66-1.00), and threat scores (0.4-1.0).

The false alarm ratios decreased from 0.5 to 0.0. The accuracy of the extent forecasts issued for southwest Florida improved during BY2004-2007. During this time, there were increases in the proportion correct (50-100%), probability of detection (0.67-1.0), and threat scores (0.4 to 0.82 to 1.0). The false alarm ratios decreased from 0.5 to 0.18 to 0.0. Extent forecasts were only issued for a bloom in northwest Florida during BY2005-2006. The forecasts were fairly accurate with a relatively high proportion correct (75%), probability of detection (1.0), and threat score (0.75), and a relatively low false alarm ratio (0.25). Extent forecasts were not issued for the bloom in east Florida.



a) Proportion correct: the number of correct extent forecasts compared to the total number of extent forecasts issued.

b) Probability of detection: the proportion of observed bloom extent events that were correctly forecast.

c) Threat score: Measure of forecasted extent events, after removing the correct rejections.

d) False alarm ratio: the number of false alarms compared to the total number of extent forecasts issued.

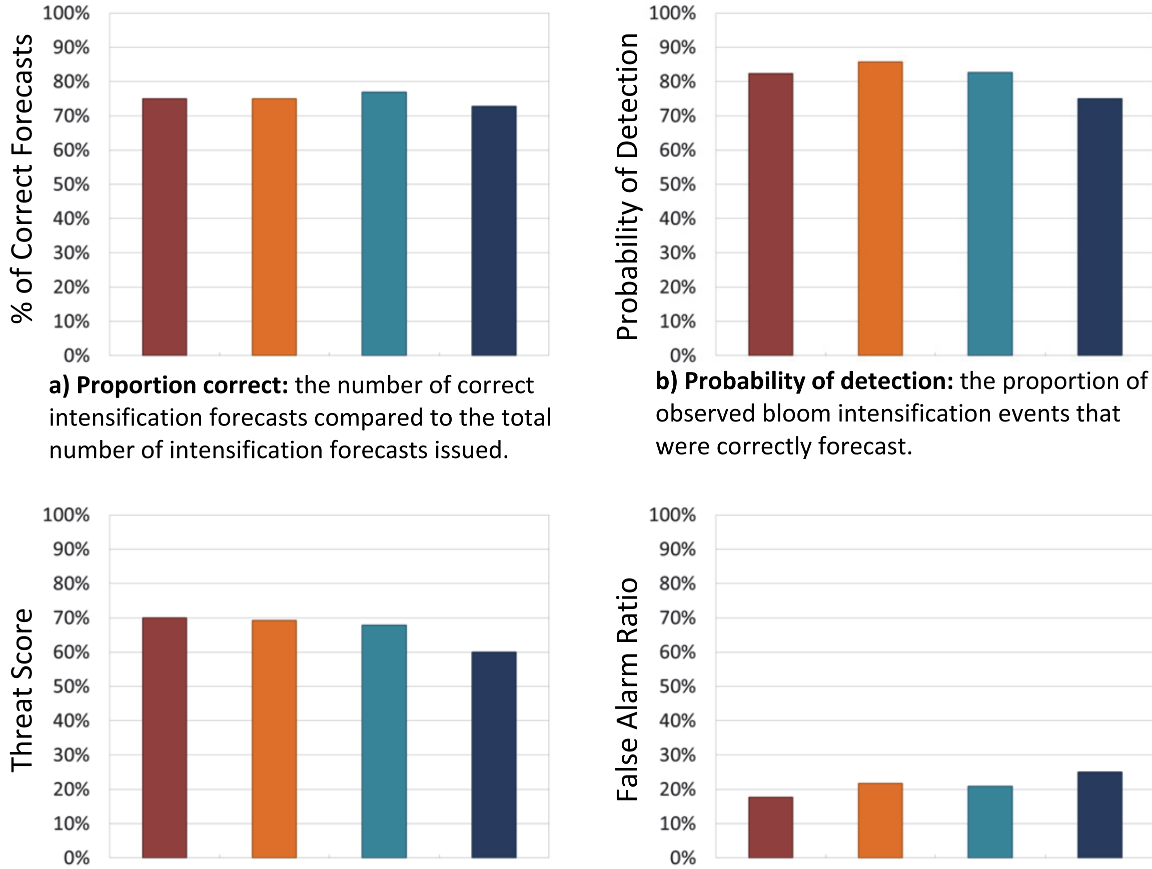
Number of Assessable Forecasts (n) for each Bloom Year				
Bloom Years	10/1/04 to 4/30/05	5/1/05 to 4/30/06	5/1/06 to 4/30/07	5/1/07 to 4/30/08
n	6	22	3	0

Figure 22. Accuracy of extent forecasts during the 2004 to 2008 bloom years.

Note: Values of N/A indicate that the denominator of the calculation was zero because observations of extent were unconfirmed (see Section 2.3.3.3 for an explanation of the statistical analyses used).

3.5.3 Intensification

Figure 23 shows that during BY2004-2008, overall, intensification forecasts issued for any of the geographic regions were consistently accurate with a relatively high proportion correct (72-77%), probability of detection (0.75-0.86), and threat scores (0.6-0.7), and relatively low false alarm ratios (0.18-0.25). The accuracy of intensification forecasts did vary by geographic region. The most consistently accurate intensification forecasts were issued for blooms in southwest Florida with a relatively high proportion correct (71-77%), probability of detection (0.82-1), and threat score (0.6-0.71). However, the false alarm ratio was somewhat variable, increasing over BY2006-2008 (0.17-0.4). The accuracy of intensification forecasts issued for blooms in northwest Florida was much more variable from year to year. The probability of detection was high in both bloom years (BY2005-2006=1.0 and BY2007-2008=0.83). However, both the proportion correct and threat score were higher in BY2007-2008 (0.90 and 0.83, respectively) than in BY2005-2006 (0.67 and 0.6, respectively). The false alarm ratio was also lower in BY2007-2008 (0.0) than in BY2005-2006 (0.4). Intensification forecasts issued for the bloom in east Florida (BY2007-2008) were the least accurate of the bulletin regions with a relatively low proportion correct (40%), probability of detection (0.33), and threat score (0.25), and relatively high false alarm ratio (0.5).



a) Proportion correct: the number of correct intensification forecasts compared to the total number of intensification forecasts issued.

b) Probability of detection: the proportion of observed bloom intensification events that were correctly forecast.

c) Threat score: Measure of forecasted intensification events, after removing the correct rejections.

d) False alarm ratio: the number of false alarms compared to the total number of intensification forecasts issued.

Number of Assessable Forecasts (n) for each Bloom Year				
Bloom Years	10/1/04 to 4/30/05	5/1/05 to 4/30/06	5/1/06 to 4/30/07	5/1/07 to 4/30/08
n	24	32	39	22

Figure 23. Accuracy of intensification forecasts during the 2004 to 2008 bloom years.

3.5.4 Respiratory Irritation Impacts

3.5.4.1 All Impact Levels

During BY2004-2008, the accuracy of impact forecasts overall was consistently high with a relatively high proportion correct (81-100%). The accuracy of impact forecasts, overall, varied by geographic region from BY2004-2008. All impact forecasts issued for southwest Florida during BY2004-2007 were consistently accurate with a relatively high proportion correct (81-100%). However, in BY2007-2008, the proportion correct was 0%, due to the low number of assessable forecasts issued for the region (n=1). Although blooms were not present in northwest and east Florida each year, the accuracy of the overall impact forecasts issued for both regions was high, with a relatively high proportion correct (NW FL: 81-96%, E FL: 92%).

3.5.4.2 No Impacts (None)

Respiratory impact forecasts were validated based on reports of coastal field observations. Due to the patchy nature of blooms, respiratory impacts typically do not affect the entire forecast area (half county) and observations are usually limited to a small number of predetermined locations along the coast. Thus, our method of assessment did not allow us to verify that no impacts were observed throughout the entire forecast area during the forecast period and forecast accuracy could not be estimated.

3.5.4.3 Very Low Impacts

There were no assessable “very low” impact forecasts issued during BY2004-2005. The accuracy of “very low” impact forecasts varied during BY2005-2008 (see Figure 24). The proportion correct was consistently high (92-100%). However, other measures of accuracy were inconsistent, with variable results for the probability of detection (N/A to 0.83 to 1.0), threat scores (N/A to 0.0 to 1.0), and false alarm ratios (N/A to 0.0 to 1.0). Similarly, for each geographic region, the accuracy of “very low” impacts varied. The proportion correct was consistently high in all regions (SW FL: 93-100%, NW FL: 93-100%, E FL: 92%). However, other measures of accuracy were inconsistent, with variation in the results for probability of detection (SW FL: N/A to 0.83 to 1.0, NW FL: N/A to 1.0, E FL: N/A), threat scores (SW FL: N/A to 0.58 to 1.0, NW FL: N/A to 1.0, E FL: N/A to 0.0), and false alarm ratios (SW FL: N/A to 0.0 to 0.33, NW FL: N/A to 0.0 to 1.0, E FL: N/A to 1.0). Note: Values of N/A indicate that the denominator of the calculation was zero because observations of “very low” impacts were unconfirmed during the assessment period (see Section 2.3.3.3 for an explanation of the statistical analyses used).

3.5.4.4 Low Impacts

There were no assessable “low” impact forecasts issued during BY2004-2005. However, Figure 25 shows that during BY2005-2008, “low” impact forecasts issued for any of the geographic regions were consistently accurate, with a relatively high proportion correct (89-100%) and probability of detection (0.75-1.0). From BY2005-2008, the threat scores ranged from 0.67-1.0. In addition, the false alarm ratios were consistently low (0.0-0.13). For southwest Florida, the only assessable “low” impact forecasts were issued during BY2005-2007. Those forecasts were fairly accurate, with a relatively high proportion correct (89-100%), probability of detection (0.75-1.0), and threat scores (0.68-1.0), and relatively low false alarm ratios (0.0-0.13). Northwest Florida “low” impact forecasts were consistently accurate, with a high proportion correct (96-100%), probability of detection (1.0), and threat scores (0.86-1.0), and relatively low false alarm ratios (0.0-0.14). The “low” impact forecasts issued for east Florida were the most accurate of the three geographic regions, with a perfect proportion correct (100%), probability of detection (1.0), threat score (1.0), and false alarm ratio (0.0).

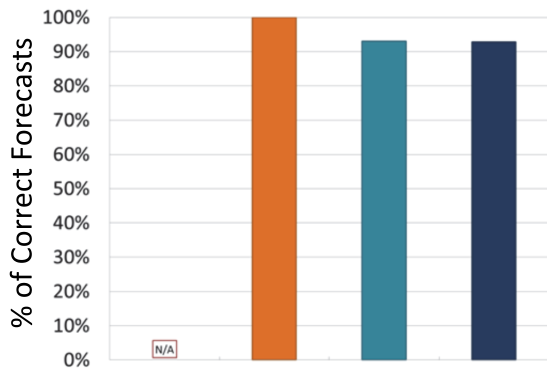
3.5.4.5 Moderate Impacts

Figure 26 shows that overall, during BY2004-2008, “moderate” impact forecasts issued for any of the geographic regions were consistently accurate, with a relatively high proportion correct (85.7-100%), probability of detection (0.73-1.0), and threat scores (0.73-1.0), and very low false alarm ratios (0.0-0.04). In general, the accuracy of “moderate” impact forecasts issued for each geographic region was relatively high. In southwest Florida, accuracy was highest during BY2004-2006, with perfect results for the proportion correct (100%), probability of detection

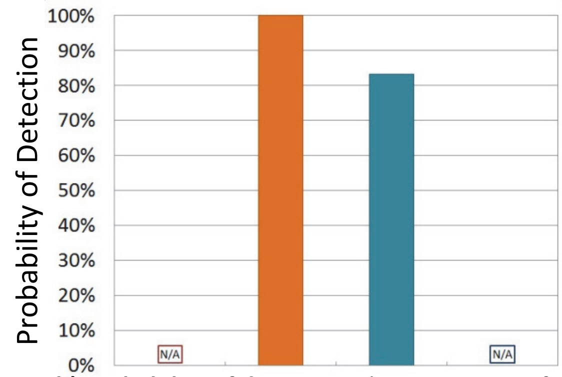
(1.0), threat scores (1.0), and false alarm ratios (0.0). During BY2006-2007, accuracy remained relatively high, as measured by the proportion correct (93.6%), probability of detection (0.81), threat score (0.79), and false alarm ratio (0.04). No assessable "moderate" impact forecasts were issued for southwest Florida from BY2007-2008. In northwest Florida, the accuracy of "moderate" impact forecasts was somewhat inconsistent. Forecasts issued during the bloom from BY2005-2006 were more accurate than those issued during the bloom from BY2007-2008, with a higher proportion correct (96.4 vs. 81.3%), probability of detection (0.95 vs. 0.67), and threat score (0.95 vs. 0.67). There were no false alarms in either bloom year. "Moderate" impact forecasts issued for the bloom in east Florida, during BY2007-2008, were also accurate, with a relatively high proportion correct (92%), probability of detection (0.83), and threat score (0.83), and no false alarms (0.0).

3.5.4.6 High Impacts

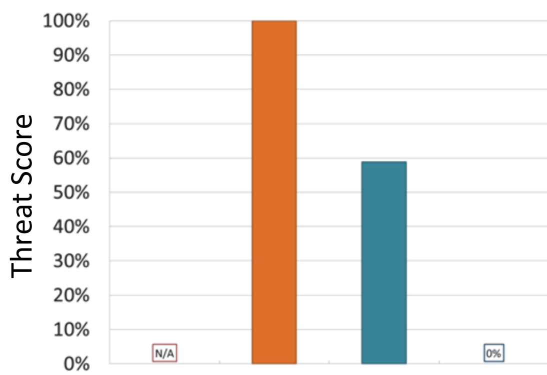
During BY2004-2008, for all of the geographic regions, the most accurate forecasts were issued for "high" impacts. Figure 27 shows that during BY2004-2006 and BY2007-2008, the "high" impact forecasts were perfectly accurate, with a proportion correct of 100%, probability of detection of 1.0, threat score of 1.0, and false alarm ratio (0.0). During BY2006-2007, accuracy remained relatively high, as measured by the proportion correct (93.6%), probability of detection (0.88), threat score (0.79), and false alarm ratio (0.13). All "high" impact forecasts issued for the blooms in southwest Florida during BY2004-2006 were accurate, with perfect results for the proportion correct (100%), probability of detection (1.0), threat scores (1.0), and false alarm ratios (0.0). However, forecast accuracy decreased slightly during the BY2006-2007, with a relatively high proportion correct (93.6%), probability of detection (0.88), and threat score (0.79), and relatively low false alarm ratio (0.12). There were no assessable "high" impact forecasts issued during BY2007-2008. In addition, all of the "high" impact forecasts issued for the blooms in northwest Florida (BY2005-2006 and BY2007-2008) and east Florida (BY2007-2008) were accurate, with perfect results for the proportion correct (100%), probability of detection (1.0), threat score (1.0), and false alarm ratio (0.0).



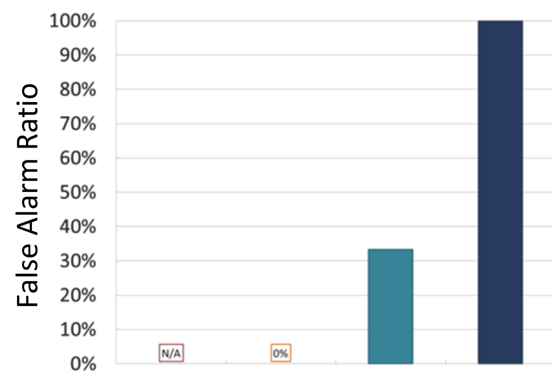
a) Proportion correct: the number of correct very low impact forecasts compared to the total number of very low impact forecasts issued.



b) Probability of detection: the proportion of observed bloom very low impact events that were correctly forecast.



c) Threat score: Measure of forecasted very low impact events, after removing the correct rejections.

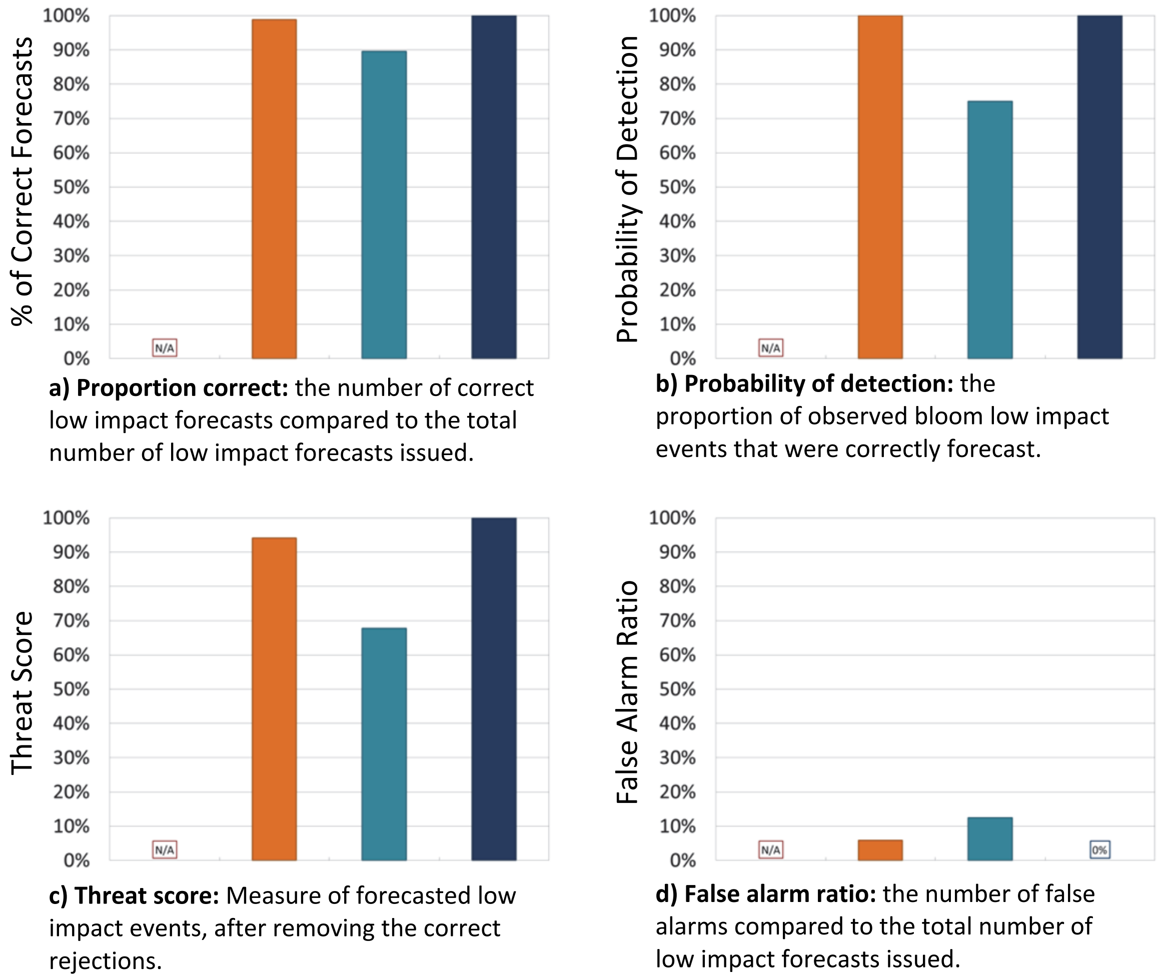


d) False alarm ratio: the number of false alarms compared to the total number of very low impact forecasts issued.

Number of Assessable Forecasts (n) for each Bloom Year				
Bloom Years	10/1/04 to 4/30/05	5/1/05 to 4/30/06	5/1/06 to 4/30/07	5/1/07 to 4/30/08
n	0	3	17	3

Figure 24. Accuracy of "very low" impact forecasts issued during the 2004 to 2008 bloom years.

Note: Values of N/A indicate that the denominator of the calculation was zero because observations of "very low" impacts were unconfirmed (see Section 2.3.3.3 for an explanation of the statistical analyses used).



a) Proportion correct: the number of correct low impact forecasts compared to the total number of low impact forecasts issued.

b) Probability of detection: the proportion of observed bloom low impact events that were correctly forecast.

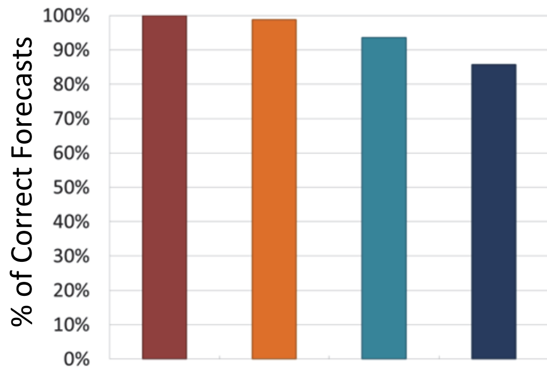
c) Threat score: Measure of forecasted low impact events, after removing the correct rejections.

d) False alarm ratio: the number of false alarms compared to the total number of low impact forecasts issued.

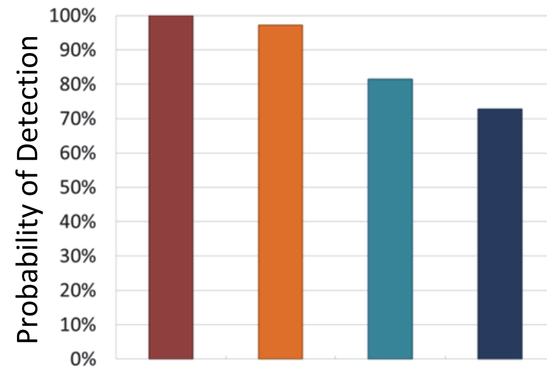
Number of Assessable Forecasts (n) for each Bloom Year				
Bloom Years	10/1/04 to 4/30/05	5/1/05 to 4/30/06	5/1/06 to 4/30/07	5/1/07 to 4/30/08
n	0	16	31	9

Figure 25. Accuracy of “low” impact forecasts issued during the 2004 to 2008 bloom years.

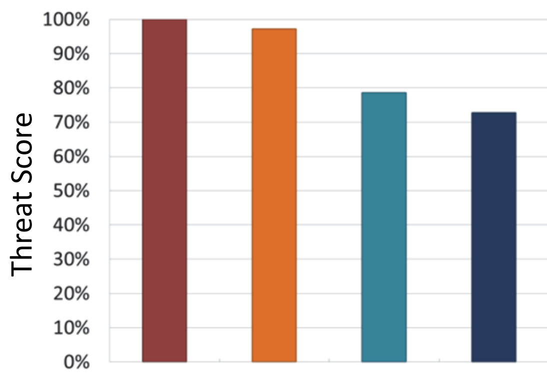
Note: Values of N/A indicate that the denominator of the calculation was zero because observations of “low” impacts were unconfirmed (see Section 2.3.3.3 for an explanation of the statistical analyses used).



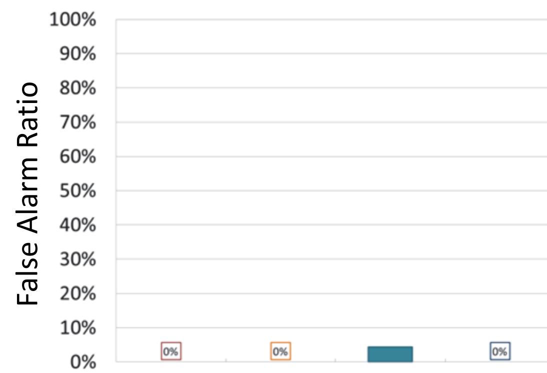
a) Proportion correct: the number of correct moderate impact forecasts compared to the total number of moderate impact forecasts issued.



b) Probability of detection: the proportion of observed bloom moderate impact events that were correctly forecast.



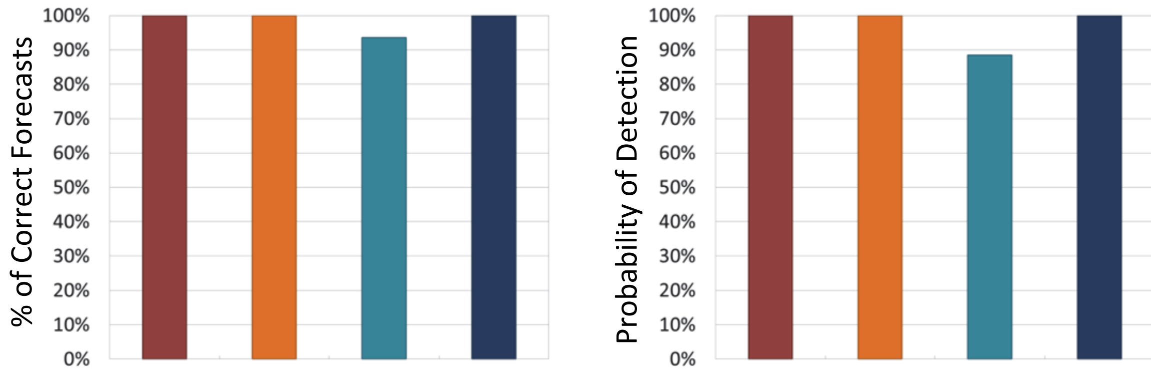
c) Threat score: Measure of forecasted moderate impact events, after removing the correct rejections.



d) False alarm ratio: the number of false alarms compared to the total number of moderate impact forecasts issued.

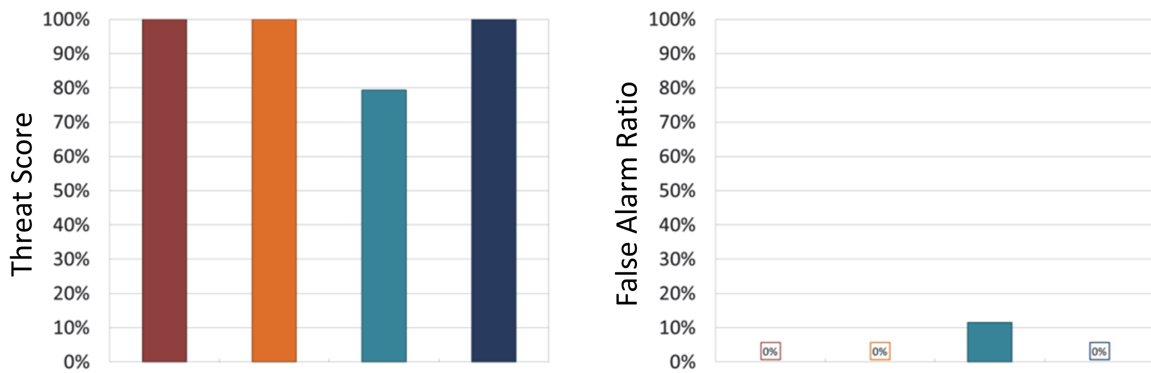
Number of Assessable Forecasts (n) for each Bloom Year				
Bloom Years	10/1/04 to 4/30/05	5/1/05 to 4/30/06	5/1/06 to 4/30/07	5/1/07 to 4/30/08
n	3	35	28	22

Figure 26. Accuracy of "moderate" impact forecasts during the 2004 to 2008 bloom years.



a) Proportion correct: the number of correct high impact forecasts compared to the total number of high impact forecasts issued.

b) Probability of detection: the proportion of observed bloom high impact events that were correctly forecast.



c) Threat score: Measure of forecasted high impact events, after removing the correct rejections.

d) False alarm ratio: the number of false alarms compared to the total number of high impact forecasts issued.

Number of Assessable Forecasts (n) for each Bloom Year				
Bloom Years	10/1/04 to 4/30/05	5/1/05 to 4/30/06	5/1/06 to 4/30/07	5/1/07 to 4/30/08
n	11	26	29	11

Figure 27. Accuracy of "high" impact forecasts during the 2004 to 2008 bloom years.

3.6 Forecast Reliability

Forecast reliability was estimated by calculating the bias, a statistic that indicates whether the forecast system consistently over-forecasted or under-forecasted events. Over-forecasting means that an event was forecast more often than it was observed, while under-forecasting means that an event was observed more often than it was forecast. Bias was calculated for each of the four forecast components: transport, extent, and intensification (see Figure 28). It was also calculated for the individual respiratory impact levels from "no impacts" to "high" impacts (see Figure 29).

3.6.1 Transport

Figure 28 shows that transport was slightly over-forecast during BY2004-2008, with bias ranging from 1.05 to 1.19. Transport forecast reliability varied among the geographic regions. In southwest Florida, transport was slightly over-forecast during BY2004-2005 and BY2006-2008 bloom years, with bias ranging from 1.1 to 1.5. However, there was no bias (1.0) in the transport forecasts issued during BY2005-2006. For the blooms in northwest Florida, transport was slightly over-forecast during BY2005-2006, with a bias of 1.25, but there was no bias (1.0) in the forecasts issued during BY2007-2008. For the bloom in east Florida during BY2007-2008, transport was under-forecast, with a bias of 0.67.

3.6.2 Extent

Extent was slightly over-forecast during BY2004-2006, with bias ranging from 1.25 to 1.33 (see Figure 28). From BY2006-2007, only three assessable extent forecasts were issued with no bias (1.0). No extent forecasts were issued during BY2007-2008. In southwest Florida, extent was slightly over-forecast during BY2004-2006, with bias ranging from 1.21 to 1.33. Although there were only three assessable extent forecasts issued during BY2006-2007, there was no forecast bias (1.0). In northwest Florida, extent was over-forecast during BY2005-2006, with a bias of 1.33. No assessable extent forecasts were issued in any geographic region during BY2007-2008.

3.6.3 Intensification

Intensification was slightly over-forecast during BY2005-2007, with a bias of 1.04 to 1.1 (see Figure 28). However, there was no bias (1.0) in the forecasts issued during BY2004-2005 or BY2007-2008. In southwest Florida, there was no bias in the intensification forecasts issued during BY2004-2006. However, over BY2006-2008, intensification was increasingly over-forecast, with a bias increasing from 1.04 to 1.67. In northwest Florida, intensification was over-forecast during BY2005-2006 (bias=1.67), but under-forecast during BY2007-2008 (bias=0.83). In east Florida, intensification was under-forecast during BY2007-2008, with a bias of 0.67.

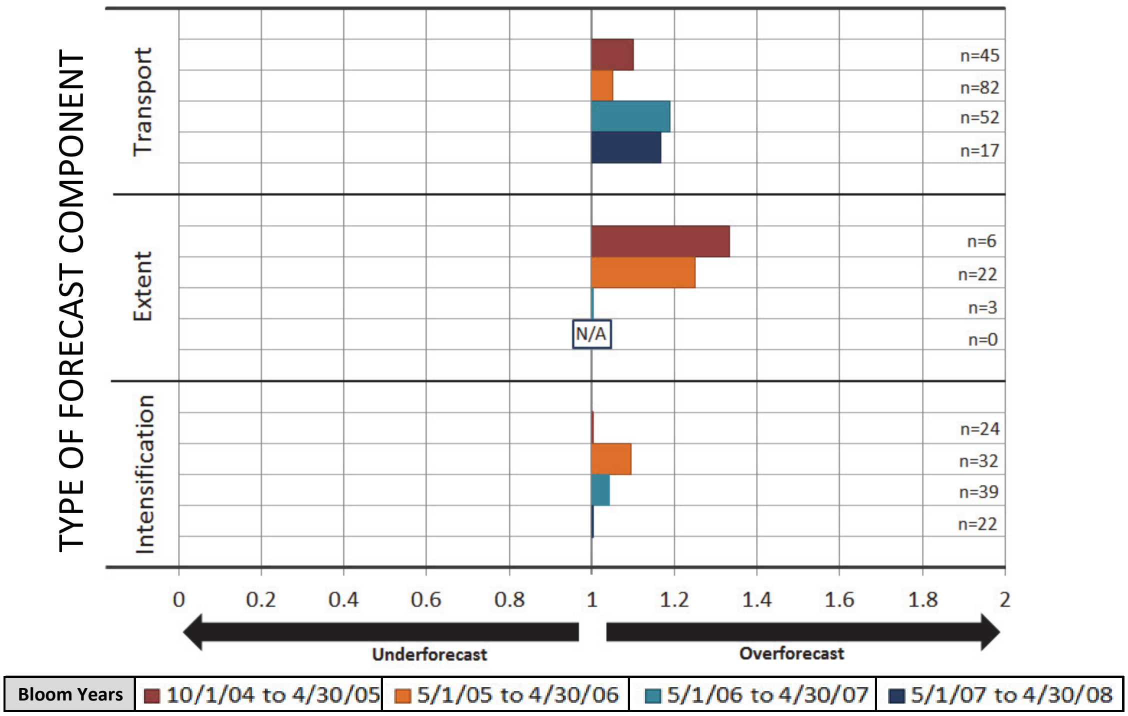


Figure 28. Forecast reliability (bias) in transport, intensification, and extent forecasts during the 2004 to 2008 bloom years.

Note: Values of N/A indicate that the denominator of the calculation was zero because observations of extent were unconfirmed (see Section 2.3.3.3 for an explanation of the statistical analyses used).

3.6.4 Respiratory Irritation Impacts

3.6.4.1 No Impacts (None)

Respiratory impact forecasts were validated based on reports of coastal field observations. Due to the patchy nature of blooms, respiratory impacts typically do not affect the entire forecast area (half county) and observations are usually limited to a small number of predetermined locations along the coast. Thus, our method of assessment did not allow us to verify that no impacts were observed throughout the entire forecast area during the forecast period so forecast bias could not be estimated for that level of respiratory irritation.

3.6.4.2 Very Low Impacts

There were no assessable "very low" impact forecasts issued during BY2004-2005. There was no bias (1.0) in the "very low" impact forecasts issued during BY2005-2006 in any geographic region, but "very low" impacts were slightly over-forecast during BY2006-2007, with a bias of 1.25 (see Figure 29). Bias could not be assessed for "very low" impact forecasts issued during BY2007-2008 because observations of "very low" impacts were unconfirmed leaving zero in the denominator of the calculation (see Section 2.3.3.3 for an explanation of the statistical analyses used). In southwest Florida, during BY2005-2006, there was no bias (1.0) in the "very low" impact forecasts issued, but "very low" impacts were slightly over-forecast during BY2006-2007 (bias=1.25). In northwest Florida, "very low" impact forecasts issued during BY2005-2006 had no bias (1.0).

3.6.4.3 Low Impacts

There were no assessable "low" impact forecasts issued during BY2004-2005. Figure 29 shows that for all geographic regions, "low" impacts were slightly over-forecast during BY2005-2006 (bias=1.06) and slightly under-forecast during BY2006-2007 (bias=0.86). There was no bias (1.0) for the "low" impact forecasts issued during BY2007-2008. In southwest Florida, there were no assessable "low" impact forecasts issued during BY2004-2005 or BY2007-2008. There was no bias (1.0) in "low" impact forecasts made during BY2005-2006, and "low" impacts were slightly under-forecast during BY2006-2007, with a bias of 0.86. In northwest Florida, "low" impacts were slightly over-forecast during BY2005-2006, with a bias of 1.17. During BY2007-2008, there was no bias (1.0) in forecasts issued for either northwest Florida or east Florida.

3.6.4.4 Moderate Impacts

There was no bias (1.0) in "moderate" impact forecasts issued in any geographic region during BY2004-2005 (see Figure 29). However, "moderate" impacts were slightly under-forecast during BY2005-2008, with a bias ranging from 0.73 to 0.97. In southwest Florida, there was no bias (1.0) in "moderate" impact forecasts issued during BY2004-2006. However, "moderate" impacts were slightly under-forecast during BY2006-2007, with a bias of 0.85. During BY2007-2008, the only assessable forecast issued for southwest Florida was an underestimate so the bias was 0.0. In northwest Florida, "moderate" impacts were slightly under-forecast during BY2005-2006, with a bias of 0.95, but the level of under-forecasting increased during BY2007-2008, with a bias of 0.67. "Moderate" impacts were also slightly under-forecast in east Florida during BY2007-2008 bloom year, with a bias of 0.83.

3.6.4.5 High Impacts

There was no bias (1.0) in "high" impact forecasts issued during BY2004-2008 in any of the geographic regions (see Figure 29).

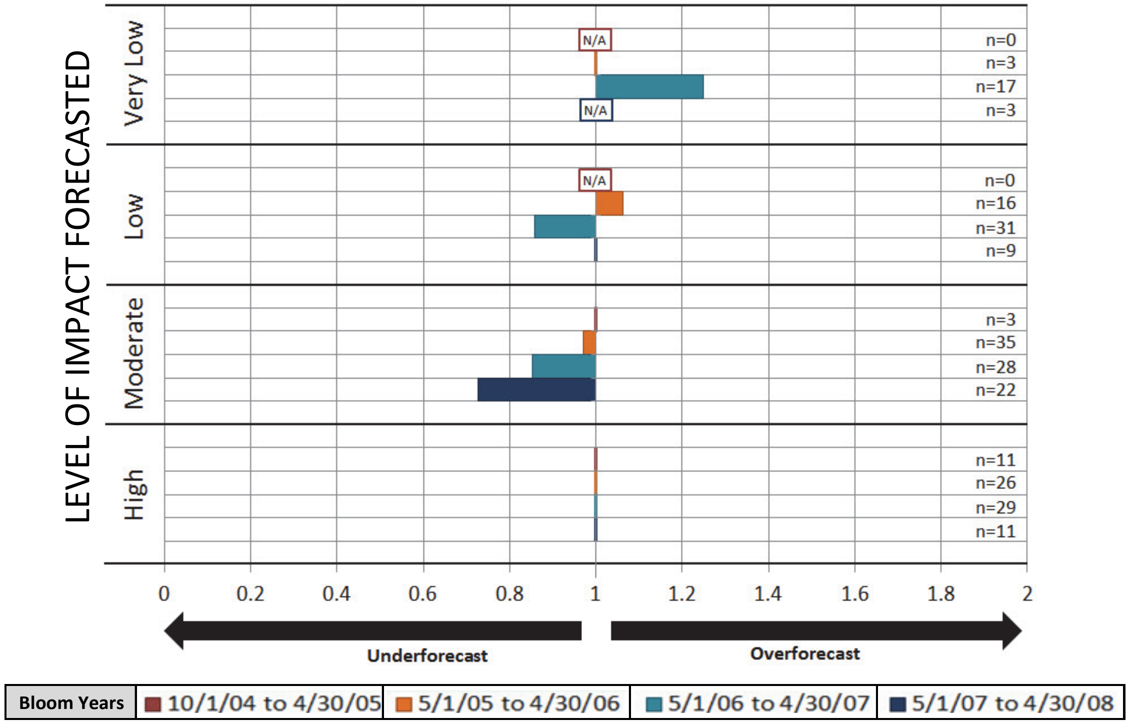


Figure 29. Forecast reliability (bias) in respiratory impact forecasts during the 2004 to 2008 bloom years.

Note: Values of N/A indicate that the denominator of the calculation was zero because observations of "very low" or "low" impacts were unconfirmed (see Section 2.3.3.3 for an explanation of the statistical analyses used).

3.7 Forecast Skill

Forecast skill was estimated by calculating the Heidke skill score, a statistic that represents accuracy relative to chance. It compares the proportion of correct forecasts with an estimate of the correct forecasts that could be due solely to random chance. A score of zero indicates that the forecast is no better than random chance at predicting the event (i.e. no forecast skill), a negative score indicates that the forecast performs worse than chance, and a perfect score is one or 100%. The Heidke skill score was calculated for transport, extent, and intensification (see Figure 30). It was also calculated for the individual impact forecasts levels, from "none" to "high" impacts, and the overall impacts (see Figure 31).

3.7.1 Transport

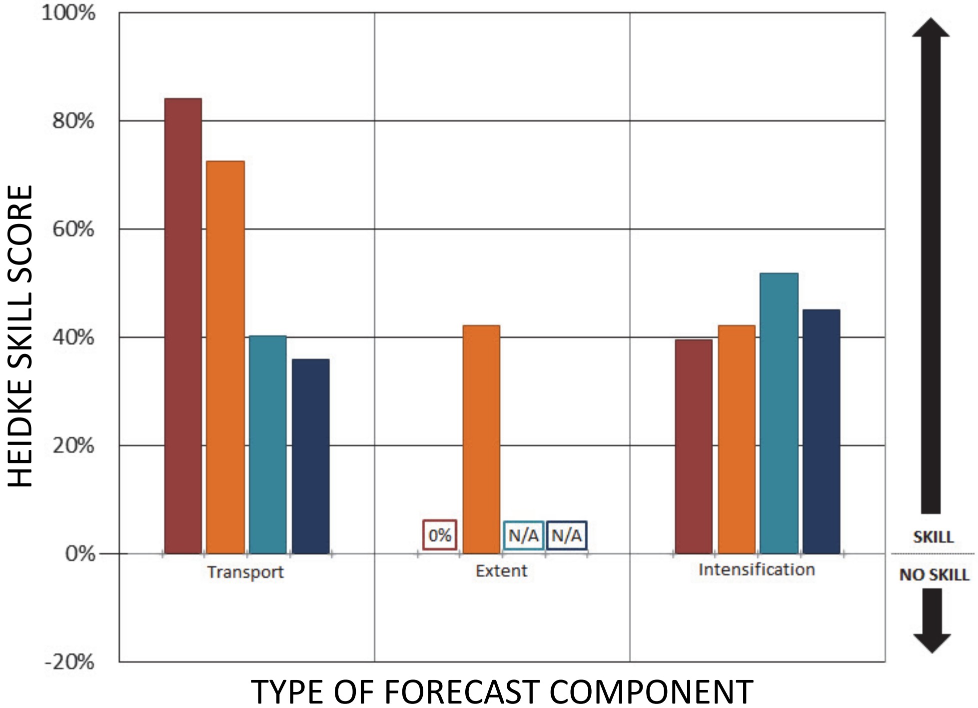
Figure 30 shows that the transport forecasts issued during BY2004-2008 performed much better than chance, with Heidke skill scores ranging from 36-84% improvement over chance. In southwest Florida, transport forecasts issued during BY2004-2008 performed much better than chance, with Heidke skill scores ranging from 40-84% improvement over chance. Similarly, in northwest Florida, during BY2005-2006, transport forecasts performed much better than chance, with a Heidke skill score of 63%. Heidke skill scores could not be calculated for the bloom during BY2007-2008 in northwest Florida because, although transport events were correctly forecasted to occur, there were no correct rejections leaving a zero in the denominator. Transport forecasts issued for east Florida during BY2007-2008 demonstrated no improvement over chance, with a Heidke skill score of 0%.

3.7.2 Extent

Extent forecasts issued during BY2004-2005 performed no better than chance, with a Heidke skill score of 0% (see Figure 30). However, forecasts performed better than chance during BY2005-2006, with a Heidke skill score of 42% improvement over chance. Heidke skill scores could not be calculated for extent forecasts issued during BY2006-2008 because there were no assessable observations of extent changes. In southwest Florida, extent forecasts issued during BY2004-2005, performed no better than chance, with a Heidke skill score of 0%. However, those issued for BY2005-2006 had a Heidke skill score that indicated a 50% improvement over chance. In contrast, extent forecasts issued for northwest Florida during BY2005-2006 performed no better than chance, with a Heidke skill score of 0%. The Heidke skill score could not be calculated for east Florida because there were no extent forecasts made for the region.

3.7.3 Intensification

Intensification forecasts issued during BY2004-2008 consistently performed better than chance, with Heidke skill scores ranging from 40-52% improvement over chance (see Figure 30). In southwest Florida, intensification forecasts issued for BY2004-2008 performed consistently better than chance, with Heidke skill scores ranging from 40-52% improvement over chance. In northwest Florida, intensification forecasts issued during BY2005-2006 demonstrated a 33% improvement over chance. During BY2007-2008, the forecasts performed even better, with a Heidke skill score indicating an 80% improvement over chance. By contrast, intensification forecasts issued during BY2007-2008 in east Florida performed worse than chance, with a Heidke skill score of -15.4%.



Number of Assessable Forecasts (n) for each Bloom Year					
	Bloom Years	10/1/04 to 4/30/05	5/1/05 to 4/30/06	5/1/06 to 4/30/07	5/1/07 to 4/30/08
Forecast Component	*Transport*	45	82	52	17
	Extent	6	22	3	0
	Intensification	24	32	39	22

Figure 30. Forecast skill of transport, extent and intensification forecasts during the 2004 to 2008 bloom years. The Heidke skill score is a skill corrected verification measure of categorical forecast performance that references the proportion of correct forecasts relative to the number of correct forecasts that could be made by random chance.

Note: Values of N/A indicate that the denominator of the calculation was zero because observations of extent were unconfirmed (see Section 2.3.3.3 for an explanation of the statistical analyses used).

3.7.4 Respiratory Irritation Impacts

3.7.4.1 All Impact Levels

Figure 31 shows that all impact forecasts issued during BY2004-2008 were consistently much better than chance, with Heidke skill scores indicating 76 to 100% improvement over chance. During BY2004-2008, the skill of overall impact forecasts was more variable in southwest Florida than in the other geographic regions. During BY2004-2007, impact forecasts issued for southwest Florida performed better than chance, with Heidke skill scores ranging from 46 to 100% improvement over chance. However, during BY2007-2008, there was no improvement over chance, with a Heidke skill score of 0% (n=1). In northwest Florida, impact forecasts, issued during BY2005-2006 and BY2007-2008, performed much better than chance, with Heidke skill scores of 93% and 73%, respectively. Similarly, impact forecasts issued for east Florida during BY2007-2008, performed much better than chance, with a Heidke skill score indicating an 88% improvement over chance.

3.7.4.2 No Impacts (None)

The Heidke skill scores could not be calculated for forecasts issued during BY2004-2006 because there were no forecasts of “none” during that period that could be assessed as “confirmed” or “false”. During BY2006-2008, forecasts issued for impacts of “none” performed no better than chance, with Heidke skill scores of 0%. Forecasts issued for impacts of “none” performed no better than chance in either southwest Florida (BY2006-2008) or northwest Florida (BY2007-2008), with Heidke skill scores of 0% improvement over chance. The Heidke skill score could not be calculated for forecasts issued for east Florida during BY2007-2008.

3.7.4.3 Very Low Impacts

There were no assessable “very low” impact forecasts issued during BY2004-2005 so the Heidke skill score could not be calculated. During BY2005-2007, “very low” impact forecasts performed much better than chance, with Heidke skill scores of 100% and 70%, respectively (see Figure 31). However, “very low” impact forecasts issued during BY2007-2008 performed no better than chance, with a Heidke skill score of 0%. The Heidke skill score could not be calculated for “very low” impact forecasts issued for southwest Florida during BY2004-2005, and no assessable “very low” impact forecasts were issued during BY2007-2008. However, during BY2005-2006 and BY2006-2007, “very low” impact forecasts issued for southwest Florida performed much better than chance, with Heidke skill scores of 100% and 70%, respectively. Forecast skill was much more variable in northwest Florida. During BY2005-2006, “very low” impact forecasts issued for northwest Florida had a Heidke skill score indicating a 100% improvement over chance. Yet, during BY2007-2008, “very low” impact forecasts performed no better than chance, with a Heidke skill score of 0%. “Very low” impact forecasts issued in east Florida during BY2007-2008 also performed no better than chance (0%).

3.7.4.4 Low Impacts

There were no assessable “low” impact forecasts issued during BY2004-2005 so the Heidke skill score could not be calculated. Figure 31 shows that during BY2005-2008, “low” impact forecasts consistently performed much better than chance, with Heidke skill scores ranging from 74 to 100% improvement over chance. The Heidke skill scores could not be calculated for “low” impact forecasts issued for southwest Florida during BY2004-2005, and no assessable “low” impact forecasts were issued during BY2007-2008. During BY2005-2007, “low” impact forecasts issued for southwest Florida performed much better than chance, with Heidke skill scores of 100% and 74%, respectively. During BY2005-2006 and BY2007-2008, “low” impact forecasts issued for northwest Florida performed even better than chance, with Heidke skill scores of 90% and 100%, respectively. In east Florida, “low” impact forecasts issued during BY2007-2008 bloom year demonstrated a 100% improvement over chance, as indicated by the Heidke skill score.

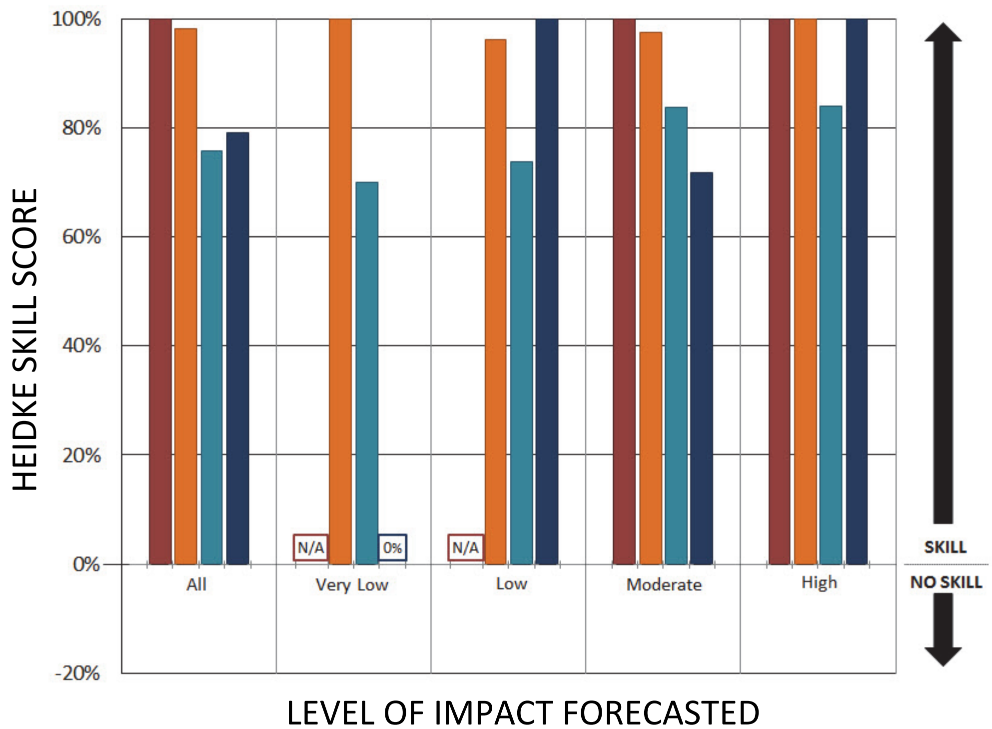
3.7.4.5 Moderate Impacts

Figure 31 shows that during BY2004-2008, “moderate” impact forecasts performed much better than chance, with Heidke skill scores indicating a 72 to 100% improvement over chance. In southwest Florida, during BY2004-2007, “moderate” impact forecasts performed much better than chance, with Heidke skill scores indicating an 84-100% improvement over chance. However, during BY2007-2008, no assessable “moderate” impact forecasts were issued. Consequently, the Heidke skill score was 0%. In northwest Florida, during BY2005-2006 and

BY2007-2008, “moderate” impact forecasts performed much better than chance, with Heidke skill scores of 92% and 64%, respectively. Similarly, in east Florida, during BY2007-2008, “moderate” impact forecasts also performed much better than chance, with a Heidke skill score of 84% improvement over chance.

3.7.4.6 High Impacts

“High” impact forecasts issued during BY2004-2008 consistently performed much better than chance, with Heidke skill scores indicating an 84-100% improvement over chance (see Figure 31). In southwest Florida, “high” impact forecasts issued during BY2004-2007 consistently performed much better than chance, with Heidke skill scores indicating an 84-100% improvement over chance. There were no assessable “high” impact forecasts made during the BY2007-2008. In northwest Florida, the Heidke skill scores calculated for “high” impact forecasts issued during BY2005-2006 and BY2007-2008 both indicate a 100% improvement over chance. In addition, in east Florida, during BY2007-2008 the Heidke skill score indicated a 100% improvement over chance.



		Number of Assessable Forecasts (n) for each Bloom Year			
Bloom Years		10/1/04 to 4/30/05	5/1/05 to 4/30/06	5/1/06 to 4/30/07	5/1/07 to 4/30/08
Forecast Component	*All*	14	81	93	42
	Very Low	0	3	17	3
	Low	0	16	31	9
	Moderate	3	35	28	22
	High	11	26	29	11

Figure 31. The forecast skill of respiratory impacts during the 2004 to 2008 bloom years. The Heidke skill score is a skill corrected verification measure of categorical forecast performance that references the proportion of correct forecasts relative to the number of correct forecasts that could be made by random chance.

Note: Values of N/A indicate that the denominator of the calculation was zero because observations of "very low" or "low" impacts were unconfirmed (see Section 2.3.3.3 for an explanation of the statistical analyses used).

4. DISCUSSION

4.1 Early Warning

Nine of the thirteen *Karenia brevis* events during BY2004-2008 were first identified by the Harmful Algal Bloom Operational Forecast System (HAB-OFS) satellite imagery and then confirmed by *in situ* sampling collected by organizations in Florida (see Appendix IV). This demonstrates that the HAB-OFS succeeds in providing advance notice of the majority of HABs before they begin to impact the coast.

Three of the four events that were not detected first by satellite imagery were located in either northwest or east Florida, where the HAB-OFS does not routinely produce bulletins unless a bloom is confirmed. The bloom detection ability of the HAB-OFS is understandably limited during periods when the satellites are obscured by clouds, but performance also varies between geographic regions depending on their distinct optical characteristics, including a tendency for certain areas to have persistent turbidity, suspended solids and colored dissolved organic matter that contribute to light attenuation (Tomlinson, et al., 2004). Additionally, the anomaly method used by the HAB-OFS may sometimes confuse blooms of *K. brevis* with non-toxic phytoplankton when both are present in the same area, resulting in false positives (Tomlinson, Wynne, & Stumpf, 2009).

A study conducted by Tomlinson et al. (2009) indicated that the number of these false positives could be effectively reduced through implementing an ensemble approach, combining the current heuristic model and three detection algorithms: the chlorophyll anomaly, backscatter (b_{bp}/b_{bp}_Morel) and spectral shape of remote-sensing reflectance at 490 nm. While the chlorophyll anomaly algorithm currently employed by the HAB-OFS highlights regions of increased chlorophyll, the backscatter and spectral shape algorithms depend on the optical properties of various blooms and might help distinguish between *K. brevis* blooms and other phytoplankton (Tomlinson, Wynne, & Stumpf, 2009). This is especially important during times when *K. brevis* blooms persist through the spring and summer months because blooms of other phytoplankton like diatoms and *Trichodesmium* spp. also become common.

4.2 Bulletin Utilization

During BY2004-2008, weekly bulletin utilization was consistently greater than 83%. Greater than 60% of the individual bulletins issued were confirmed utilized. Utilization was greatest for bulletins labeled as “high priority”. This demonstrates that the priority categories assigned to bulletins successfully indicate the importance of their content to bulletin subscribers.

Despite inter-regional differences in bloom frequency, utilization was high in both southwest Florida and east Florida. Blooms are more frequent in the southwest Florida region, and the majority of Florida bulletin subscribers reside in southwest Florida. Confirmed bulletin utilization was consistently the highest in southwest Florida. Blooms are less frequent in east Florida, and the least number of Florida bulletin subscribers reside in east Florida. However, during the east Florida bloom during BY2007-2008, a high proportion of bulletins were confirmed utilized. This indicates that bulletins are helpful to subscribers involved in response to both frequent and rare bloom events. Confirmed utilization was lower for bulletins issued for the blooms in northwest Florida, but this seems to be due to under-reporting. In southwest Florida and east Florida, routine reports issued by organizations such as the Collier County Natural Resources Department, made frequent mention of NOAA HAB bulletin data and forecasts, clearly demonstrating usage (see Appendix IV). However, there were no such reports for northwest Florida, and all bulletin utilization was inferred from samples that were collected in areas specifically recommended by the bulletin. However, utilization could not always be verified through this indirect method.

Overall, utilization was most likely underestimated because it could only be confirmed when there was evidence available that bulletin content was used by another reputable source such as a state or county agency, research institution or public media entity. Since data on utilization of the product is extremely important for guiding improvements, efforts should be made to evaluate utilization and usefulness through other methods, including implementing routine surveys and tracking website statistics.

4.3 Frequency of Forecasts

There was a wide range in the frequency that components were forecasted. Respiratory impacts were forecasted the most often, followed by transport, intensification and extent. There are four likely reasons for this variation.

First, some bulletins contained multiple forecasts. Depending on the size of the bloom and changing wind conditions, multiple respiratory impact forecasts might be issued for more than one half-county area, impact level or date range. Multiple transport and intensification forecasts might also be issued, if conditions were expected to change over a given date range or if the conditions were different across the extent of the bloom. For instance, differences in forecasted winds within the southwest Florida region might suggest the possibility of southerly transport of a bloom alongshore Pinellas to Sarasota County, but northerly transport of the same bloom located offshore Collier County.

Secondly, some conditions tend to occur more frequently rendering some forecast components more widely-applicable than others. For instance, almost all bulletins contained at least one impact forecast because even when there was no bloom present, analysts forecasted that no impacts were expected in the region. In order to forecast transport or extent, predicted wind conditions must be in a consistent direction for 24 hours or more, and 48 hours or more for intensification. Bloom transport can be forecasted for both active blooms and unconfirmed features visible in satellite imagery. However, intensification can only be forecasted when there is a developing bloom present along the coast.

Thirdly, limited forecast resolution and availability of data might make some components easier to forecast than others. By definition, extent forecasts required confidence that a bloom would transport into a new half or whole county region. Often the distance that a bloom might transport was uncertain because of the limited resolution in the forecast models. Furthermore, clouds in imagery make it difficult to ascertain the exact bloom boundaries. The frequency with which extent forecasts were issued decreased markedly from BY2006-2007 to BY2007-2008, as analysts became more aware of the limitations of the forecast model. The limitations included those summarized by Stumpf et al. (2009) that only large HABs, covering >10-30 km of coast could be reliably located and validated by sampling and imagery.

Finally, if certain components were indeed easier to forecast for the reasons given above, then there may have been variability between HAB-OFS analysts, dependent on their level of training and the time available for data analysis. Considerable effort was made to maintain consistency. For instance, to ensure quality control, each bulletin was written by a primary analyst and reviewed by a second analyst. New analysts were always paired with a more experienced analyst. Still, the reliance on mental integration methods to apply established scientific rules and heuristic and numerical models, might introduce variation between analysts (Stumpf, et al., 2003; Tomlinson, et al., 2004; Stumpf, Litaker, Lanerolle, & Tester, 2008). Although the review process for bulletins maintains the quality of forecasts, factors like the time required for data analysis could potentially reduce the frequency of issuance of more complicated forecasts, such as transport and intensification. This is supported by the fact that the highest percentage of forecasts were issued during BY2006-2007, when there were six analysts on the HAB-OFS team, rather than five. The next bloom year, the team was reduced to five analysts again. Unfortunately, during BY2007-2008 all three geographic regions in Florida were impacted by blooms. This meant that the HAB-OFS team was issuing multiple bulletins per day and time limitations may have accounted for the reduction in the frequency of transport and intensification forecasts during that time. The HAB-OFS is truly dependent on the time and expertise of the analyst team, and thus, it is imperative to maintain at least six fully trained analysts.

4.4 Assessment Capability

Respiratory impact forecasts tend to be among the most difficult to assess components because they rely solely on reports of observations in the field. Observational data was not collected on a routine and widespread basis until Mote Marine Laboratory (MML) began the Beach Conditions Reporting System for Sarasota County in 2006 and expanded the system to Pinellas, Manatee, Lee and Collier counties in 2007. Blooms are patchy by nature and their associated impacts are intermittent. Even with daily monitoring at select beaches, respiratory irritation is most likely under-reported. Some forecast areas might have brevetoxin aerosols blowing onshore as forecasted, but without experienced observers present, the respiratory irritation associated with the bloom might not be reported. For this reason, forecasts of “none” could not be assessed. Similarly, since “very low” impacts only affect people who have chronic respiratory conditions (like asthma) and are especially sensitive to brevetoxin aerosols, “very low” forecasts could only be confirmed if reports specified that “very low” impacts were observed.

While respiratory impact forecasts are the most difficult to assess of the forecast components, they were forecast with the most frequency for reasons noted in the above section. During BY2004-2008, the number of respiratory impact forecasts increased, especially from BY2006-2008. However, the number of assessable forecasts also decreased during BY2006-2008. This is likely due to a change in the bulletins (see Table 8 in the Methods section) that was adopted. Beginning in BY2006-2007, bulletins issued during both active and inactive bloom periods included a “no expected impacts” forecast statement for regions predicted to be unaffected by respiratory impacts. In effect, this served to increase the number of respiratory impact forecasts included in bulletins, but since forecasts of "no impacts" cannot definitively be assessed due to the patchy nature of blooms, these forecasts were marked "unconfirmed". In addition, during BY2007-2008, blooms were present in the southwest, northwest and east Florida geographic regions. At the time, observations of respiratory impacts were only recorded and reported on a routine basis along sections of the southwest Florida coastline by the MML Beach Conditions Reporting System. Thus, the assessment of respiratory impact forecasts for areas of southwest, northwest and east Florida that were not monitored by the MML Beach Conditions Reporting System relied on intermittent communications of observed impacts in those regions. Such anecdotal information has a bias toward reporting major respiratory impacts, which made it much more difficult to assess the respiratory impact forecasts associated with the small, patchy blooms in southwest Florida during BY2007-2008 (Stumpf, et al., 2009).

Unlike respiratory impact forecasts, the validation of transport, extent and intensification forecasts depend mostly on the availability of quality satellite imagery in the HAB region during the date range of the forecast. Still, some forecast types may be easier to evaluate than others. Intensification relies on clear changes in chlorophyll concentration in the area and/or sample data. Transport and extent may be more difficult to assess at times because they require a series of satellite images where the bloom location is consistently distinguishable. Clouds in imagery render bloom boundaries indiscernible. Stumpf et al. (2009) determined that only large HABs, covering >10-30 km of coast could be reliably located and validated by sampling and imagery so the ability to assess transport forecasts may have decreased during BY2007-2008 because of the small, patchy blooms in southwest Florida that rendered the forecasts more difficult to confirm.

4.5 Forecast Quality

4.5.1 Transport and Extent

During BY2004-2008, overall, bloom transport forecasts were highly accurate and consistently performed better than chance at predicting bloom movement. On the other hand, extent forecasts were issued much less frequently with variable accuracy and skill. Extent forecasts performed no better than chance during BY2004-2005, but demonstrated a great improvement over chance during BY2005-2007. Estimates of forecast reliability indicated that transport was slightly over-forecast, while the bias was even greater for extent forecasts. This means the model was biased towards predicting either the direction of bloom movement or change of spatial extent into a new county more often than bloom transport or changes in extent were observed. There was some variation in performance among the geographic regions. In both southwest and northwest Florida, transport forecasts were highly accurate, with a slight tendency to over-forecast the potential for bloom movement. Extent forecasts for blooms in southwest Florida were accurate, but the model only out-performed chance during BY2005-2006. Similarly, the extent forecasts issued for the northwest Florida bloom during BY2005-2006 were accurate, but performed no better than chance at predicting extent. Transport forecasts were estimated to have a slightly lower accuracy in east Florida and performed no better than chance at predicting bloom movement. Transport was slightly under-forecast in this region, meaning at times no bloom movement was predicted, but transport was observed. No extent forecasts were issued for east Florida.

This suggests that the model for predicting bloom transport and extent should be improved for all geographic regions, but especially for east Florida. During BY2004-2007, the model performed inconsistently at predicting changes in bloom extent. By BY2007-2008, no extent forecasts were issued. Further extent forecasts should not be made until the model is improved. Since bloom extent is closely linked to bloom transport, these results support the need to develop better ways of estimating how far and how fast a bloom is likely to move.

Uncertainties in the resolution of satellite imagery and water samples combined with the natural patchiness of *Karenia brevis* blooms often make it difficult to identify the precise boundaries of the bloom (Stumpf, et al., 2009). This complicates the accurate assessment of transport and extent forecasts. Stumpf et al. (2009) found that the resolution of the model used to forecast bloom transport and extent is such that only large HABs, spanning >10-30 km of coast, can be consistently located and validated by satellite imagery and water samples. One possible reason for the forecast bias is that, although the model performed well at predicting the direction that a bloom might move, there were limitations when attempting to predict the potential speed and distance of the movement. Transport and extent forecasts are made for 3-4 days into the future. Thus, a bloom may be moving south as predicted, but if the pace is slower and it does so over a 7 day period, it would seem that no transport was occurring and there would be no extent change observed. A slight bias towards over-forecasting bloom transport and extent change might be tolerated by the user community because it still may allow coastal resource managers to prepare early for potential bloom impacts. However, it is clear that the resolution, accuracy and reliability of the model could be improved. Bulletin users, like coastal resource managers and public health officials, would benefit most from a model that predicted the distance of bloom movement, better predicted transport direction, reliably predicted changes in spatial extent and minimized false alarms.

As part of the Integrated Ocean Observing System (IOOS) Data Integration Framework (DIF) assessment, the use of 2D and 3D particle trajectory models for predicting the movement of *Karenia brevis* blooms were compared. The results of the evaluation suggested that a 3D trajectory model better describes the movement of *K. brevis*. The authors found that such a model would improve the bloom transport and extent forecasts in the following ways: enhance the forecast availability, increase the length of the forecast to 7 days (from 3-4 days), and increase the objectivity of the forecast methods (Integrated Ocean Observing System, 2010). These improvements would be meaningful to members of the bulletin user community, such as coastal resource managers and public health officials, who require reliable, accurate and precise forecasts of both the direction and the distance of bloom movement with as much advance warning as possible in order to help them mitigate bloom impacts.

4.5.2 Intensification

Forecasts of bloom intensification were highly accurate and consistently performed better than chance, overall, during BY2004-2008. Intensification was slightly over-forecast during BY2005-2007, but no bias was evident in the other two years.

Performance did vary greatly among the geographic regions though. Forecasts of bloom intensification in southwest Florida and northwest Florida were accurate and consistently performed better than chance. There was no consistent bias in either region. On the other hand, intensification forecasts made for the bloom in east Florida were not as accurate as those made for the other geographic regions. In fact, the Heidke skill score suggested that the forecast model performed worse than chance at predicting intensification in east Florida. Intensification was also under-forecast in east Florida.

There are some possible reasons for the poor performance of the intensification forecast model in east Florida. Along the east coast of Florida, it is more difficult to discern features in satellite imagery, especially north of Cape Canaveral, where high chlorophyll levels are not uncommon. A bloom may become confused with other features also present in the imagery. This means that intensification might be predicted for a feature that was erroneously identified as a bloom or that it is simply more difficult to confirm intensification in a series of images where the bloom extent might be ambiguous. In southwest and northwest Florida, upwelling conditions promote the potential for bloom intensification (Stumpf, Litaker, Lanerolle, & Tester, 2008). However, this seems not to be the case in east Florida. Downwelling winds have been suggested to promote bloom intensification at the coast if an offshore feature has been present, but this needs to be investigated further. Based on the results, intensification can be forecast with confidence for southwest and northwest Florida, but it should not be forecast for east Florida until a better model for that region is developed.

4.5.3 Impact Forecasts

4.5.3.1 All Impact Levels

The respiratory impact forecasts are one of the most important components of the HAB-OFS (Stumpf, Fleming-Lehtinen, & Graneli, 2010). All impact forecasts issued during BY2004-2008 were highly accurate and consistently performed much better than chance. Such high quality respiratory irritation forecasts are imperative because these are the only forecasts that are made immediately available to the public and they directly warn the public about possible health risks.

Stumpf et al. (2009) found that although respiratory impact forecasts perform well at a half-county scale, when the forecasts were assessed for individual beaches they only correctly predicted the observed conditions at a particular location and time of day 20% of the time. This indicates patchiness of blooms at scales finer than about 10 km (Stumpf, et al., 2009). This patchiness was always communicated along with the half-county forecast, but there is still a possibility that individuals might misinterpret the precautionary information given and avoid all beaches/areas within the entire half-county forecast region. For this reason, developing finer resolution forecasts is vital as it will improve the ability of the HAB-OFS to enable informed decision-making that protects public health, while reducing over-warning that might negatively impact local economies.

4.5.3.2 No Impacts and Very Low Impacts

Forecasts of "no impacts" could not be adequately assessed. Likewise, since "very low" impacts are limited to members of the population who suffer from chronic respiratory issues, the forecast level was difficult to assess. "Very low" impact forecasts were only rarely confirmed when reports of observed respiratory impacts specified that someone suffering from chronic respiratory issues had experienced symptoms associated with a bloom. For the most part, the impacts were only assessable when higher impact levels were observed. For example, observations of “moderate” or “high” respiratory impacts would invalidate a forecast of “no impacts” or “very low”.

Due to the patchy nature of blooms, it is common that beach-goers experience respiratory irritation, while those at nearby beaches are unaffected. Without a finer forecast resolution, it will remain difficult to assess forecasts of “no impacts” because even if no impacts are observed at several beaches in the forecast region, there is no certainty that no impacts were observed throughout the region. However, “very low” impact forecasts were also rarely assessable because the level is limited to those suffering from chronic respiratory impacts.

In an effort to improve the forecasts, the definitions of the forecast levels may need to be revised. Perhaps the “very low” and “low” forecast levels could be combined. The “low” impact level is limited to members of the population who suffer from chronic respiratory issues and otherwise healthy individuals who may be more sensitive to brevetoxin aerosols. The benefit of combining the two categories would be that the assessability of the forecasts would increase, since “low” levels of respiratory irritation are observed and reported more frequently than “very low” levels.

4.5.3.3 Low Impacts

Of the “low” impact forecasts that were issued in BY2004-2005, none were assessable. However, during BY2005-2007, the assessable “low” impact forecasts were consistently accurate in all forecast regions. In BY2007-2008, “low” impact forecasts were consistently accurate in both northwest and east Florida, but no “low” respiratory impact forecasts were assessable in southwest Florida. The reliability of “low” impact forecasts varied over the bloom years. They were slightly over-forecast during BY2005-2006, but under-forecast during BY2006-2007. There was no bias in the forecasts issued during BY2007-2008. The “low” impact forecasts consistently performed better than chance in all regions.

By definition, the “low” respiratory impact level forecasted by the HAB-OFS is limited to individuals who do not necessarily have a chronic respiratory illness, but may nonetheless be more sensitive to brevetoxin aerosols than the general population. This makes the forecast level difficult to assess because a limited number of people will be able to observe the level of respiratory irritation forecasted. The HAB-OFS definition also differs from that of the Mote Marine Laboratory’s Beach Conditions Reporting System for the Gulf Coast of Florida although, the respiratory irritation observations were used to assess HAB-OFS respiratory impact forecasts as much as possible. The “slight” level of respiratory irritation is defined as the observation of a “few coughs/sneezes heard” in a thirty second sample period (Mote Marine Laboratory, 2013). This would seem to more aptly describe the HAB-OFS’ definition of a “moderate” level of impact, which indicates that “people at the beach may notice mild symptoms” (NOAA, 2013). Further investigation is needed in order to make sure the observational data is being applied to the evaluation in a way that best represents the observed respiratory conditions at the time.

4.5.3.4 Moderate and High Impacts

The assessable “moderate” and “high” respiratory impact forecasts were highly accurate in all years. In fact, forecasts of “high” respiratory impacts had nearly perfect accuracy. Both “moderate” and “high” respiratory impact forecasts also performed much better than chance at predicting the observed conditions. Not only were forecast accuracy and skill found to be very high, but there was also no forecast bias found in “high” impact forecasts issued during BY2004-2008 or in “moderate” impact forecasts issued during BY2004-2005. From BY2005-2008, “moderate” impact forecasts were slightly under-forecast. There was a slight decrease in the accuracy, reliability and skill of “moderate” respiratory impact forecasts from BY2006-2008. This seemed mainly due to incomplete sampling data or unexpected wind conditions, since the errors were recorded when “very low” respiratory impacts were forecasted and “moderate” respiratory impacts were observed.

In southwest Florida, both “moderate” and “high” respiratory impact forecasts were perfectly accurate during BY2004-2006. The accuracy decreased slightly in BY2006-2007. In northwest Florida, “high” impact forecasts were perfectly accurate. “Moderate” impact forecasts had nearly perfect accuracy in BY2005-2006, but accuracy decreased slightly from BY2007-2008. In east Florida, “high” impact forecasts were again perfectly accurate, while “moderate” respiratory impact forecasts had nearly perfect accuracy.

These findings are significant because the “moderate” and “high” respiratory impact forecasts are arguably the most vital forecasts for directly protecting public health, and they are the best performing forecasts issued by the HAB-OFS. Not only were they highly accurate, but they were also not over-forecast. Over-forecasting the “moderate” or “high” respiratory impact forecasts could have potentially undermined the believability of the forecasts themselves and jeopardized tourism by unnecessarily discouraging people from visiting the forecast regions. However, it is also important to minimize under-forecasting and err on the side of caution when warning the public about possible health risks. “Moderate” impact forecasts were slightly under-forecast during BY2005-2008, which means that there were occasions when people experienced “moderate” respiratory irritation without being adequately warned by the forecasts. Even though the under-forecasting was slight, this bias should be addressed in the future to ensure that the forecast system protects public health as much as possible.

Nonetheless, the assessment ability did vary in each year. None of the “moderate” and “high” respiratory impact forecasts issued for southwest Florida in BY2007-2008 were assessable. During this time, southwest Florida had recurrent episodes of patchy bloom concentrations that might have been more difficult to forecast respiratory impacts within the limitations of the forecast resolution. It is possible that the bloom was so patchy that impacts went unobserved or that little brevetoxin was produced. This is further supported by the fact that no fish kills attributed to the *K. brevis* bloom were recorded in southwest Florida during that time, despite many being recorded in northwest and east Florida (Florida Fish and Wildlife Conservation Commission, 2013). This demonstrates the need to continue to improve the forecast model to incorporate observations beyond cell concentrations. Mote Marine Laboratory’s Beach Conditions Reports are an excellent tool for estimating the current beach conditions. Since cell concentrations are only a proxy for how much brevetoxin aerosol might be present, but the actual amount produced varies, in the future, direct measures of the concentration of brevetoxin both in the water and the air should be explored.

5. CONCLUSION

Since October 1, 2004, the Harmful Algal Bloom Operational Forecast System (HAB-OFS) has provided the eastern Gulf of Mexico with operational forecasts for *Karenia brevis*, the species commonly known as red tide in the region. HAB-OFS forecasts and analyses were disseminated to subscribers through the HAB bulletin product on a biweekly basis during an active bloom and once a week when no bloom was present in southwest Florida. This report provides an evaluation of the HAB-OFS products issued for Florida during the bloom years from May 1, 2005 to April 30, 2008, with a re-analysis of previously published data for October 1, 2004 to April 30, 2005 to allow comparison across all years (Fisher, et al., 2006). The analysis includes an assessment of bulletin utilization, early warning capability and forecast quality. Although the procedures discussed in this report pertain to the years from BY2005-2008, there have been minimal modifications to the HAB-OFS since 2008 so the conclusions of this assessment report remain relevant.

From the time the HAB forecast system was transitioned to operations on October 1, 2004 to the end of the fourth bloom year on April 30, 2008, a total of 398 bulletins and 30 supplemental bulletins and/or conditions updates were issued. The average confirmed utilization of all bulletins was 72%. Of these, greater than 83% of the time at least one bulletin was confirmed utilized per week in each bloom year.

During BY2004-2008, the bulletins assisted in guiding the sampling efforts of organizations in Florida (see Appendix IV). In fact, nine out of thirteen *K. brevis* events were first identified in satellite imagery by the HAB-OFS, and then confirmed by water samples collected in the field. This early warning ability could be further improved by implementing an ensemble approach to satellite imagery combining the current heuristic model and three detection algorithms: the chlorophyll anomaly, backscatter (b_{bp}/b_{bp}_Morel) and spectral shape of remote-sensing reflectance at 490 nm. This would help analysts distinguish between *K. brevis* blooms and other phytoplankton (Tomlinson, Wynne, & Stumpf, 2009).

A total of 435 forecasts were issued indicating the potential for bloom transport, extent change, intensification and associated respiratory irritation during BY2004-2008. Transport forecasts were highly accurate and consistently performed much better than chance at predicting bloom movement, with Heidke skill scores indicating a 35-84% improvement over chance. Although transport was slightly over-forecast, this low level of bias might have been tolerated by the user community because it still allowed coastal resource managers to prepare three to four days in advance of potential bloom impacts. Extent forecasts were issued infrequently with variable accuracy and skill, and a slight bias towards over-forecasting. This indicates that although the model performs well when predicting the direction of bloom movement, it needs to be improved to enable high-quality forecasts of transport distance and bloom expansion in order to better prepare coastal resource managers to mitigate a bloom's impacts in advance of its movement into their area of responsibility. Forecasts of bloom intensification were highly accurate and consistently performed with a 39-52% improvement over chance. Intensification was slightly over-forecast during BY2005-2007, but no bias was evident in the other two years. All respiratory impact forecasts issued during BY2004-2008 were highly accurate and performed consistently much better than chance, with Heidke skill scores indicating a 46 to 100%

improvement over chance. The “moderate” and “high” level respiratory impact forecasts had the greatest accuracy, reliability and skill of all forecast components issued by the HAB-OFS. This is especially significant as these forecasts have the greatest potential to directly protect public health.

The success of the HAB-OFS during BY2004-2008 relied on the expertise of a full team of multiple (5-6) analysts, specially trained to utilize established standard operating procedures and analytical methods. The results of this assessment will be used to guide enhancements to the operational forecast system with the goals of improving forecast quality through increased scientific understanding and the refinement of current forecast models as follows:

- Continued maintenance of a full team of at least 5-6 analysts specially trained for Florida HAB bulletins
- Implementation of an ensemble approach to satellite imagery that combines the currently-used chlorophyll anomaly with two additional detection algorithms: a backscatter ratio product and spectral shape of remote-sensing reflectance at 490 nm,
- Refinement of the model used to forecast bloom transport and extent in order to:
  - enable high resolution spatial and temporal predictions of bloom movement,
  - more accurately predict transport direction,
  - improve the quality of forecasts for changes in spatial extent,
  - increase the forecast frequency,
  - extend the forecast duration beyond 3-4 days,
  - increase the objectivity of the forecast methods, and
  - improve the efficiency of data analysis and forecast development
- Investigation of methods to enable the generation of high quality forecasts of bloom intensification along the east Florida coast
- Enhancement of respiratory impact forecasts through:
  - refining the resolution of the forecasts,
  - developing tools to directly measure the concentration of brevetoxin in the air and water, and
  - reviewing the definitions of the respiratory impact levels to ensure that they are comparable to the main source of observational data, Mote Marine Laboratory Beach Conditions Reporting System for the Gulf Coast of Florida (Mote Marine Laboratory, 2013)

These enhancements are proposed with the Florida HAB bulletin forecast components in mind. However, some of the recommendations may also be applicable to the Western Gulf of Mexico (Texas) HAB Forecast System, which was transitioned to the HAB-OFS in 2010. On a broader scale, the assessment results may also be relevant to the potential expansion of the HAB-OFS to include new forecast regions in the United States.

6. ACKNOWLEDGEMENTS

The success of the Gulf of Mexico HAB-OFS is due to the contributions of numerous individuals and organizations. We would like to acknowledge the personnel in NOAA's Center for Operational Oceanographic Products and Services that served on the HAB-OFS analyst team during this assessment period: Allison Allen, Zachary Bronder, Lori Fenstermacher, Kathleen Fisher, Heidi Keller, Cristina Urizar and Mark Vincent. Other key NOAA individuals that assisted during the assessment period included Richard Stumpf and Michelle Tomlinson (National Centers for Coastal Ocean Science); Michael Soracco and Kent Hughes (National Environment Satellite Data and Information Service); and John Cassidy (Center for Operational Oceanographic Products and Services). Additional organizations that contributed to the HAB-OFS during this period included the Florida Fish and Wildlife Conservation Commission's Fish and Wildlife Research Institute, Mote Marine Laboratory, Sarasota County Health Department, Collier County Natural Resources Department, NASA SeaWiFS project, NOAA's National Data Buoy Center and NOAA's National Weather Service. We would also like to thank additional members of NOAA's HAB-OFS analyst team for their suggestions and reviews which helped to improve this report: Robert Burrows, Edward Davis and Hua Yang.

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APPENDICES

APPENDIX I
Example of a HAB bulletin for the southwest Florida region.

APPENDIX II
Example of a HAB bulletin for the northwest Florida region.

APPENDIX III
Example of a HAB bulletin for the east Florida region.

APPENDIX IV
List of organizations that contributed to the 2004-2008 HAB-OFS bulletins for Florida.

APPENDIX V
Summaries of bloom events from October 1, 2004 to September 30, 2005 previously published in the Annual Report of the Gulf of Mexico HAB-OFS (Fisher, et al., 2006).

APPENDIX I

Example of a HAB bulletin for the southwest Florida region. The HAB-OFS Bulletin Guide provides further information on the data that are integrated, components of the bulletin and how it is used: http://tidesandcurrents.noaa.gov/hab/habfs_bulletin_guide.pdf.

Example of a HAB bulletin for the southwest Florida region (page 1).

Gulf of Mexico Harmful Algal Bloom Bulletin

26 October 2006

NOAA Ocean Service

NOAA Satellites and Information Service

Last bulletin: October 23, 2006

Conditions Report

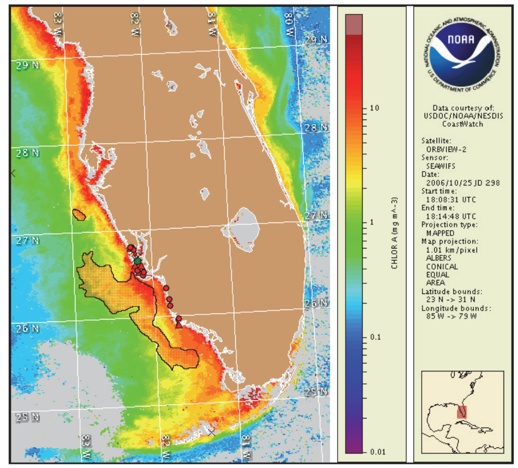
A harmful algal bloom has been identified from Pinellas to central Collier County. Patchy low impacts are possible in Pinellas County and patchy very low impacts are possible from Manatee to central Collier County today, Friday, Sunday and Monday, with moderate impacts possible in the Sanibel Island region on Friday. Friday night through Saturday, patchy high impacts are possible in central Pinellas County and patchy moderate impacts are possible from southern Pinellas to central Collier County.

Analysis

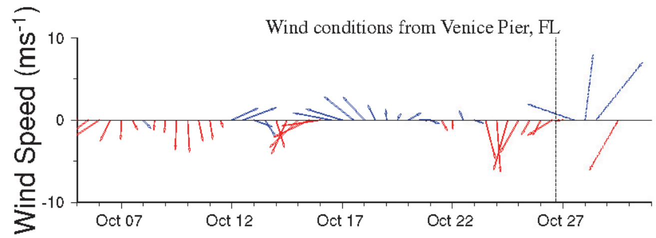
A harmful algal bloom persists from Pinellas to central Collier County. High concentrations of *K. brevis* were identified at Redington Pier, Pinellas County this week (FWRI, 10/23). Concentrations have also increased up to medium in the lower Tampa Bay region, the Pine Island and Gasparilla Sound regions of Charlotte and Lee County, and in the Marco Island region of central Collier County (FWRI, 10/23) over the past week. Medium concentrations have also been identified offshore central Collier County. The bloom is predominantly mixed in the northern portion. Although chlorophyll levels appear to have intensified along the coast over the last couple days, levels are generally slightly lower than reported in the previous bulletin based on satellite imagery (10/21-10/25). Chlorophyll levels offshore Pinellas to northern Sarasota County continue to be elevated up to 17μg/L from 27°56.3'N 82°59'W to 27°22.4'N 82°45.1'W, and up to 33μg/L in the Siesta/Casey Key and Englewood Beach regions. Patches of elevated chlorophyll are also visible in a band south to 26°10.2'N 82°4.9'W and alongshore northern Collier County.

Reports of dead fish in Pinellas and discolored water in Lee County have been received over the past few days, as well as respiratory irritation in Collier County. Further intensification of the bloom is possible over the next few days; particularly in Pinellas, Lee and Collier County where the bloom extends offshore. Continued southerly transport is expected.

-Fisher, Keller



Satellite chlorophyll image with possible HAB areas shown by red polygon(s). Cell concentration categories and corresponding cell count values from Florida Fish and Wildlife Research Institute. For a key to the cell concentration descriptions, visit http://research.myfwc.com.Cell concentration sampling data from October 16-23 shown as red squares (high), red triangles (medium), red diamonds (low b), red circles (low a), orange circles (very low b), yellow circles (very low a), green circles (present), and black "X" (not present).



Wind speed and direction are averaged over 12 hours from buoy measurements. Length of line indicates speed; angle indicates direction. Red indicates that the wind direction favors upwelling near the coast. Values to the left of the dotted vertical line are measured values; values to the right are forecasts.

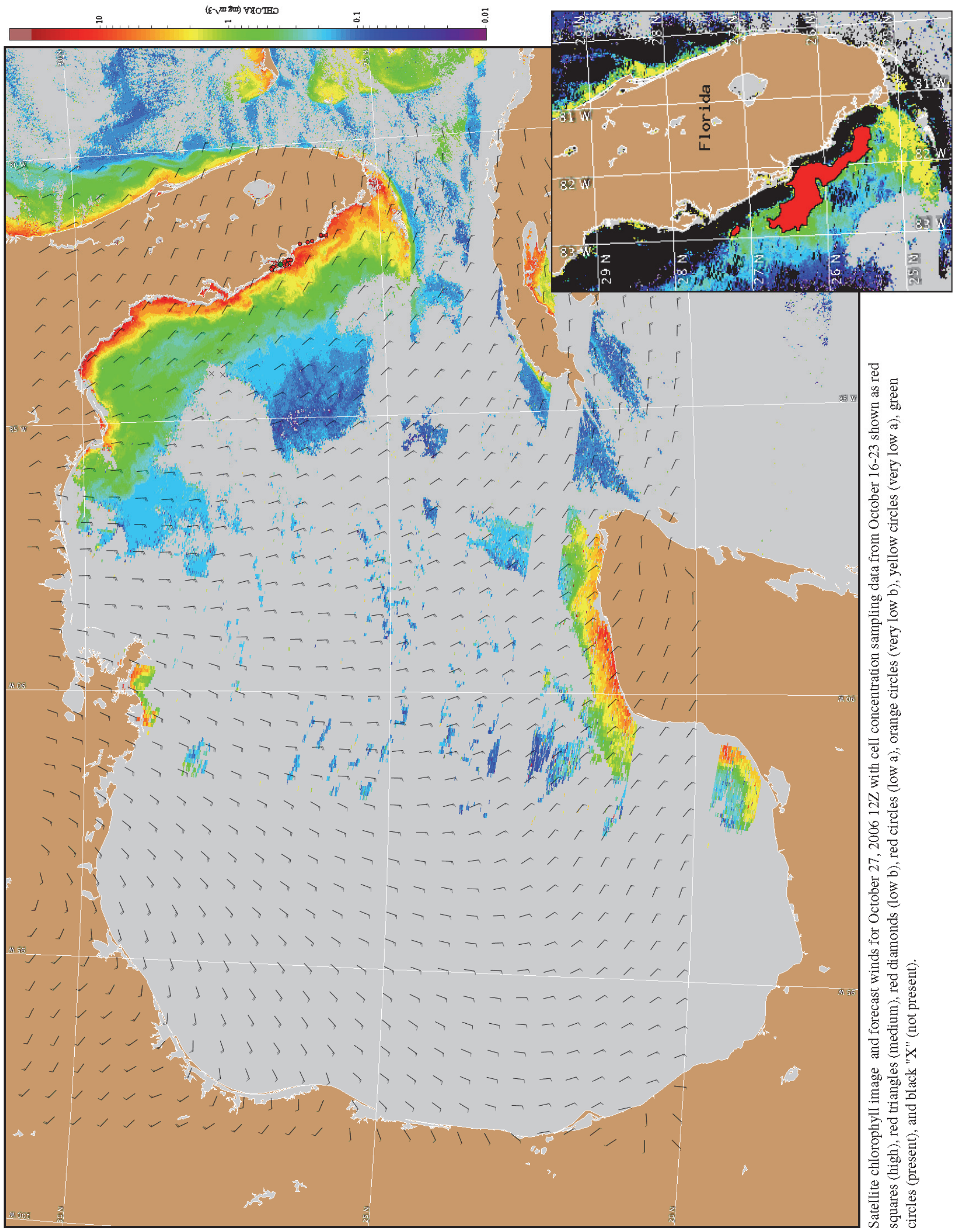
Easterlies today (10kts, 5m/s) will strengthen (15-20kts,8-10m/s) and shift southerly by Friday. Southwest- erlies Friday night shifting northwesterly Saturday(15-20kts). Northerlies Saturday night expected to become northeasterly Sunday and Monday up to 15kts.

Please note the following restrictions on all SeaWiFS imagery derived from CoastWatch.

1. Data are restricted to civil marine applications only; i.e. federal, state, and local government use/distribution is permitted.
2. Image products may be published in newspapers. Any other publishing arrangements must receive GeoEye approval via the CoastWatch Program.

Example of a HAB bulletin for the southwest Florida region (page 2).

-2-



Satellite chlorophyll image and forecast winds for October 27, 2006 12Z with cell concentration sampling data from October 16-23 shown as red squares (high), red triangles (medium), red diamonds (low b), red circles (low a), orange circles (very low b), yellow circles (very low a), green circles (present), and black "X" (not present).

Verified HAB areas shown in red. Other bloom areas shown in yellow (see p. 1 analysis for interpretation).

APPENDIX II

Example of a HAB bulletin for the northwest Florida region. The HAB-OFS Bulletin Guide provides further information on the data that are integrated, components of the bulletin and how it is used: http://tidesandcurrents.noaa.gov/hab/habfs_bulletin_guide.pdf.

Example of a HAB bulletin for the northwest Florida region (page 1).

Gulf of Mexico Harmful Algal Bloom Bulletin

22 October 2007

NOAA Ocean Service

NOAA Satellites and Information Service

Last bulletin: October 18, 2007

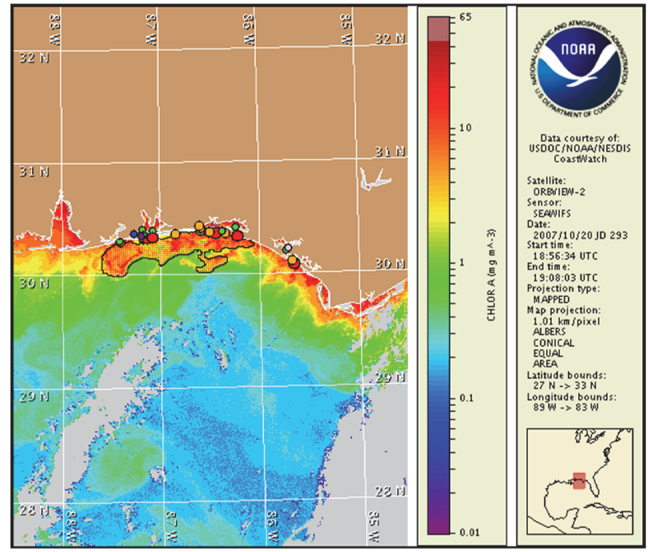
Conditions Report

A harmful algal bloom has been identified in patches from Bay County, Florida to Baldwin County, Alabama. Patchy moderate impacts are possible in Baldwin County today through Tuesday, with patchy very low impacts possible on Wednesday and Thursday. Patchy high impacts are possible in Escambia, Santa Rosa, and Walton Counties today and Tuesday, with patchy low impacts on Wednesday and Thursday. Patchy moderate to high impacts are possible in the bay regions of Okaloosa and Bay Counties through Thursday, with patchy low impacts possible along the coast on Wednesday and Thursday. Patchy low impacts are possible today and Tuesday for Gulf County, with patchy very low impacts possible on Wednesday and Thursday. Reports of dead fish have been received in the last several days.

Analysis

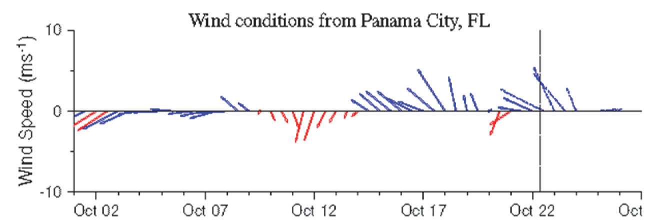
A harmful algal bloom persists along the northwest coast from Baldwin County, Alabama to Bay County, Florida. Concentrations range from very low to high alongshore Baldwin, Escambia, Okaloosa, Walton, and Bay Counties (FWRI; 10/19). No recent samples were received for Gulf County; however, due to continued reports of fish kills and respiratory irritation in the area, further sampling is recommended. Samples received last week indicated that *k.brevis* was not present in Franklin County. Recent satellite imagery (10/20) illustrates that chlorophyll levels are elevated in patches along the coast from Gulf to Baldwin County, with concentrations as high as 20$\mu g/L$. Continued sampling is recommended both onshore and offshore from Gulf to Baldwin County. Southerly winds throughout most of the week will likely increase impacts along the northwestern coast.

~Keller, Fenstermacher



Satellite chlorophyll image with possible HAB areas shown by red polygon(s). Cell concentration sampling data from October 14 to 18 shown as red (high), orange (medium), yellow (low b), brown (low a), blue(very low b), purple (very low a), pink (present), and green (not present). For a list of cell count data providers and a key to the cell concentration categories, please see the HABFS bulletin guide:

http://www.csc.noaa.gov/crs/habf/habfs_bulletin_guide.pdf



Wind speed and direction are averaged over 12 hours from buoy measurements. Length of line indicates speed; angle indicates direction. Red indicates that the wind direction favors upwelling near the coast. Values to the left of the dotted vertical line are measured values; values to the right are forecasts.

NW Florida: Strong southeasterly winds (15-20 knts; 8-10 m/s) today followed by south to southwesterlies on tonight and Tuesday (10-15 knts; 5-8 m/s). North to northwesterlies on Wednesday through Friday (5-15 knts; 3-8 m/s).

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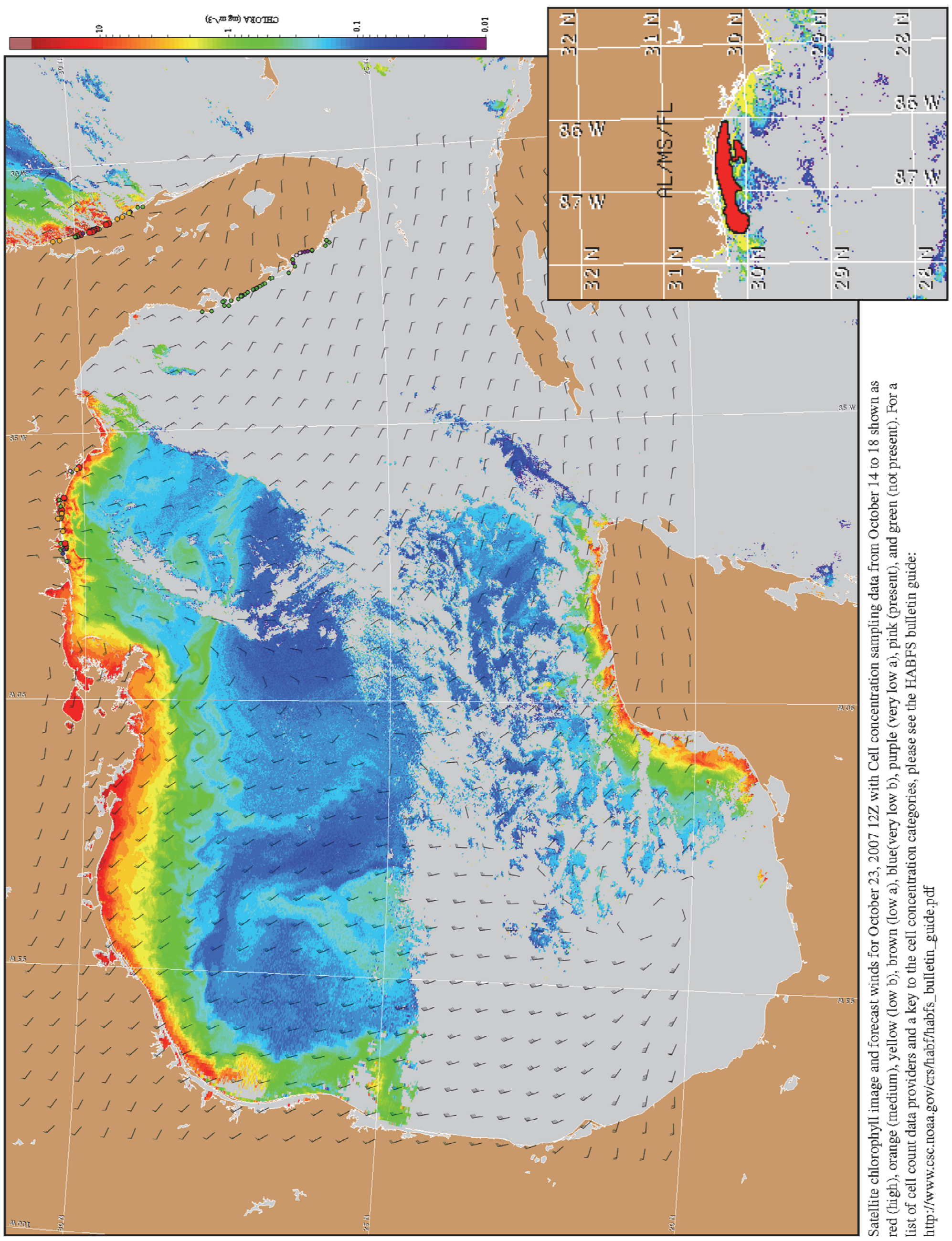
2. Image products may be published in newspapers. Any other publishing arrangements must receive GeoEye approval via the CoastWatch Program.

Example of a HAB bulletin for the northwest Florida region (page 2).

-2-



Satellite chlorophyll image and forecast winds for October 23, 2007 12Z with Cell concentration sampling data from October 14 to 18 shown as red (high), orange (medium), yellow (low b), brown (low a), blue(very low b), purple (very low a), pink (present), and green (not present). For a list of cell count data providers and a key to the cell concentration categories, please see the HABFS bulletin guide: http://www.csc.noaa.gov/crs/habf/habfs_bulletin_guide.pdf

Verified and suspected HAB areas shown in red. Other areas of high chlorophyll concentration shown in yellow (see p. 1 analysis for interpretation).

APPENDIX III

Example of a HAB bulletin for the east Florida region. The HAB-OFS Bulletin Guide provides further information on the data that are integrated, components of the bulletin and how it is used: http://tidesandcurrents.noaa.gov/hab/habfs_bulletin_guide.pdf.

Example of a HAB bulletin for the east Florida region (page 1).

Gulf of Mexico Harmful Algal Bloom Bulletin

13 December 2007

NOAA Ocean Service

NOAA Satellites and Information Service

Last bulletin: December 11, 2007

Conditions Report

E Florida: A harmful algal bloom has been identified from southern Volusia to southern Indian River County. Patchy moderate impacts are possible today through Sunday from southern Volusia to northern Indian River County, with patchy high impacts possible today through Sunday in southern Brevard and southern Indian River Counties.

SW Florida: A harmful algal bloom has been identified in northern Collier County. Patchy very low impacts are possible in northern Collier County through Saturday, with patchy moderate impacts possible Saturday night through Sunday. No other impacts are expected in southwest Florida through Sunday, December 16.

Analysis

E Florida: The bloom located in eastern Florida persists from southern Volusia to southern Indian River County, with low concentrations of *Karenia brevis* confirmed as far south as central St. Lucie County at Fort Pierce (12/11, FWRI). Background concentrations of *K. brevis* were confirmed this week in Martin County near St. Lucie Inlet (12/8-9, FWRI). Medium concentrations of *K. brevis* have been confirmed from New Smyrna Beach, in Volusia County, to Round Island Park, on the Indian River-St. Lucie County line, with high concentrations confirmed at Vero Beach in Indian River County (12/9-11, FWRI). Reports of respiratory irritation have been received over the past few days from Cape Canaveral to Melbourne. Several high chlorophyll features are visible along the coast of eastern Florida based on satellite imagery from 12/12. A high chlorophyll feature (>10μg/L) extends from the coast of Volusia County near New Smyrna Beach at 28°52'40"N 80°44'35"W offshore to 29°4'17"N 80°36'21"W. Chlorophyll is elevated (5-9μg/L) along the coast of northern Brevard County, with higher chlorophyll levels (>10μg/L) from 28°28'55"N 80°30'42"W, near Cape Canaveral, to 28°19'53"N 80°35'38"W, just north of Melbourne. High chlorophyll levels (>10μg/L) are visible along the coast of Brevard and Indian River Counties from 28°7'41"N 80°32'45"W to 27°42'22"N 80°20'19"W. High chlorophyll levels also extend in a band offshore from 29°6'2"N 80°27'32"W to 29°16'41"N 80°21'49"W. Continued sampling in St. Lucie County is recommended, as continued slight southerly transport of the bloom is possible through the weekend. Onshore winds through Sunday will likely increase the potential for impacts along the coast, with slightly lower impacts possible Saturday night and Sunday. -Allen, Keller

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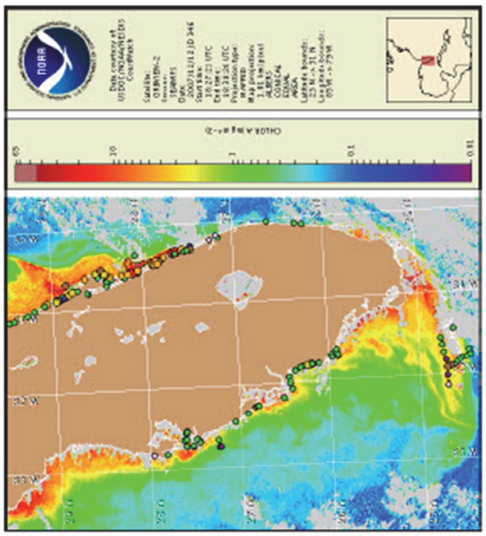
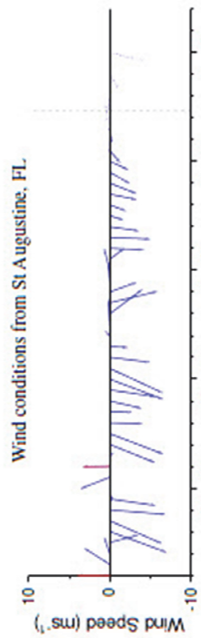


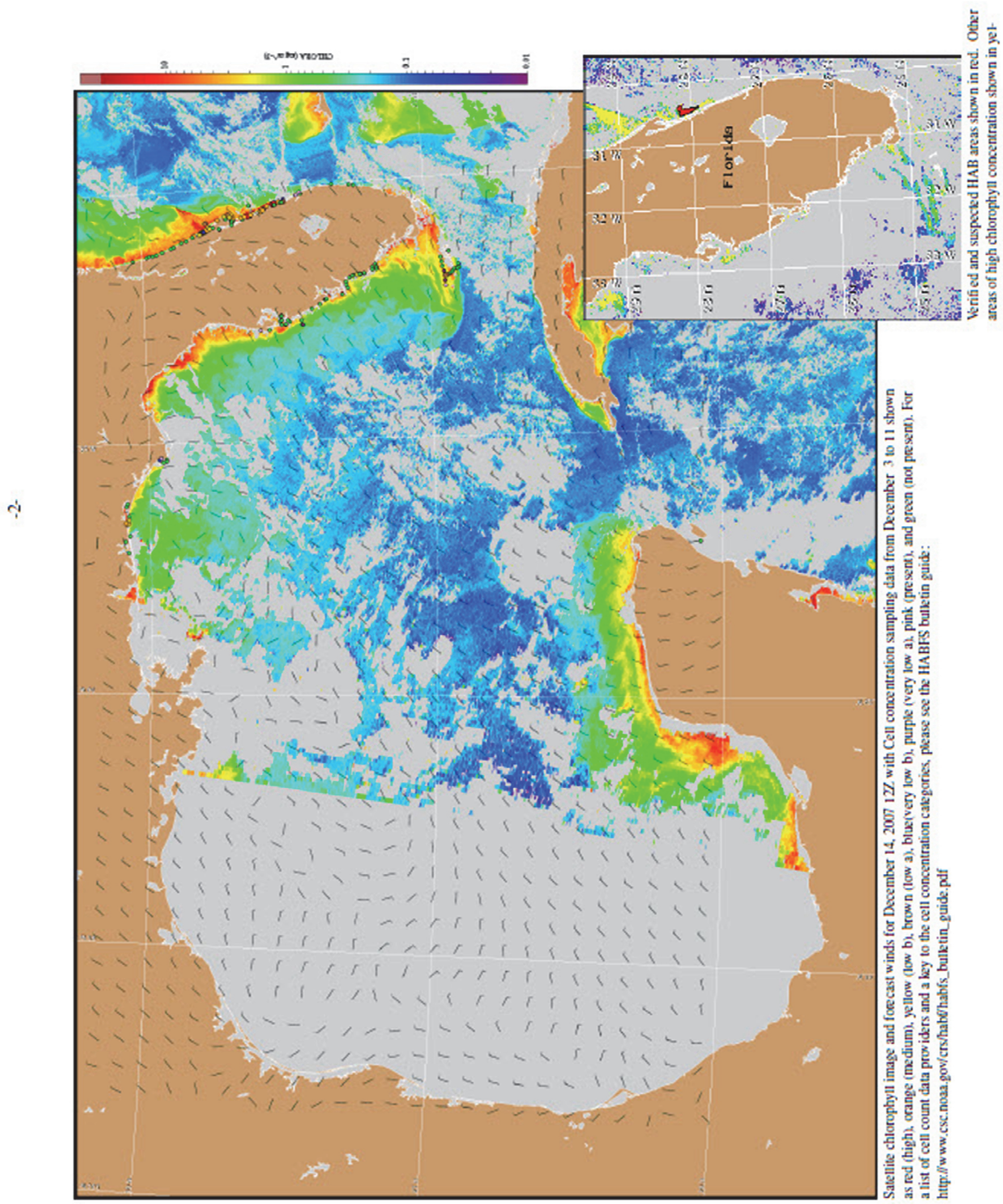
Satellite chlorophyll image with possible HAB areas shown by red polygon(s). Cell concentration sampling data from December 3 to 11 shown as red (high), orange (medium), yellow (low b), brown (low a), blue(very low b), purple (very low a), pink (present), and green (not present). For a list of cell count data providers and a key to the cell concentration categories, please see the HABFS bulletin guide:
http://www.csc.noaa.gov/crs/habf/habfs_bulletin_guide.pdf



Wind speed and direction are averaged over 12 hours from buoy measurements. Length of line indicates speed; angle indicates direction. Red indicates that the wind direction favors upwelling near the coast. Values to the left of the dotted vertical line are measured values; values to the right are forecasts.

E Florida: Easterly winds today at 5-10 knots (3-5 m/s) becoming northeasterly tonight and northerly Friday at 10-15 knots (5-8 m/s). Easterly winds Saturday becoming south to southwesterly Saturday night and building to 15-20 knots (8-10 m/s). Northerly winds Sunday.

Example of a HAB bulletin for the east Florida region (page 2).



APPENDIX IV

List of organizations that contributed to the 2004-2008 HAB-OFS bulletins for Florida. The HAB-OFS Bulletin Guide provides further information on the data that are integrated, components of the bulletin and how data is used: http://tidesandcurrents.noaa.gov/hab/habfs_bulletin_guide.pdf.

List of organizations that contributed to the 2004-2008 HAB-OFS bulletins for Florida

Organization	HAB-OFS Contributions	Website
NOAA Center for Operational Oceanographic Products & Services	• Forecast analysis • Operations	http://tidesandcurrents.noaa.gov
NOAA National Centers for Coastal Ocean Science	• Research & Development	http://coastalscience.noaa.gov
NOAA CoastWatch	• Remote sensing data	http://coastwatch.noaa.gov/cwn
NASA SeaWiFS Project	• Remote sensing data	http://oceancolor.gsfc.nasa.gov/SeaWiFS/
NOAA Coastal Services Center	• Initial technology development	http://www.csc.noaa.gov
NOAA National Data Buoy Center	• Wind data	http://www.ndbc.noaa.gov
NOAA National Weather Service	• Wind data	http://www.weather.gov
Florida Fish and Wildlife Conservation Commission's Fish and Wildlife Research Institute	• *In situ* cell count data • Water sample results • Fish kill database • Other reports of health impacts (i.e. respiratory irritation or discolored water)	http://myfwc.com/research
Mote Marine Laboratory	• *In situ* cell count data • Water sample results • Beach Conditions Reporting System (including observations of respiratory irritation, dead fish, discolored water, and wind direction)	http://www.mote.org
Sarasota County Health Department	• Water sample results	http://www.ourgulfenvironment.net/HomePage.aspx
Collier County Natural Resources Department	• Water sample results • Other reports of health impacts (i.e. respiratory irritation or discolored water)	http://www.colliergov.net/Index.aspx?page=113
Alabama Department of Public Health, Mobile Division Laboratory	• Water sample results • Other reports of health impacts (i.e. respiratory irritation or discolored water)	http://www.adem.state.al.us/

APPENDIX V

Summaries of bloom events from October 1, 2004 to September 30, 2005 previously published in the Annual Report of the Gulf of Mexico HAB-OFS (Fisher, et al., 2006).

Summaries of bloom events from October 1, 2004 to September 30, 2005 previously published in the Annual Report of the Gulf of Mexico HAB-OFS (Fisher, et al., 2006).

Bloom Year: 2004-2005

Two blooms, both detected first by satellite imagery, occurred during the 2004-2005 bloom year. The following descriptions of these blooms are also published in the Annual Report of the Gulf of Mexico HAB-OFS (Fisher, et al., 2006).

The first bloom of the Fiscal Year 2004-2005 HAB season (referred to as Bloom Allie) was detected via satellite imagery near Marco Island, Florida on November 3, 2004 by operational HAB forecasters, and was confirmed by sampling reports the following week. The bloom moved slowly and steadily down the coast of southwest Florida until it reached the Florida Keys in late December 2004. Further southern movement was halted by the east-west landmass of the Keys, and the bloom remained relatively stable in location and strength north of the Keys for approximately two months. The bloom eventually split, with part of it traveling north, then west, around Key West before dissipating in the Florida Current south of the Keys. The additional portion of the bloom migrated slightly east and slipped through the straights near Marathon, FL, also dissipating in the Florida Current in late February 2005. Following its travels through the straights of the Florida Keys, forecasters watched for traces of *K. brevis* to resurface on the eastern coast of Florida. No HABs were reported in eastern Florida as a result of this bloom. There was a slight resurgence of a bloom northeast of Marathon in mid-March 2005, almost a month after it seemed to have disappeared. Sampling was limited; however, chlorophyll levels remained high in the area for about six weeks. Genetic testing results are not available to determine whether the strains of the initial bloom and the small subsequent bloom in the Keys were related, although this is highly probable. NOAA issued a total of 48 bulletins covering this event, including both twice weekly bulletins and addendum bulletins as events deemed necessary.

The second bloom of the season (referred to as Bloom Bronder) developed into an extremely damaging event that affected much of western Florida. The bloom was detected via satellite imagery in early January 2005 and was quickly confirmed by *in situ* sampling data to be a harmful *K. brevis* bloom. It surfaced near Tampa Bay and migrated south to Sanibel and Captiva Islands, causing fish kills and approximately 40 manatee deaths in March before moving back north into the bay systems south of Tampa Bay. In late May 2005, the bloom migrated back out from the bays into coastal waters and rapidly expanded to cover much of the western coast of Florida. The resurgence had a significant impact along much of the southwest Florida coast, with massive fish kills, respiratory irritation, and discolored water reported in many coastal and bayside areas, including substantial impacts during the July 4, 2005 holiday weekend. Its widespread effects continued throughout the next several months, and were further magnified by the 2005 hurricane season. In late summer 2005, Hurricanes Katrina and Rita, in rapid succession, are suspected to have carried the bloom north into the Big Bend region of Florida where a *K. brevis* patch was identified shortly after the hurricane events. However, due to the lack of clear satellite imagery during these extreme weather events and the absence of genetic testing procedures, this presumed migration could not be proven with certainty. The large degree of upwelling and resuspension occurring throughout the month of September 2005 contributed to the bloom's persistence alongshore Southwest Florida. In late October, 10 months following its first appearance, the bloom began to dissipate, move offshore, and eventually be confirmed "not present" through sampling efforts. However, soon after its disappearance from the coast, an offshore bloom was detected west of Sarasota immediately following a resuspension event brought about by Hurricane Wilma. Again, it is likely these blooms were related, but lack of satellite and genetic evidence to support this theory required the offshore bloom to be classified as a new and separate event. Meanwhile, as the bloom migrated offshore and dissipated in Southwest Florida, it persevered to the north in Dixie and Levy Counties, until slowly dissipating to "not present" status in late December, 4 months after its suspected migration.

The very active 2005 hurricane season had a tremendous effect on chlorophyll levels and *K. brevis* bloom activity along the Southwest Florida coast. The hurricanes greatly reduced satellite visibility during the weather events, limiting not only the ability to forecast bloom components and identify present extents, but also the ability to substantiate many forecasts that were generated. Sampling efforts were vital during these months. With an unusually late appearance in the year, relative to historically observed trends in this area, and prolonged existence of nearly 12 months, this unique bloom was an extremely costly and damaging event. A total of 91 bulletins were issued on this event, at a rate of twice weekly. Multiple verifications of forecasted conditions have been received from the public, coastal resource managers, and the media.

Bloom Year: 2005-2006

The first bloom of the 2005-2006 bloom year was detected in northwest Florida from samples collected on September 1, 2005. Since it began in fiscal year 2005, the following description is also included in the Annual Report of the Gulf of Mexico HAB-OFS (Fisher, et al., 2006). On September 1, 2005, immediately following Hurricane Katrina, a third bloom (Bloom Culver) was identified within and adjacent to Apalachicola Bay on the Florida Panhandle. While resuspended material following the hurricane inhibited initial bloom identification via satellite imagery, sampling efforts confirmed the presence of *K. brevis*, thus initiating bulletin analysis of the event on September 6, 2005. This bloom existed concordantly with the bloom just to the east in Dixie and Levy counties (Bloom Bronder); however, differing geographical originations deemed the blooms to be classified as separate and unique. At the height of Bloom Culver a great expanse of the northeastern Gulf of Mexico, from Big Bend through Alabama, was heavily impacted with numerous fish kills. The bloom coverage existed as a disconnected series of large, high chlorophyll patches. By the end of October, "medium" to "high" concentrations of *K. brevis* had been identified by *in situ* sampling (Alabama Dept. of Public Health), and the bloom had spread as far west as Alabama. Hurricane and resuspension activity made it difficult at times to distinguish *K. brevis* bloom extents from resuspension events, and cloud-obscured imagery produced additional difficulty in analyzing bloom components. Sampling reports were extremely important for determining regional impact conditions throughout the Panhandle, and narrowing impact forecasts to those areas most heavily impacted. In addition, a wind transport model developed by NCCOS was introduced and utilized by the analysts as an alternative method for identifying possible bloom locations and extents in instances when clear satellite imagery was not available. By the end of November 2005, the bloom patches had dissipated and were found primarily to the west of Cape San Blas and in the Apalachicola Bay vicinity. The bloom finally terminated in late December 2005. A total of 34 bulletins were issued for this event over 17 weeks.