Gulf Monitoring Network
Monitoring Design

Gulf of Mexico Alliance (GOMA)
Water Quality Team

Gulf of Mexico Coastal Ocean
Observing System (GCOOS)

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Acknowledgements

Steering Committees for design workshops:

Alice Dossett, Mississippi Dept. of Environmental Quality

Jennifer Haslbauer, Alabama Dept. of Environmental Management

Dr. Ann Jochens, Gulf of Mexico Coastal Ocean Observing System, Regional Assoc.

Dr. Virginia Garcia, Gulf of Mexico Large Marine Ecosystem Project

Fred Leslie, Alabama Dept. of Environmental Management

Kate Muldoon, Florida Dept. of Environmental Protection

Dr. Troy Pierce, U.S. Environmental Protection Agency, Gulf of Mexico Program

Lynn Sisk, Alabama Dept. of Environmental Management

Gail Sloane, Florida Dept. of Environmental Protection

Dr. Amber Whittle, Florida Fish and Wildlife Research Institute

Steve Wolfe, Florida Institute of Oceanography

Laura Yarbro, Florida Fish and Wildlife Research Institute

Report preparation:

Steve Wolfe, Florida Institute of Oceanography

Kate Muldoon, Florida Dept. of Environmental Protection

Raymond Leary, Florida Dept. of Environmental Protection

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Participants in Design Workshops

STATE AGENCIES

ALABAMA

Carol Dorsey [2], Microbiologist Supervisor, Alabama Dept. of Public Health
carol.dorsey@adph.state.al.us

Jennifer Haslbauer [1], Environmental Engineer, Water Quality Branch, Alabama Dept. of Environmental Management   jhaslbauer@adem.state.al.us

Fred Leslie [1,2], Chief, Montgomery Branch, Alabama Dept. of Environmental Management
fal@adem.state.al.us

Lynn Sisk [2], Chief, Water Quality Branch, Alabama Dept. of Environmental Management
ls@adem.state.al.us

FLORIDA

Dr. Alina Corcoran [2], Research Scientist, Fish and Wildlife Research Institute, Florida Fish and Wildlife Conservation Commission   alina.corcoran@MyFWC.com

Charles Kovach [1,2], Chief Scientist, Southwest District Office, Florida Dept. of Environmental Protection
charles.kovach@dep.state.fl.us

Ray Leary [1,2], Assistant Coordinator, GOMA & Florida Dept. of Environmental Protection
raymond.leary@dep.state.fl.us

Kate Muldoon [1,2], Water Quality Team Florida State Lead, GOMA & Florida Dept. of Environmental Protection   Kathryn.Muldoon@dep.state.fl.us

Bob Vincent [2], Environmental Administrator, Florida Department of Health
Bob_Vincent@doh.state.fl.us

Dr. Amber Whittle [1,2], Habitat Research Administrator, Fish and Wildlife Research Institute, Florida Fish and Wildlife Conservation Commission   amber.whittle@myfwc.com

Steve Wolfe [1,2], Coordinator, Gulf of Mexico Alliance, Florida Institute of Oceanography
Steven.Wolfe@fio.usf.edu

Laura Yarbro [1], Research Staff, Florida Fish and Wildlife Research Institute laura.yarbro@myfwc.com

LOUISIANA

Jeff Dauzat [2], Environmental Staff Scientist, Louisiana Dept. of Environmental Quality
Jeff.Dauzat@LA.GOV

Carol Parsons-Richards [1], Coastal Resources Scientist Supervisor, Louisiana Coastal Protection and Restoration Agency   carol.richards@la.gov

MISSISSIPPI

Alice Dossett [1,2], Chief, Surface Water Monitoring Section, Mississippi Dept. of Environmental Quality
alice_dossett@deq.state.ms.us

TEXAS

Robin Cypher [1,2], Aquatic Scientist, Surface Water Quality Monitoring, Texas Commission on Environmental Quality   robin.cypher@tceq.texas.gov

---

[1] Attended nutrient-monitoring design workshop, Sept. 2012

[2] Attended human-health priorities monitoring design workshop, Mar. 2013

Design Workshop Participants (continued)

FEDERAL AGENCIES

U.S. EPA

Dr. Ed Decker [1], Nutrient Regional Coordinator, Region IV, Atlanta, GA   decker.ed@epa.gov

Dr. Jan Kurtz [1], Research Biologist, Gulf Breeze Environmental Research Laboratory, Gulf Breeze, FL
kurtz.jan@epa.gov

Dr. Troy Pierce [2], Life Scientist, Gulf of Mexico Program Office, Stennis Space Center, MS
pierce.troy@epa.gov

Tim Wool [1], Senior Water Quality Modeler, Region IV, Atlanta, GA   wool.tim@epa.gov

NOAA

Dr. Jan Moore [2], Microbiologist, National Ocean Service, CCEHBR, Charleston, SC
janet.moore@noaa.gov

David Kidwell [1,2], Program Manager: Hypoxia Programs, Center for Sponsored Coastal Ocean Research,
Silver Spring, MD   david.kidwell@noaa.gov

Dr. Chris Sinigalliano [1,2], Director, Environmental Microbiology Program, Atlantic Oceanographic &
Meteorological Laboratory, Miami, FL christopher.sinigalliano@noaa.gov

USGS

Dr. Alyssa Dausman [1], Coordinator, Gulf Coast Science Coordination Office, Stennis Space Center, MS
adausman@usgs.gov

Richard Rebich [1], Chief, Investigations Section, Mississippi Water Science Center, Jackson, MS
rarebich@usgs.gov

Dr. Greg Steyer [1], Branch Chief, National Wetlands Research Center, Baton Rouge, LA
steyerg@usgs.gov

U.N. Gulf of Mexico Large Marine Ecosystems Project- Mexico

Dr. Porfirio Alvarez-Torres [2], Project Coordinator, Gulf LME, Mexico City, MX
alvarez.porfirio@gmail.com

Dr. Virginia Y. Garcia Rios [1,2], Co-Coordinator, Monitoring Pilot Project, Veracruz, MX
vickygar@gmail.com

UNIVERSITIES

Adrienne Flowers [2], Researcher, Univ. of Southern Mississippi, Gulf Coast Research Lab, Ocean Springs,
MS   adrienne.r.flowers@usm.edu

Dr. Jason Lenes [2], Modeler, College of Marine Sciences, Univ. of South Florida, St. Petersburg, FL
lenes@usf.edu

Larry Lloyd [1], Research Specialist, Texas A&M University – Corpus Christi, TX
larry.lloyd@tamucc.edu

Dr. Paul Montagna [2], Professor, Texas A&M University – Corpus Christi, TX
Paul.Montagna@tamucc.edu

-- continued --

Design Workshop Participants (concluded)

UNIVERSITIES (concluded)

Dr. Kyeong Park [1], Associate Professor, Department of Marine Sciences, Univ. of South Alabama
kpark@disl.org

Dr. Ernst Peebles [1,2], Associate Professor, College of Marine Science, Univ. of South Florida; Director of Coastal Systems Ecology, The Water Institute of the Gulf epeebles@usf.edu

Dr. Darren Rumbold [2], Professor of Marine Sciences, Florida Gulf Coast Univ., Ft. Myers, FL
drumbold@fgcu.edu

Dr. Jim Simons [2], Associate Research Scientist, Center for Coastal Studies, Texas A&M Univ. – Corpus Christi, TX   james.simons@tamucc.edu

Evan Turner [1,2], Researcher, Texas A&M University – Corpus Christi, TX
evan.turner@tamucc.edu

Non-Governmental Organizations (NGOs)

Dr. Kellie Dixon [1], Senior Scientist, Mote Marine Laboratory, Sarasota, FL
lkdixon@mote.org

Dr. Ernest Estevez [1], Senior Scientist, Emeritus, Mote Marine Laboratory, Sarasota, FL
estevez@mote.org

Dr. Ann Jochens [2], Executive Director, Gulf of Mexico Coastal Ocean Observing System (GCOOS) Regional Association ajochens@tamu.edu

Dr. Barbara Kirkpatrick [1], Senior Scientist, Program Manager-Environmental Health, Mote Marine Laboratory, Sarasota, FL   bkirkpat@mote.org

Executive Summary

The Water Quality Team (WQ Team) of the Gulf of Mexico Alliance (GOMA) consists of state, federal, non-governmental-organization (NGO), and private members. The WQ Team, one of six GOMA teams, implements the water-quality portions of the GOMA Governors' Action Plan II.

The WQ Team is composed of four workgroups, with one focused on monitoring; the remaining workgroups are focused on Mercury, Pathogens, and Harmful Algal Blooms (HABs). The Monitoring Workgroup's Action Plan includes creation of a framework to support Gulf-wide monitoring. As part of this effort, the Workgroup has collaborated with the agencies and entities that make up GOMA as well as the Gulf Coast Ecosystem Restoration Task Force (GCERTF), the Hypoxia Task Force, and the Gulf of Mexico Coastal Ocean Observing System (GCOOS) to create an organizing structure for the Gulf Monitoring Network (GMN).

Two design workshops were held, one in September 2012 that focused on monitoring for nutrients, and the other in March 2013, which added the GOMA human-health priorities: pathogens, HABs, and mercury in seafood. The first workshop resulted in a draft monitoring network design to address priority nutrient-monitoring questions developed by the GOMA Nutrients Team. The second workshop added monitoring designed to address priority monitoring questions developed by the GOMA WQ Team.

Design workshop participants included State representatives from the WQ Team and Nutrients Team, monitoring design experts, GOMA federal partners, water quality modelers, and experts in monitoring of nutrients, HABs, pathogens, and mercury. For each scale, participants were provided with an overview of the existing knowledge about nutrients in the Gulf, factors to consider in designing the monitoring by scale, and the GOMA priority monitoring questions.

The resulting monitoring strategy includes meshed monitoring designs for each scale of the Gulf: the estuaries, the coastal areas (coastline out to the 10 m contour), the shelf (10 m to the edge of the Continental Shelf), and the deep Gulf beyond the shelf. The monitoring designs complement and feed into each other to provide a basic overall understanding of Gulf drivers, such as circulation patterns and vertical and horizontal processes. More specifically, the designs also focus on how flux, transport, fate, sources and sinks respond to the drivers and processes. The larger-scale shelf and deep-Gulf designs use a combination of remote sensing, permanent and fixed (i.e., no permanent structure but a repeatedly-used site) stations, gliders, and flow-through meters on ships to obtain an understanding of the larger ecosystems. The smaller monitoring scales, estuaries and coastal segments, are designed as templates to either support design of the estuary monitoring system that integrates with the Gulf Monitoring Network or—if sufficient information is unavailable—provide a starting point for intensive studies. Such studies can assist local decision-making to inform permanent station placement, sampling frequency, and required analytes and measurements needed to integrate with the Gulf-wide network.

The design is a monitoring strategy using satellite imagery as a backdrop to develop models of water circulation and key constituent transport and fate (for instance, that of nutrients), with

permanent stations at pilings or buoys collecting continuous surface and at-depth data at key locations to add information about depth-related factors, to ground-truth the satellite data, and to validate the models. The strategy incorporates additional information collected during trips to maintain the permanent stations, with collections at both fixed intermediate stations and via flow-through measurements between buoys. In shallower parts of the Gulf, this basic data collection scheme is augmented by probabilistic sampling to improve the ability to detect change over time.

The overall conclusion is that monitoring of the deep Gulf and continental shelf areas is required to properly understand and predict nutrient and other loads and effects in coastal and estuarine waters. Most importantly, participants emphasized that coastal and estuarine models need to properly account for nutrient and other inputs transported from Gulf upwelling events and coastal watersheds, as well as those from uplands and rivers draining to the area of interest.

Introduction

The Water Quality (WQ) Team of the Gulf of Mexico Alliance (GOMA) consists of state, federal, non-government-organization (NGO), and private members. One of six GOMA teams, the WQ Team works to implement the water-quality portions of the GOMA Governors' Action Plan II.

The WQ Team is composed of four workgroups, one of which is focused on monitoring. The Monitoring Workgroup's Action Plan includes creation of a framework to support Gulf-wide monitoring. As part of this effort, the Workgroup has collaborated with the agencies and entities that make up the Alliance as well as the recent Gulf Coast Ecosystem Restoration Task Force, the Hypoxia Task Force, and the Gulf of Mexico Coastal Ocean Observing System (GCOOS) to create an organizing structure for the Gulf Monitoring Network (GMN).

Working toward implementing a GMN has been designed as a step-wise process:
1) Identify a structure to organize the development and implementation;
2) Identify the most important GOMA water-quality monitoring issues for the Gulf;
3) For each of those issues, identify and rank the highest priority questions (that monitoring can address);
4) Design the minimum monitoring system necessary to address the priority questions;
5) Perform a "gap analysis" comparing the necessary monitoring to that which already exists;
6) Prepare an implementation plan, including funding, for putting a monitoring network in place in the Gulf to address GOMA priorities;
7) Implementation of the monitoring network.

System design for the GMN is intended to provide answers to specific monitoring questions ("priority monitoring questions"). The organizing structure relates monitoring system design to the physical scale of the monitoring required to address the monitoring question. The WQ Team identified four scales around which to organize the GMN, three of which are of direct interest to the WQ Team.   The fourth (local scale) was defined for continuity with river and stream monitoring, but is not directly addressed by the GMN. The three scales of interest to the WQ Team are:

- **Estuary or Similar-Size Coastal Segment scale** – answering the monitoring question requires monitoring of a single estuary or a similarly-sized segment along the coast. This scale tends to be based on coastal drainages. Examples: What are the trends in nutrient concentrations in an estuary (or in each of many estuaries)? How are chlorophyll concentrations related to specific nutrient regimes?
- **Regional scale** – answering the monitoring question requires monitoring of a specific region of the Gulf. The WQ Team has defined a "region" as anything smaller than the Gulf-wide scale but larger than the Estuary or Similar-Size Coastal Segment scale. Examples: What is the timing and size of hypoxic and anoxic waters in the Gulf Hypoxic Zone off the Mississippi River? What is the distribution of primary red-tide-supporting nutrients on the West Florida Shelf?

- **Gulf-wide scale** – answering the monitoring question requires monitoring throughout the Gulf of Mexico. Examples: What is the seasonal distribution and density of red tide blooms in the Gulf of Mexico, and what is the trend over time? What is the distribution of mercury and methylmercury across the Gulf and how is it transported?

In November 2011, the GOMA Water Quality Team held its annual Monitoring Forum in Pensacola, FL. An important outcome of the meeting and follow-up review by the five GOMA states was identification of a set of GOMA priorities for long-term water-quality monitoring. The long-term monitoring goals of the Gulf Coast Ecosystem Restoration Task Force Strategy were discussed and incorporated in establishing these priorities. The GOMA water quality monitoring priorities identified during the 2011 Monitoring Forum are:

1. Nutrients and their biological effects
2. The GOMA human health priorities (of equal rank): Harmful algal blooms (HABs), pathogens, and mercury in seafood.

A decision was made by the WQ Team to first develop monitoring designs for nutrients at all scales (accomplished at the Sept. 2012 workshop), then to modify that design to accommodate the GOMA human health priorities (carried out at the March 2013 workshop). The combined results are contained in this report.

The GOMA Nutrients Team participated in the first workshop by identifying the highest priority nutrient monitoring questions for the three scales of interest. In the second workshop, appropriate Workgroups of the GOMA WQ Team were responsible for identifying the highest-priority monitoring questions for their respective areas for the three scales of interest. The monitoring design efforts of this workshop were focused on designing the minimum monitoring system needed to properly address those questions. This report describes the results of that effort, including maps and tables of the measurements and analytes called for in the design. For a complete list of the priority questions, see Appendix 1.

Because these priority questions address the information needs of the various entities making up GOMA, it is anticipated that the analysis and interpretation of that portion of the GMN data will remain primarily their responsibility. For those questions that are larger than single existing programs, the GMN would have responsibility for analysis and interpretation. There is the specific intent that any data collected will be analyzed and the information extracted will be disseminated to the appropriate audiences.

During the first workshop, it became clear that the design of the GMN, including station location, parameters monitored, and frequency, required a modified framework. Questions were originally framed to include addressing "Gulf-wide" or "Regional" scale monitoring; however, monitoring over the continental shelf requires a different design than that for deep water because different circulation models are required for the two areas as a result of the great differences in depth. As a result, the physical system design for answering the priority monitoring questions evolved into a meshed system of monitoring designs for estuary, coastal (out to the 10 m contour), shelf (10 m to the edge of the Continental Shelf), and deep Gulf (beyond the shelf edge) systems (Fig. 1).

Together, these provide the integrated monitoring system necessary to collect the data required to answer the priority questions. These are discussed in more detail in the body of this report.
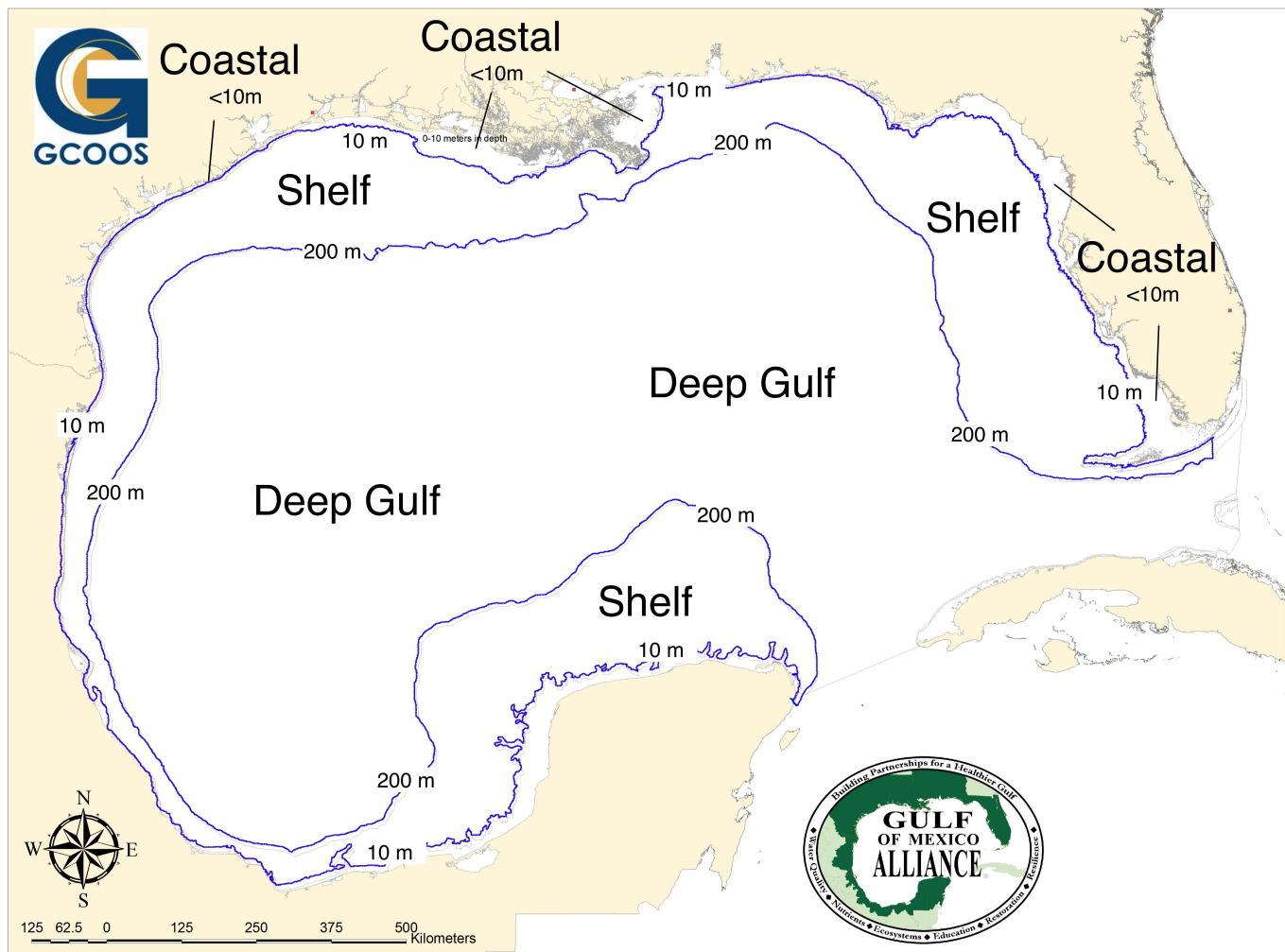
Figure 1. Gulf of Mexico monitoring areas (estuaries not labeled)

Gulf Monitoring Network Design

This report presents the overall water-quality monitoring design for the Gulf Monitoring Network (GMN). For the purposes of the GMN, water-quality monitoring is defined as those physical, chemical, and biological measures needed to indicate that an area's water quality supports a healthy and productive ecosystem. The GMN is primarily intended to monitor water-quality status and trends and to support a broad array of other monitoring by creating the opportunity to build upon the network's "monitoring foundation".

The network design addresses two basic goals, though these are not all-inclusive:
- estimating the fluxes of important constituents at key points in the system being monitored; and,
- monitoring between these flux points to understand the processes affecting the quantity and form of the constituents, and their effect on biological endpoints.

Using models to minimize network sampling requirements

The essential design concept recognizes that monitoring at the scales found across the Gulf of Mexico is cost prohibitive using conventional sampling densities. The GMN design provides a means to deliver information on water quality that enables managers to address priority monitoring questions while minimizing the required sampling and analysis. It does this by establishing a system of water-quality and ecosystem models that are continually verified and improved by comparing their output to the information collected through monitoring and from remote sensing. This feedback loop provides the ability to focus monitoring resources where they provide the most benefit.

Network Objectives

The key objectives of the design are somewhat different for the four monitoring priorities.

For Nutrients, the key objectives are:
- to estimate fluxes of nutrients between different key parts of the Gulf system, and
- to understand nutrient fate, transport, and biological effects.

For HABs, the key objectives are:
- to identify the spatial and temporal distribution of HAB species around the Gulf, and
- to link populations of HAB species to the environmental conditions in which they are found and to understand the triggers that cause blooms.

For Pathogens, the key objectives are:
- to identify the spatial and temporal distribution of pathogen species around the Gulf;
- to link occurrence of pathogens to the environmental conditions in which they are found, and triggers that cause increases in abundance, and;
- to understand the conditions that affect pathogen virulence and increased health risks.

For Mercury, the key objectives are:
- to estimate fluxes of the different species of mercury between different key components of the Gulf system,
- to identify the locations and conditions under which mercury is methylated or demethylated, and
- to identify the sources of the mercury that accumulates in the seafood harvested in different areas of the Gulf.

Scale and Structure

Workshop participants decided that the scales of the physical system design should be somewhat different than the scales used to organize the priority monitoring questions as physical features have a major effect on monitoring system requirements. As a result, the design laid out in this report has evolved into a cohesive, interlocking monitoring design that better supports the development of an integrated set of models able to predict water quality spatially and temporally. The monitoring network described here relies and builds upon nested general circulation models described within the GCOOS documentation. Participants realized that water-quality status and trend monitoring sufficient for good management decisions is cost-prohibitive at this scale. Therefore, models and probabilistic monitoring are employed to capture between-station conditions to address management needs.

The physical design consists of four meshed components: estuaries, coastal segments, continental shelf, and deep-Gulf monitoring systems. The GMN monitoring area for estuaries was defined as starting at the most downstream point of the estuary's tributaries where freshwater flow can be measured absent of tidal influence. They extend to the estuary's interface to the coastal waters, this location being a local decision. Coastal segments comprise the waters lying along the coast out to the 10m contour line. Coastal segment lengths are generally driven by coastal drainages and bathymetry; locations of segment boundaries will be decided locally. The shelf consists of those areas from 10m to the edge of the Continental Shelf. Following GCOOS and Mexican guidance, the Shelf is divided into three sections in the U.S. (the Texas-Louisiana Shelf, Northeastern Gulf Shelf, and West Florida Shelf) and three in Mexico (the Dry Zone Shelf, Wet Zone Shelf, and Yucatan Shelf). The deep Gulf includes the Continental Slope and the abyssal areas. These four components reflect the fact that the factors controlling circulation are significantly different in each. As a result, the hydrodynamic models (and the water-quality models built upon them) for each of these areas must be different and the monitoring systems that feed data to the models have different designs.

Within this approach, participants also designed the network to incorporate any monitoring planned for implementation by the Gulf of Mexico Hypoxia Task Force in the northern Gulf ("Gulf of Mexico Hypoxia Monitoring Implementation Plan", found at http://www.ncddc.noaa.gov/activities/healthy-oceans/gulf-hypoxia-stakeholders/).

Estuary and Coastal-Segment Monitoring Designs: Local Guidance Templates

The incredible variety of the estuarine and coastal segments around the Gulf will require locally-driven development of a design for each. To meet the need for consistent design elements across the Gulf and for flexibility to address local issues, guidance templates were developed; these lay out the minimum requirements for a design to function as part of the Gulf Monitoring Network.

A. Guidance Template for Estuary Monitoring

For the purposes of the GMN, estuaries were defined as beginning at the most downstream point in the estuary's tributaries where freshwater flow can be measured absent of tidal influence. Location of the seaward boundaries is a local decision, but they must align with the inshore boundary of the coastal waters so that there are not gaps in coverage between estuary models and coastal models.

Basic design rationale for estuaries

The underlying rationale for the basic estuary template is threefold:
- to estimate the constituent fluxes into and out of the estuary, whether from tributaries, surface runoff, or tidal exchange with coastal waters, and to tie them into the adjoining coastal model to relate them to nearshore processes;
- to provide information about the processes taking place between the flux-monitoring points; and
- to assess health-risks from coastal pathogens and HABs.

Flux monitoring for estuaries

The design of additional estuarine sampling (beyond that laid out in the template) is locale-specific, and is envisioned as a local process. To inform the local process, monitoring is designed to detect a useful amount of change over an equally-useful time period. For nutrients, it was suggested that designing to detect a 10% change over a two year period—based on the response of sensitive, rapidly-responding indicators tied to primary production—would provide strong support for development and assessment of nutrient criteria. Depending on the situation in a particular estuary, the ability to establish monitoring to detect this level of change may not be practical, but designs should provide a best estimate of the amount of change that can be detected for the primary monitoring goals. These estimates should be updated as data collection proceeds.

In the absence of pre-existing information, use of historical satellite data may be needed to guide development of initial circulation models and to establish locations for monitoring stations. In some cases, early intensive monitoring may be needed to help determine this siting. Locations of estuarine permanent and fixed-monitoring stations should be developed with the idea of relating them to the coastal-segment monitoring stations.

The template requires that a minimum number of permanent stations with mounted instruments be used to collect continuous data (Fig. 2 and enlarged version in Appendix 3a). In most cases, these will include deployments at the major freshwater inflow points to the estuary, the mouths of primary tributaries where significant constituent flux is anticipated, and at locations within the

estuary where significant changes in estuary dynamics take place, such as at flow "choke points". The stations (generally buoys or pilings) should be located to support the validation and calibration of the needed models. Because an important component of the estuary template focuses on quantifying flux, employed models must include tidal fluctuations.

The template calls for permanent-station (e.g., buoys/pilings) and boat-based monitoring at the surface (0.3m) and bottom (where sufficient depth exists for stratification to occur), thereby providing a greater resolution of water column processes, including subsurface flow and chemistry.

The basic data collection (contained in more detail at link in *Appendix 2 – GMN Monitoring System Metadata*) includes continuously-monitored physical and chemical data to support the circulation model (e.g., salinity, temperature, current speed and direction) and to measure as many of the primary flux variables that are called for in the next sections as available technology allows. Additionally, complete meteorological parameters (e.g., wind speed and direction, humidity, barometric pressure, temperature, rainfall) are needed from a monitoring location that appropriately represents conditions across the estuary.

Figure 2. Example of estuarine locations for permanent stations bearing continuous-recording instruments.

Additionally, if required by the local design to support the flux model, boat-based monitoring may be needed at fixed stations between the permanent stations during the sensor-maintenance trips and flow-through monitoring may be needed while the boat moves between stations.

Monitoring environmental processes between estuary flux points
Monitoring environmental processes and their effects on key biological-community endpoints is much more variable than monitoring of flux. The goal of this portion of the estuary monitoring is

to understand the processes affecting the constituents of interest as they move through the estuary and as they pertain to the priority monitoring questions. This portion of the monitoring design may also be appropriate for status monitoring, for instance by employing probabilistic sampling designs (Fig. 3).

Because the process monitoring design is so dependent on the selection of the biological indicators such as seagrasses, phytoplankton, or oysters, template requirements are minimal and the primary guidance is to ensure that the design addresses at least the priority monitoring questi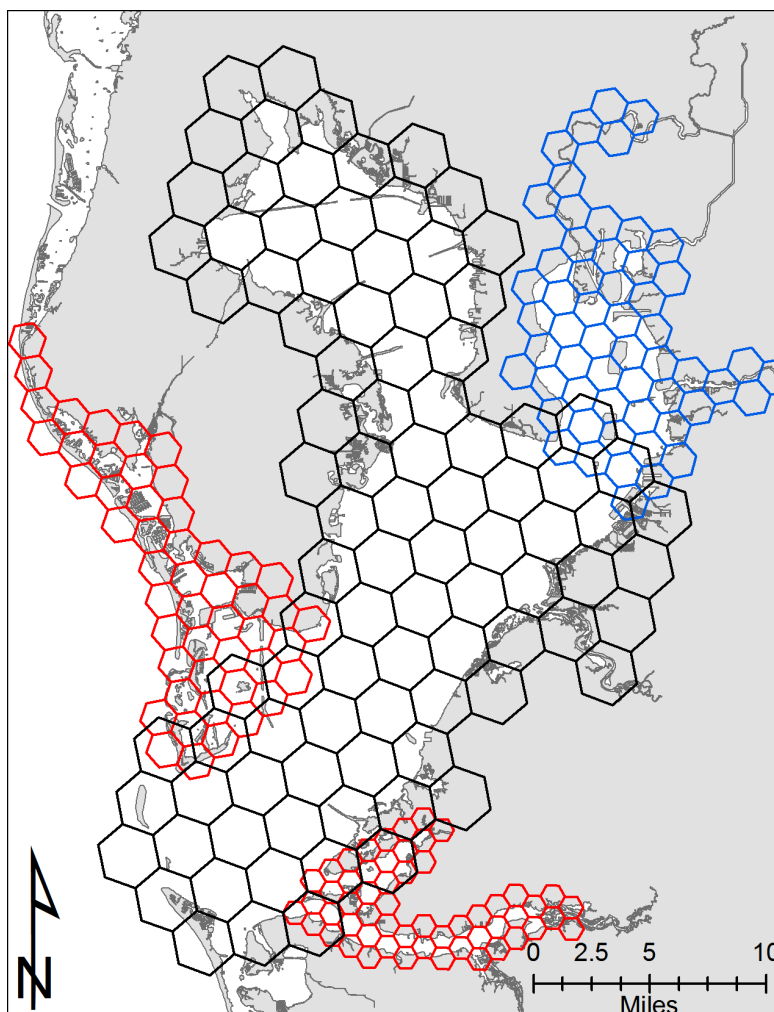ons. Additionally, the process design should consider local geological issues, such as karst topography resulting in groundwater inputs, to better understand estuarine processes. Designs for different types of estuaries will be developed and distributed to serve as examples.

Nutrient-specific design aspects for estuaries

In addition to the required field measurements, the analyte list (see link in

Figure 3. Example of grids used for probabilistic selection of sampling locations in an estuary.

GMN Monitoring System Metadata) includes the basic suite of nutrient analytes, as well as supporting parameters. Field measurements at permanent stations will be made in 15-minute intervals to assist in ground-truthing remote sensing data, validating and initiating models, and assessing variability to optimize associated periodic sampling.

Boat–mounted flow-through sensors operated between the permanent and fixed stations provide complementary monitoring data to assess and identify changes in nutrients during transit between flux points (Fig. 4). The list of analytes needed to accomplish this focuses, at a minimum, on the chemical suite listed for permanent and fixed stations, including surface and bottom measurements at sites deep enough to develop stratification. The design includes sediment monitoring of nutrients and of markers for the overlying phtyo- and zooplankton communities during the first two years and every five years thereafter to understand sediment oxygen demand, nutrient flux, and nutrient-based changes in community composition and abundance.

Atmospheric deposition of nitrogen (also detailed at link in *Appendix 2*) is necessary to complement the coastal monitoring of nutrient fluxes. Atmospheric deposition sites are not needed for every estuary, but appropriate regional sites should be identified to provide the data required for the estuary models.

Mercury-specific design aspects for estuaries

The spatial and temporal design for nutrient monitoring is highly compatible for use as a framework for monitoring mercury. Moreover, the parameters monitored under the nutrient plan would also be highly valuable for interpreting results from mercury monitoring. Although mercury monitoring does not yet enjoy the same level of sensor-based, autonomous data collection as that for nutrients, ship-based sampling for mercury can occur during transect sampling for nutrients and when sensors mounted on buoys or pilings are visited for maintenance. To avoid possible

Figure 4. Example of estuarine locations for fixed stations and tracks for sampling during maintenance trips to permanent stations.

contamination (from construction materials or lost batteries) at the piling or buoy, ultra-trace mercury sampling would occur at a specified distance away from the structure. The addition of mercury parameters (described at link in *Appendix 2*) to the sampling regime and to the atmospheric-deposition stations provides the necessary information to address the priority questions. It is anticipated that following an intensive sampling period (perhaps two years), the collected data would provide a better understanding of the different systems, allowing monitoring to be scaled back.

In addition to collecting mercury analytes in the water column at the permanent and fixed stations, sediment sampling would be conducted along estuary transects to monitor changes in

mercury and methylmercury flux in sediment and infauna. This sampling would be conducted quarterly-to-annually in conjunction with water-quality sampling.

Atmospheric monitoring should be ground-based within the coastal watershed. This monitoring will be coordinated with the Atmospheric Mercury Network (AMNet) (atmospheric concentrations and dry deposition) to ensure that any new efforts are meshed appropriately with existing network sites. As with other aspects of the design, an important use of these sites will be to evaluate models.

The sampling of tissues from seafood and food-web organisms (i.e., specific prey of the valued seafood resource) is necessary to assess trends in methylmercury concentration and to validate predictive models. Where possible, this sampling will be coordinated with state fishery agencies and NOAA's Mussel Watch. However, past inconsistences among states in targeted species (and size, age and other influential factors leading to bioaccumulation) must first be resolved to improve comparability. Tissue samples from key estuarine-dependent species, e.g., spotted sea trout , red drum, and oysters, should be collected across the Gulf estuaries using standard protocols for size and age class. The frequency of tissue collections for oysters or other short-lived species (which integrate their exposure over a shorter time) should be quarterly to coincide with WQ sampling and capture seasonality. Organisms lower in the food web, such as oysters, blue crabs, white shrimp, and brown shrimp should be targeted since they serve as key prey species for mid-level predators known to bioaccumulate mercury. Annual sampling would be sufficient for larger gamefish.

HABs-specific design aspects for estuaries
The coastal and estuarine stations are the most important for HAB monitoring because it is at these scales that HABs exert their negative effects on human and environmental health. Estuarine-scale monitoring consists of a network of permanent continuous-monitoring buoys, fixed sentinel boat- and shore-based monitoring stations, underway boat-based monitoring en route to servicing the fixed stations, and adaptive event-response monitoring.

Continuous monitoring stations with phytoplankton parameters are necessary for two reasons: (1) to provide the information to develop the predictive models of HAB initiation and transport and (2) to provide early warning for HABs in critical areas (see below guidance on station placement). Some continuous monitoring stations already exist throughout the GOM, although most are operated from a research rather than a monitoring or management perspective. Sensors should be added to existing stations where possible for integration and include where appropriate HAB-toxin sensors. In addition, continuous automated monitoring for phytoplankton community composition should be implemented in estuaries with a history of bloom problems. Equipment for sensing both community composition and toxins in the water column have become mature technologies with commercial versions beginning to become available.

For fixed sentinel stations monitored by boat or from shore in estuaries, stations should be placed not only to assess population distributions but also to identify the source populations of HABs. At these stations, weekly sampling is needed for existing and emerging HABs, biotoxins (specific

toxins will depend on the local HABs present), and physical and environmental parameters (Appendix 2). Sediment sampling on a less frequent basis is also needed to detect both toxins and cysts, as baseline data and in response to bloom events.

In general, estuary monitoring for HABs should be implemented at:
- Major ports
- Recreationally-important regions (i.e., beaches, recreational fishing, boating)
- Economically-important regions (i.e., regions of high population densities, high tourism, commercial or cultural destinations, commercial fisheries)
- HAB hotspots (locations having a history of blooms)
- Shellfish harvesting areas (commercial, recreational, and subsistence)

As a general practice, duplicate samples should be processed and archived in anticipation of more sensitive HAB cell and toxin detection technologies. While underway between stations, data should be collected with flow-through sampling to map surface phytoplankton biomass and phytoplankton community composition and associated parameters (Appendix 2). Samples should be taken during mapping for ground-truthing of flow-through data.

Pathogen-specific design aspects for estuaries
The design for pathogen sampling may require the addition of monitoring sites near shellfish beds or bathing beaches, as well as areas of known potential discharge sources (e.g., urban stormwater, wastewater discharges, or livestock feeding operations).

The probabilistic sampling performed for other purposes (e.g., nutrient processes), should suffice for pathogen population monitoring. Monthly sampling for appropriate pathogens or pathogen indicators (see link in *Appendix 2*), with intensive sampling twice per year (e.g., wet and dry seasons) serves to improve exposure-risk modeling. Any stations added solely for pathogen measurements must also monitor the minimum physical and chemical parameters listed for pathogens at the link in *Appendix 2.*

Given the high spatial and temporal variability of pathogenic organisms and indicators in natural waters, planning experts must determine the best method to obtain a representative sample of the areas being sampled.

Existing models frequently fail during episodic events such as rainfall; therefore, an objective of this monitoring is to improve the models' ability to predict changes in health risk resulting from events. Monitoring designs should include model validation sites to improve model prediction capability relative to changes in health risk based on the occurrence of such events.

B. Guidance Template for Coastal-Segment Monitoring
A coastal segment, for the purpose of the GMN, is defined as a section of coastal waters between the coastline and the 10m contour. The boundaries between segments are determined locally, but would generally be driven by coastal drainages and local hydrography (Fig. 5). Where estuaries adjoin a coastal segment, the two must share a common boundary to prevent gaps in model coverage and provide for the collection of boundary-exchange information.

The design of coastal monitoring (Fig. 5 and enlarged version in Appendix 3b) should take place locally to accommodate both the variety of coastal systems and of local needs. The design should provide a system for collecting data to support local and state decisions (e.g., nutrient criteria development to protect aquatic resources) and other local needs.

Basic design rationale for coastal segments

The underlying rationale for the basic coastal template follows that for estuaries and is also threefold:

- to estimate the fluxes into and out of the coastal segment to relate water quality in the coastal segment to both offshore upwelling and nearshore processes;
- to provide information about the processes taking place between the flux points; and
- to assess health-risks from coastal pathogens and HABs.

Flux monitoring for coastal segments

Coastal flux monitoring generally follows that laid out in the estuary guidance template. Modifications to the estuary guidance template include additions of primary locations to estimate flux at the common boundary with any estuaries, at significant non-estuarine tributaries, and along the 10 m-deep boundary with the

Figure 5. Example of coastal segment boundaries and locations of permanent monitoring stations bearing continuous-recording instruments.

Continental Shelf monitoring region. Moreover, some karst regions may require estimation of fluxes where significant groundwater flows directly into the coastal segment.

The same goal laid out in the estuary guidance of setting a change-detection target for the design (10% change over a two-year period is suggested) applies to the coastal segment, as well as the steps for developing circulation and water-quality models.

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The template focuses on quantifying flux in a tidal environment, with the assumption that the accompanying models include tidal fluctuations. In most cases, the permanent stations located at the interface with adjacent estuaries are shared with the estuarine monitoring system (Fig. 5). Permanent-station buoys at the seaward boundary with the Continental Shelf region (i.e., at the 10m contour) will also be shared with that region's monitoring d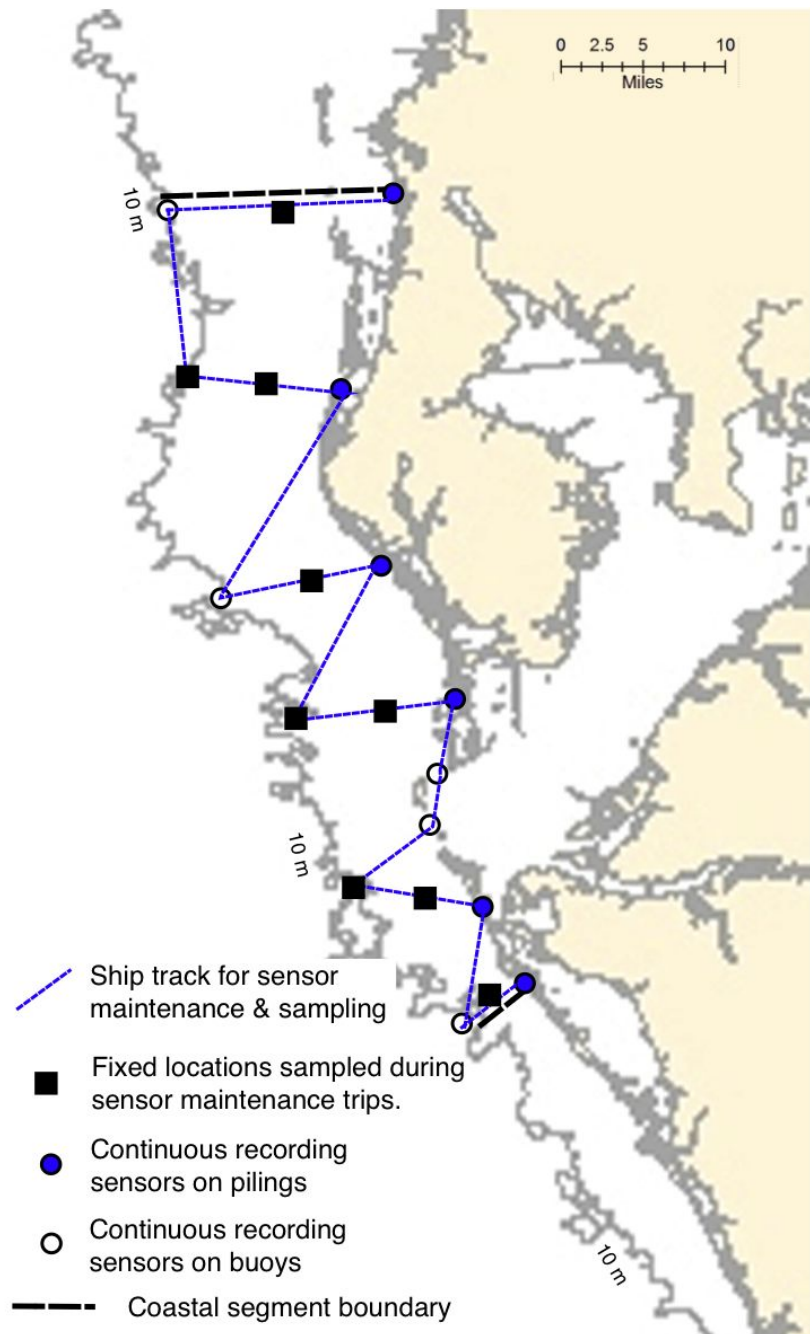esign. A 10m contour line more than three (3) miles from shore, which characterizes the Yucatan, parts of the west Florida shelf, and parts of Louisiana, may require additional buoys located between the 10m line and the coastline to properly capture transport processes. These intermediate buoys will be repeated alongshore at a frequency determined in the local design process as necessary to support the development of coastal models. The template requires a minimum number of fixed stations within the coastal segment to adequately characterize the state of coastal waters; these would collect data daily, weekly, or monthly (Fig. 6).

The basic data collection (described in more detail at link in *Appendix 2 – GMN Monitoring System Metadata)* includes

Figure 6. Example of coastal-segment locations for fixed stations and tracks for sampling during maintenance trips to permanent stations.

physical and chemical data to support the circulation model (e.g., salinity, temperature, current speed and direction, etc.) and to measure as many of the primary flux variables as available technology allows. Additionally, complete meteorological parameters (e.g., wind speed and direction, humidity, barometric pressure, temperature, rainfall, solar radiation) should be obtained from a site that appropriately represents conditions across the coastal segment.

Additionally, boat-based monitoring takes place at fixed stations between permanent stations during the quarterly maintenance trips and flow-through monitoring occurs while the boat moves between stations.
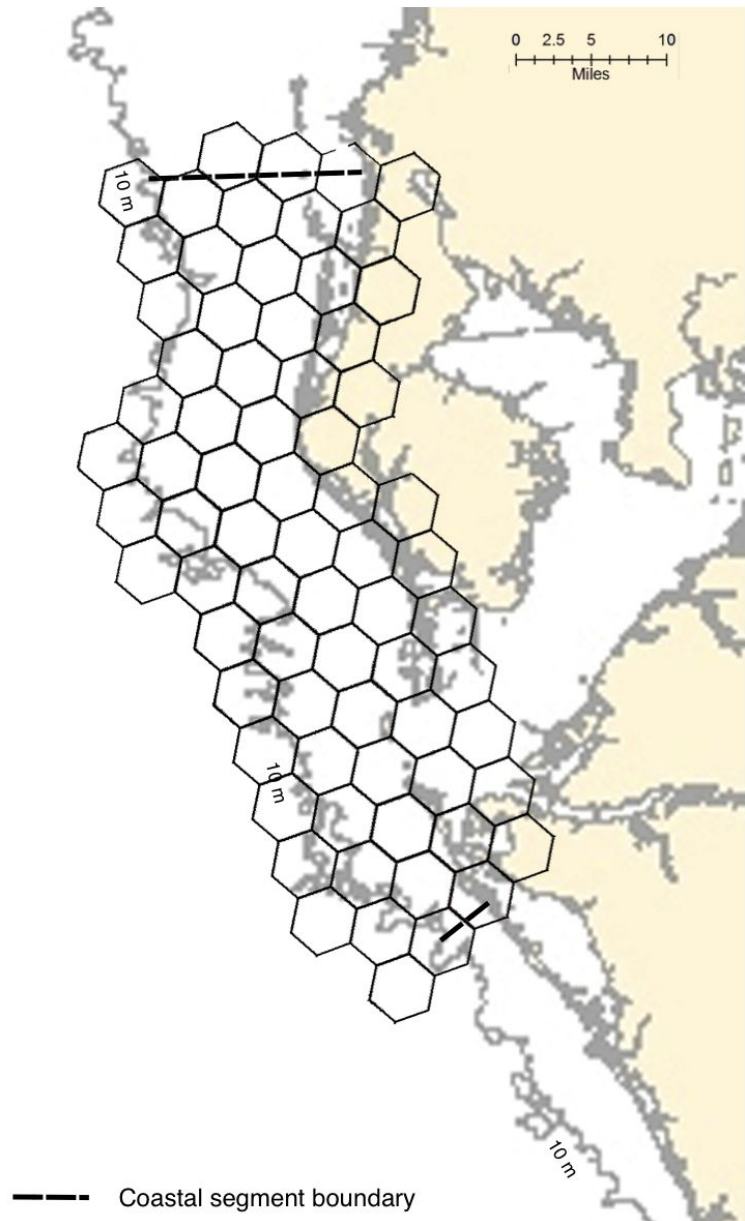
Monitoring of environmental processes between coastal-segment flux points

Monitoring of environmental processes and their effects on key biological-community endpoints is much more variable than monitoring of flux. The goal of this portion of the coastal monitoring is to understand the processes affecting the constituents of interest as they move across and along the coastal area and as they pertain to the priority monitoring questions. This portion of the monitoring design may also be appropriate for status monitoring; for instance, by employing probabilistic sampling designs (Fig. 7).

Because the process monitoring design is highly dependent on the selection of the biological indicators and end-points, template requirements are minimal. The primary guidance is to ensure that the design addresses the priority monitoring questions and is appropriate for the type of coastal system under consideration. Designs for different types of coastal areas will be developed and distributed to serve as examples.

Figure 7. Example of method for probabilistic selection of sampling locations in a coastal segment.

Nutrient-specific design aspects for coastal segments

Complementary probabilistic and deterministic monitoring is needed to assess and identify changes in the way nutrients are processed during transit between the flux points (i.e., as they move to the shelf or from offshore upwelling or longshore-transport sources into the estuary). This includes monitoring using flow-through sampling from boats traveling along transects between the permanent and fixed stations. The list of analytes needed to accomplish this focuses at a minimum on the chemical suite listed in the table for buoy/piling stations, including surface and bottom measurements (see link in *Appendix 2 – GMN Monitoring System Metadata*).

In coastal segments where the bottom is in the photic zone, the local monitoring design process should address biological indicators, such as seagrass, phytoplankton, oysters, or other primary producers/consumers that will rapidly reflect nutrient changes. Additionally, the local design process should also consider important local geological features, such as karst topography facilitating groundwater inputs, to better understand coastal segment processes.

Complete meteorological parameters (e.g., wind speed and direction, humidity, barometric pressure, temperature, solar radiation) are necessary. Additionally, at locations where such information is not available, atmospheric deposition of nitrogen should be included to complement the coastal monitoring of nutrient fluxes and mercury sources.

The design includes sediment monitoring of nutrients and phyto- and zooplankton communities during the first two years and every five years afterward to understand sediment oxygen demand, nutrient flux, and nutrient-based changes in community composition and abundance.

Mercury-specific design aspects for coastal segments
The water-sampling design for mercury in coastal segments again closely aligns with that for nutrients and matches that laid out for estuaries. See the earlier section *Mercury-specific design aspects for estuaries* for details.

HABs-specific design aspects for coastal segments
Coastal monitoring consists of a network of permanent continuous-monitoring buoys (see estuarine scale for description of needs); fixed sentinel boat- and shore-based monitoring stations; underway boat-based monitoring; AUV monitoring; and adaptive event-response monitoring.

In addition to the continuous-monitoring stations in coastal segments, routine monitoring should include (1) an alongshore transect about 8-16 km offshore with fixed sentinel stations located every 10 km, (2) coupled with beach-based sampling every 10 km; and (3) inshore-offshore transects at major estuarine systems with fixed sentinel stations determined at a local level to provide a basic routine monitoring framework. Samples should be taken monthly along the alongshore and inshore-offshore transects and weekly from beaches.

For the fixed sentinel stations, samples should be taken for existing and emerging HABs, biotoxins (specific toxins will depend on local HABs present) and physical and environmental measurements (Appendix 2). Sediment sampling on a less frequent basis is also needed to detect both toxins and cysts, as baseline data and in response to bloom events. In general, coastal monitoring for HABs should be implemented at:
- Recreationally-important regions (i.e., beaches, recreational fishing, boating);
- Economically-important regions (i.e., regions of high population densities, high tourism, commercial or cultural destinations, commercial fisheries);
- HAB hotspots (locations having a history of blooms); and
- Shellfish harvesting areas (commercial, recreational, and subsistence).

As a general practice, duplicate samples should be processed and archived in anticipation of more sensitive HAB cell and toxin detection technologies. Also, while underway between stations, data

should be collected with flow-through sampling to map surface phytoplankton biomass, phytoplankton community composition, and associated parameters (Appendix 2). Samples should be taken during mapping for ground-truthing flow-through data.

Pathogen-specific design aspects for coastal segments

The design for pathogen sampling in coastal segments parallels that for estuaries and requires the greatest change to the design for nutrient and mercury monitoring. For coastal waters containing shellfish beds or bathing beaches, the design for nutrients/mercury may need to be amended to include sites that accommodate these locations as well as those of known potential sources of pathogens (e.g., wastewater discharges or livestock feeding operations).

If probabilistic sampling is performed for nutrient purposes, it should suffice for pathogen population monitoring. Quarterly sampling should be conducted for appropriate land-based pathogens or pathogen indicators and monthly sampling for pathogenic *Vibrio* species (see link in *Appendix 2*), with intensive sampling twice per year (e.g., wet and dry seasons) to better capture events and improve exposure-risk modeling. For any stations that must be added solely for pathogen measurements, the link at *Appendix 2* contains the minimum physical-chemical environmental measurements needed to accompany those for pathogens and pathogen indicators.

## Monitoring Designs for Shelf and Deep-Gulf Areas

Unlike the templates to guide development of localized coastal and estuary designs, the shelf and deep-Gulf regions are sufficiently similar to allow single overall designs for each.

A. Design for Shelf Monitoring

The shelf area around the Gulf is defined for GMN purposes as that area from the 10m contour out to the edge of the Continental Shelf (about 200m deep) (Fig 8). GCOOS has recommended that the U.S. portion be divided into roughly three segments for model-development purposes. These are the West Florida Shelf, the North Eastern Gulf Shelf, and the Texas-Louisiana Shelf. They are based on hydrodynamics of each area, which are different due to orientation of the shelf and other coastal features. These segments can be expanded or narrowed to meet specific objectives, but ultimately the goal is to have the regional component models mesh with each other in a scientifically defensible manner. The shelf in Mexican waters is composed of segments named for the adjacent land characteristics, the Dry Zone Shelf (little freshwater input), The Wet Zone Shelf (80% of the river flow), and the Yucatan Shelf (primarily groundwater flow). These may also be appropriate areas for model development, with the same ultimate goal to have the regional component models mesh with each other. The monitoring-design factors for each segment are similar.

Basic design rationale for monitoring the shelf

Monitoring over the shelf differs from that near the coast in varying degrees for the different monitoring priorities. Different circulation models are needed over the shelf than the coastal areas due to the increased depth and other factors. The rationale for the proposed station locations (Fig.
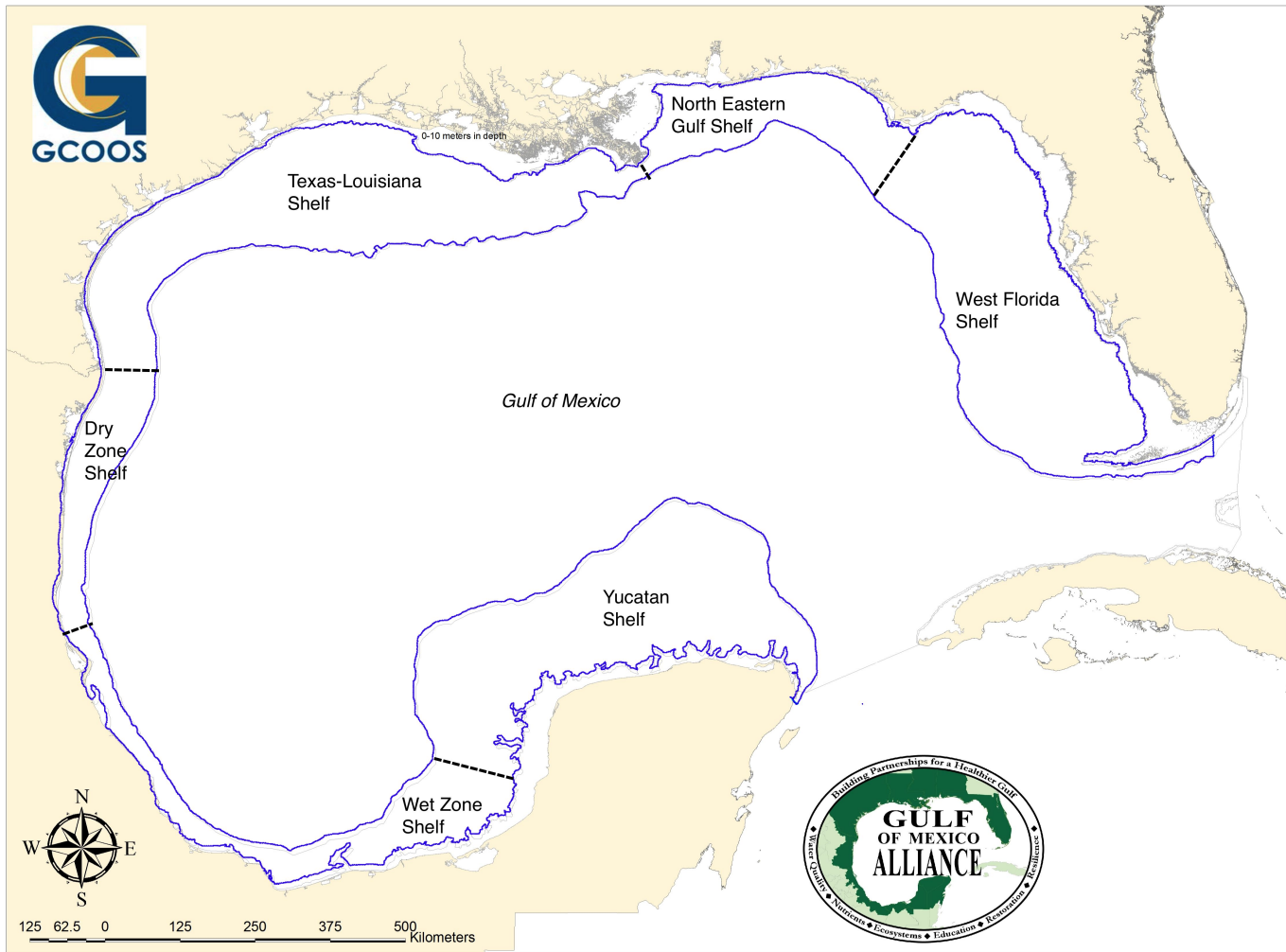
Figure 8. Potential shelf modeling regions.

9, Shelf Buoy transects and enlarged version in Appendix 3c), frequency, and parameters selected for this scale is primarily to provide information on boundary conditions to coastal and deep Gulf models.

The basic goal of estimating fluxes of important constituents remains the same as for the inshore monitoring systems. However, when monitoring over the shelf the main sources are inshore movements across the shelf by circulation features from the adjacent areas of deepwater upwelling, offshore movements from adjacent coastal areas, and transport coastwise by deeper currents that follow the bottom contours. Additionally, vertical mixing becomes significant.

The need for monitoring of the processes operating between the flux points is reduced on the shelf for some of the monitoring priorities, as will be described below.
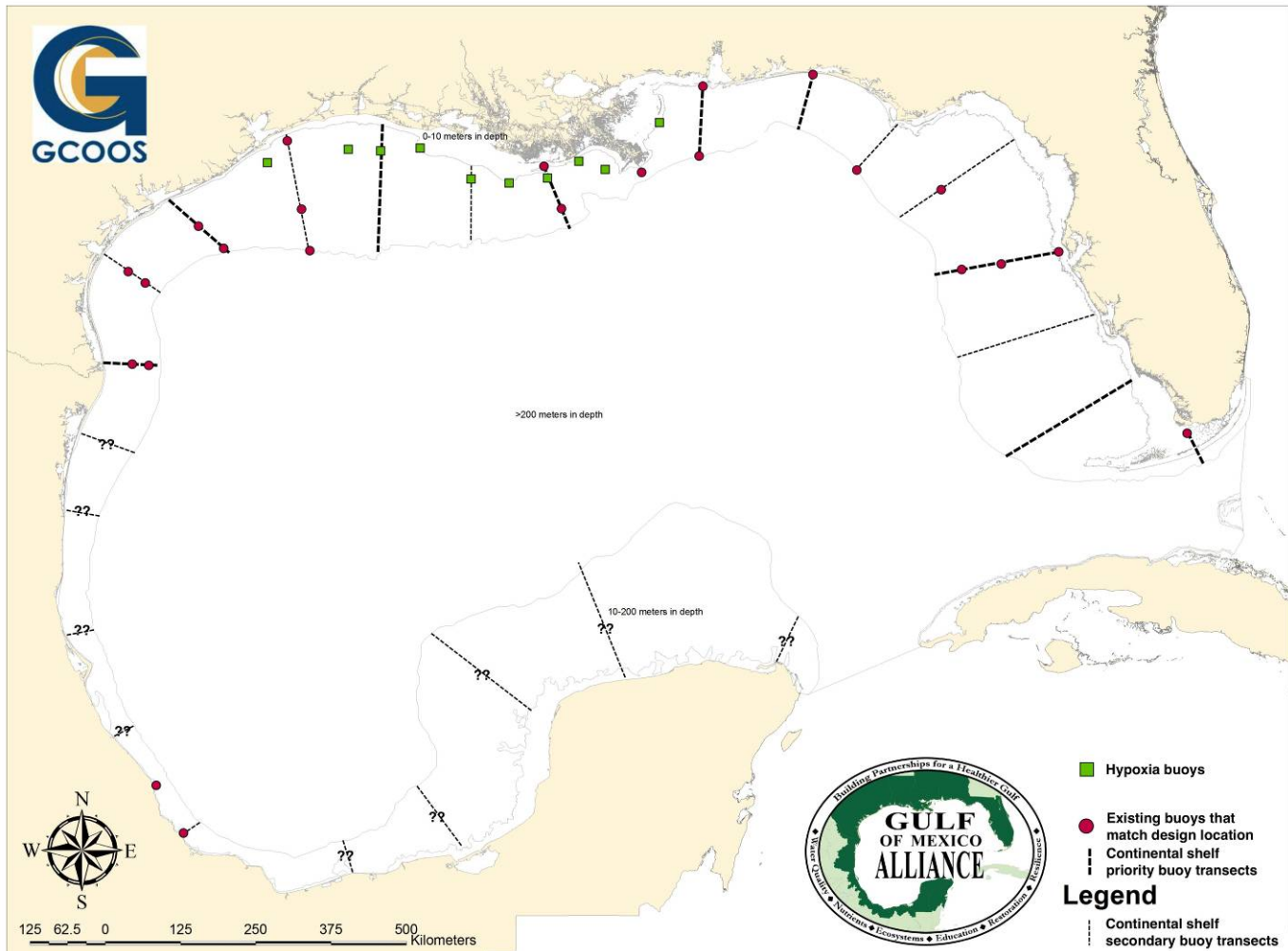
Figure 9. Location of buoy transects on the Continental Shelf and additional buoys for monitoring of the Gulf Hypoxic Zone (after GCOOS).

Flux monitoring over the continental shelf

Through the use of nested models (GCOOS 2011), flux estimates in and out of the borders of the shelf segments are generated for each shelf segment. Buoys with recording instruments are positioned roughly along transects from shallow to deep water and positioned near the 10m, 50m, 100m, and 200m depth contours (see Fig 9). Those along the 10m contour are shared with the monitoring systems for the adjacent coastal areas. Those along the 200m contour are shared with the deep-Gulf monitoring system. Adjustments to buoy placement or number may be needed at broad or narrow sections of the shelf; for example, mercury and HABs monitoring requires the addition of a buoy at about the 25m contour on the West Florida Shelf to provide more even geographic coverage of the processes they are monitoring. Best support of models may require movement along depth contour between buoy transects and to boundaries between shelf segments to properly estimate flow and flux between them.

Additional buoys are located in the Gulf Hypoxic Zone (see *Fig. 9*). These data points serve to increase the resolution of the models to accurately assess changes in the zone's size and in the processes resulting in hypoxia.

The basic data collection (displayed in more detail at the link in *Appendix 2 – GMN Monitoring System Metadata)* includes physical-chemical data to support the circulation model (e.g., salinity, temperature, current speed and direction, etc.) and to measure as many of the primary flux variables that are called for in the next sections. Additionally, complete meteorological parameters (e.g., wind speed and direction, humidity, barometric pressure, temperature, rainfall, and solar radiation) are needed from a site that appropriately represents conditions across the coastal segment.

Ship-based monitoring takes place at fixed stations between buoys during the buoy-maintenance cruises and flow-through monitoring occurs while the ship moves between stations and buoys.

Hydrodynamic and water-quality models for the shelf regions are improved by data from routine glider sampling across the shelf. These provide the otherwise missing ability to ground-truth model predictions at depth.

Monitoring of environmental processes between continental shelf flux points
The Shelf component of the GMN is designed to include complementary deterministic (trend) sampling carried out from ships. Deterministic sampling is carried out at and between the permanent and fixed stations (Fig. 10), and probabilistic stations are sampled at randomly-generated sites. A power analysis based on information from monitoring the Gulf Hypoxic Zone could be used to conservatively identify the station density needed for probabilistic monitoring on the shelf. This is based upon the workshop participants' understanding that the Gulf Hypoxic Zone is one of the most variable of the shelf environments. Additional or subsequent data collection may allow regional shelf station densities to be reduced. For example, this design could include transects using sensor-equipped gliders to sample selected parameters, which would identify flux points and reduce station densities.

The rationale for using a variety of monitoring strategies, such as buoys, ships, remote sensing, etc. is to provide both interpolation of data between permanent stations and "ground-truthing" of models and remotely-sensed data. Stationary buoys would monitor continuously or at periodic intervals, with flow-through ship-based monitoring occurring along transects between buoys on a monthly basis during buoy maintenance. The design proposes both buoys and ships monitoring at surface (0.3m), mid-depth, and 3 m from the bottom, thereby providing a greater resolution of water column processes, including subsurface flow and chemistry.

## Nutrient-specific design aspects for the continental shelf

Understanding nutrient status and trends, fluxes delivered to and from the shelf, and better understanding of circulation patterns and their affect on nutrient fate and transport is important for shelf monitoring.

Depending on the local hydrography, additional lateral buoys may need to be sited along the 100m isobaths between each transect to measure hydrodynamics as well as water quality parameters. The rationale for this siting is to support design of nutrient water-quality models, facilitate statistical comparisons between and among stations, monitor nutrient inputs from estuarine areas to the shelf, and monitor nutrient transport across the shelf.

Complete meteorological parameters (e.g., wind speed and direction, humidity, barometric pressure, temperature), plus atmospheric deposition of nitrogen would be included to complement regional monitoring of nutrient fluxes.

Fixed sites to sample during buoy maintenance trips

○ buoys with continuous-sampling equipment

━ Ship track for sensor maintenance & sampling

Figure 10. Example of fixed-station sampling sequence during buoy-maintenance trips.

Sampling of aerial deposition of nutrients is an important part of the monitoring design. Some petroleum rigs may be suitable for sampling of nutrient deposition, but many may bias results as a result of contamination related to rig activities. Ship-based sampling may be a necessary component.

The design includes sediment monitoring once every five years to understand sediment oxygen demand, nutrient flux, and nutrient-based changes in community composition. Abundance-based analyses of phyto- and zooplankton communities are also included to improve existing models and to inform inferences on regional processes.
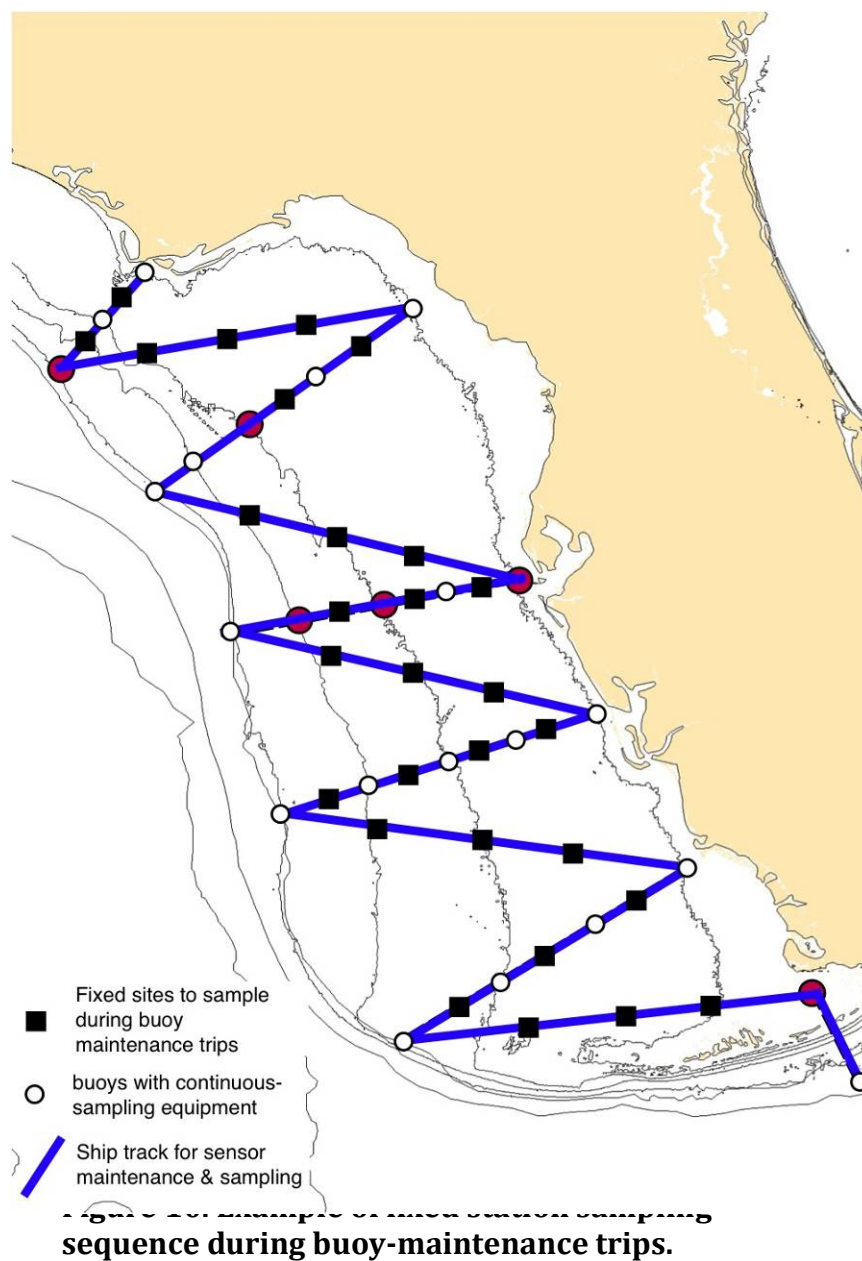
In addition to the required field measurements, the analyte list includes the basic suite of marine nutrient analytes, as well as supporting parameters and isotopes needed for understanding nutrient processes (see link at *Appendix 2 – GMN Monitoring System Metadata*).

Mercury-specific design aspects for the continental shelf

The water-sampling design for mercury on the shelf closely matches that for nutrients. While mercury monitoring does not require the same level of sensor-based, autonomous data collection as that of nutrients, ship-based sampling for mercury can occur during transect sampling for nutrients and when sensors mounted on buoys or pilings are visited for maintenance. To avoid possible contamination (from construction materials or lost batteries) at the piling or buoy, ultra-trace mercury sampling would occur at a specified distance away from the structure.

The addition of mercury parameters (described at link in *Appendix 2*) to the same sampling regime and to the atmospheric-deposition stations provides the necessary information along with the addition of sampling at the 25m contour on the West Florida shelf and another sampling transect at the southern portion of the West Florida Shelf to capture flux from the Everglades. In addition to the sampling scheme used for nutrients, mercury sampling within the water column will also take place at the oxycline and pycnocline levels, and from within any observed hypoxic zones.

If feasible (based on design of the buoys), atmospheric deposition of mercury, both wet and dry, and atmospheric mercury concentrations will be monitored on selected buoys at the 200m depth-contour. If not feasible, other options will be explored, including use of oil platforms. If no permanent deployments are feasible, extended-duration sampling can take place from shipboard at those buoys during maintenance visits. This monitoring will again be coordinated with Mercury Deposition Network (MDN) (wet deposition) and the Atmospheric Mercury Network (AMNet) (atmospheric concentrations and dry deposition). It is anticipated that following an intensive sampling period (perhaps two years), the collected data would provide a better understanding of deposition and allow reduced monitoring. As with other aspects of the design, an important use of these measurement data will be to evaluate models.

Sampling of tissues from seafood and food-web organisms (i.e., specific prey of the valued seafood resource) will also be necessary on the shelf to assess trends in methylmercury concentration and to validate predictive models. Where possible this effort should be coordinated with state and federal fishery agencies as long as targeted species and associated data (size, age and other influential factors leading to bioaccumulation) are consistent. Key species to include Gulf-wide on the shelf will likely be chosen from the following: king mackerel, red snapper, cobia, groupers, amberjack, jack crevalles, and sharks, with tissue samples collected semi-annually to capture some seasonal events. Sampling should take place coincident with routine water quality sampling trips when possible.

As part of the monitoring for nutrients at probabilistic stations, bulk sediment will be collected for determination of mercury species. Where nutrient flux measurements are collected, mercury analytes should be included. Annual benthic infauna and sediment sampling is needed at the

fixed stations along buoy transects for measurements of mercury and methylmercury. This sampling should be conducted annually in conjunction with water-quality sampling.

Mercury in sediments should also be monitored offshore from the Mississippi River due to sediment buildup, sloughing, and landslides in the shelf area, which may result in changes in the mercury to methylmercury ratios.

HABs-specific design aspects for the continental shelf

The shelf-scale design is important to identify phytoplankton community composition and potential source populations for shelf-scale transport models. For HAB priority goals, the default placement of buoys at the 10, 50, 100, and 200m isobaths recommended by GCOOS in support of circulation models should be amended to provide greater cross-shelf geographic coverage. It is important to note that HAB formation and transport is not *per se* linked to bathymetry in the same way as circulation and nutrient transport. Important aspects of shelf buoy locations for HAB monitoring purposes include:

- For monitoring blooms of species such as *Karenia brevis*, offshore data (e.g., 20-50 miles) are necessary, but the need for sampling further offshore is limited. For the monitoring of *Gambierdiscus* spp., stations near oil-rigs and on artificial reefs should be targeted.

- Inshore-offshore buoy arrays should align with major freshwater flows (riverine and groundwater), particularly within 20-50 miles of shore. Additional buoy arrays are needed near historically relevant or suspected locations of HAB initiation, determined at regional and local scales.

Buoys placed in near-shelf regions (e.g., 10 or 20 miles from shore, dependent on region) will have the most value for HAB detection. At these stations, buoys should incorporate sensors that continuously monitor phytoplankton biomass and nutrient concentrations, in addition to the physical and chemical parameters at the link in Appendix 2. Vertical profiling sensors should be incorporated because the vertical water column structure and location of nutrient maxima are critical to bloom development and dynamics. During the monthly maintenance trips to all buoys, discrete samples should be taken as contained at the link in Appendix 2. Efforts should include CTD casts as well as discrete sampling along vertical profiles. These will primarily serve as baseline and long-term monitoring data, although they may have utility for immediate HAB detection and initiation.

As a general practice, duplicate samples should be processed and archived in anticipation of more sensitive HAB cell and toxin detection technologies. Also, while underway between stations, data should be collected with flow-through sampling to map surface phytoplankton biomass; phytoplankton community composition; and key physical parameters (Appendix 2). Samples should be taken during mapping for ground-truthing flow-through data.

Pathogen-specific design aspects for the continental shelf

The design for pathogen sampling on the shelf differs substantially from the other monitoring priorities. From the 10m depth-contour out to the 25M contour, sampling is the same as for the

coastal areas. Beyond 25m, sampling consists simply of the three pathogenic *Vibrio* species taken quarterly at the buoy locations. However, this is modified off the Mississippi Delta because it is a known high-volume source. In this region, the coastal sampling extends out to the shelf edge.

Additionally, opportunistic sampling of weed lines, hurricane paths, and similar events—selected by remote sensing before the cruise if necessary—is needed to establish baseline populations of these *Vibrio* species.

B. Design for Deep Gulf Monitoring

For purposes of the Gulf Monitoring Network, the Deep Gulf is defined as the Continental Slope (beginning at a depth greater than about 200m) and the abyssal areas of the Gulf.

Basic design rationale for monitoring of the deep Gulf

The Deep Gulf requires a different model than those for the shelf as a result of the significantly greater depths. The depth of the area ranges from 200m at the edge to 4,384m, with half of the total area being greater than 3,000m. Two key features are the wind-driven deep-water upwelling events that bring nutrient-enriched deep waters to near-surface and the Loop Current, formed by water flowing into the Gulf via the Yucatan Channel and out via the Florida Channel. The Loop Currents location in the eastern Gulf varies widely and spins off large eddies and turbulent features that affect large areas of the Gulf by pulling water off the shelf or injecting nutrient poor-waters onto the shelf. The Loop Current eddies spin up other, counter spinning eddies that also can result in upwelling of nutrients from depth. Buoys are located to support circulation and water-quality models that can inform the models in the other Gulf areas about inshore effects from deep-water events.

Flux monitoring of the deep Gulf

The deep-water part of the Gulf monitoring network employs a deterministic network (permanent and fixed-station), ship-based sampling during buoy-maintenance trips, and remote sensing. A variety of monitoring strategies are employed to provide both interpolation of data among fixed stations and "ground-truthing" of models and remotely-sensed data.

Stationary buoys monitor continuously or at periodic intervals, including as many of the flux parameters needed for the monitoring priorities as technology allows (Fig. 11-Deep Gulf Stations and enlarged version in Appendix 3d). Additionally, ship-based monitoring takes place at fixed stations between buoys during the quarterly buoy-maintenance cruises and flow-through monitoring of near-surface water (~3m, where ship intake is located) occurs while the ship moves between stations and buoys. The design proposes both buoys and ships to monitor at surface (0.3 m), mid-depth (but still within the photic zone), and "bottom" (or as deep as available sensor technology allows), thereby providing a greater resolution of water column processes, including subsurface flow and chemistry.

The GMN design follows the recommendations of GCOOS for buoy locations in U.S. waters to provide information to support a circulation and water-quality model for that region (GCOOS2011). This model provides flux estimates to the boundaries of the adjacent shelf models.
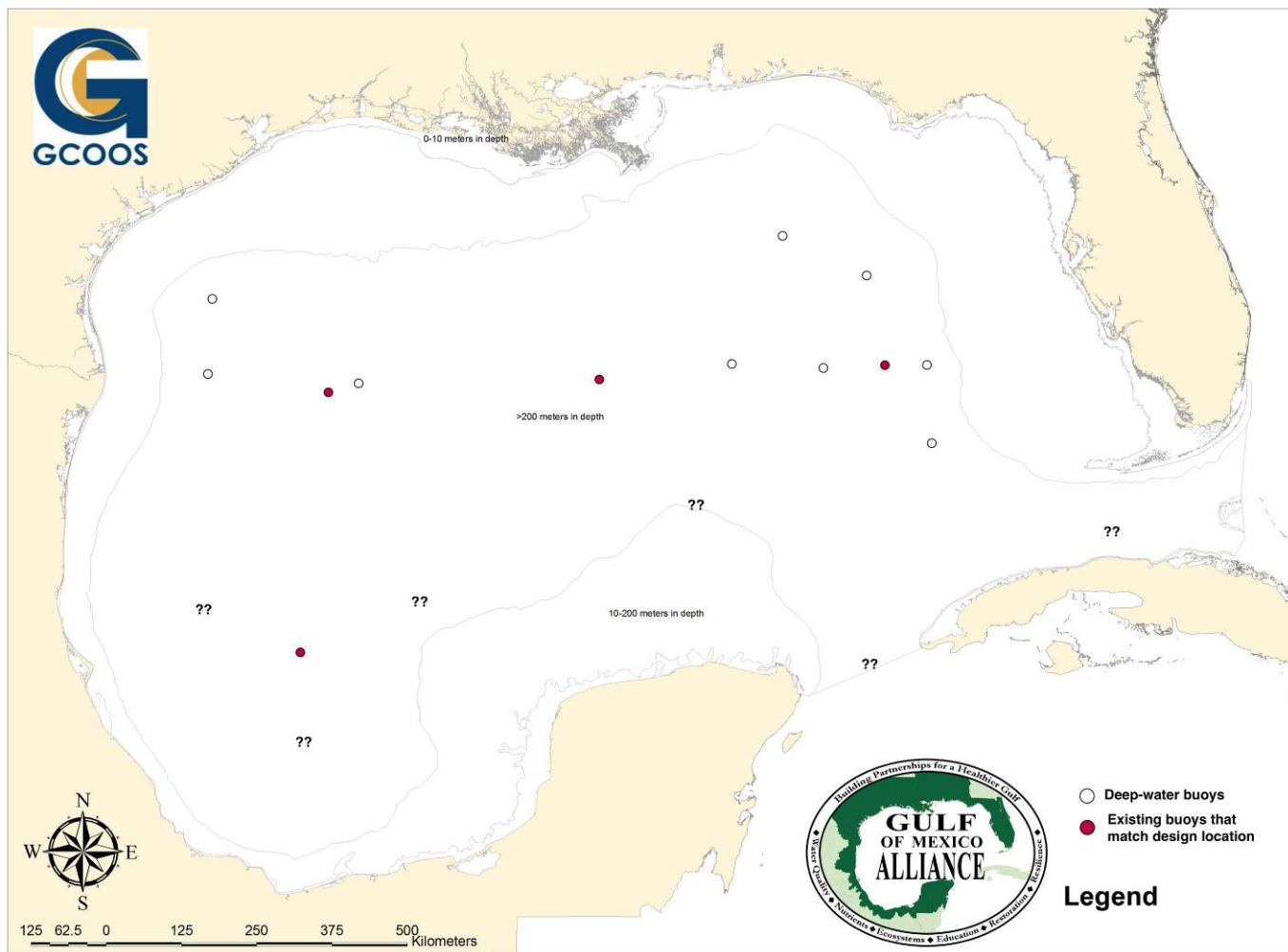
Figure 11. Locations of deep-Gulf stations with buoys bearing continuous-recording equipment. "??" indicates stations to be determined.

Single stations shown at the Gulf entrance, exit, and other locations represent what is expected to be a more complex set of stations needed to accomplish these goals.

 The basic data collection (displayed in more detail at the link in *Appendix 2 – GMN Monitoring System Metadata)* includes physical-chemical data to support the circulation model (e.g., salinity, temperature, current speed and direction, etc.) and to measure as many of the primary flux variables that are called for in the next sections as available technology allows. Additionally, complete meteorological parameters (e.g., wind speed and direction, humidity, barometric pressure, temperature, rainfall, solar radiation) are needed from sites that appropriately represent conditions across the deep Gulf.

*Monitoring of environmental processes in the deep Gulf*
The deep Gulf component of the GMN is designed to include complementary deterministic (trend) sampling at and between the permanent and fixed stations (buoys and ship sites). The

rationale for using a variety of monitoring strategies, such as buoys, ships, remote sensing, etc. is to provide both interpolation of data between fixed stations and "ground-truthing" of both models and remotely-sensed data. Fixed sites between buoys would be sampled during buoy-maintenance cruises, along with flow-through ship-based monitoring during quarterly buoy maintenance (Fig. 12). The design proposes both buoys and ships monitoring at surface (0.3m), mid-depth (but still within the photic zone), and as deep as sensor technology permits, thereby providing a greater resolution of water column processes, including subsurface flow and chemistry.

Nutrient-specific design aspects for the deep Gulf

The rationales for selection of station locations, monitoring frequency, and parameters selected for the deep-water design (see link in *Appendix 2 – GMN Monitoring System Metadata)* are to:

- relate nutrient changes to ecosystem shifts (and changes in ecosystem services),
- provide data on boundary conditions for shelf models,
- understand nutrient fluxes between deep water and the shelf, and
- identify and better understand circulation patterns.
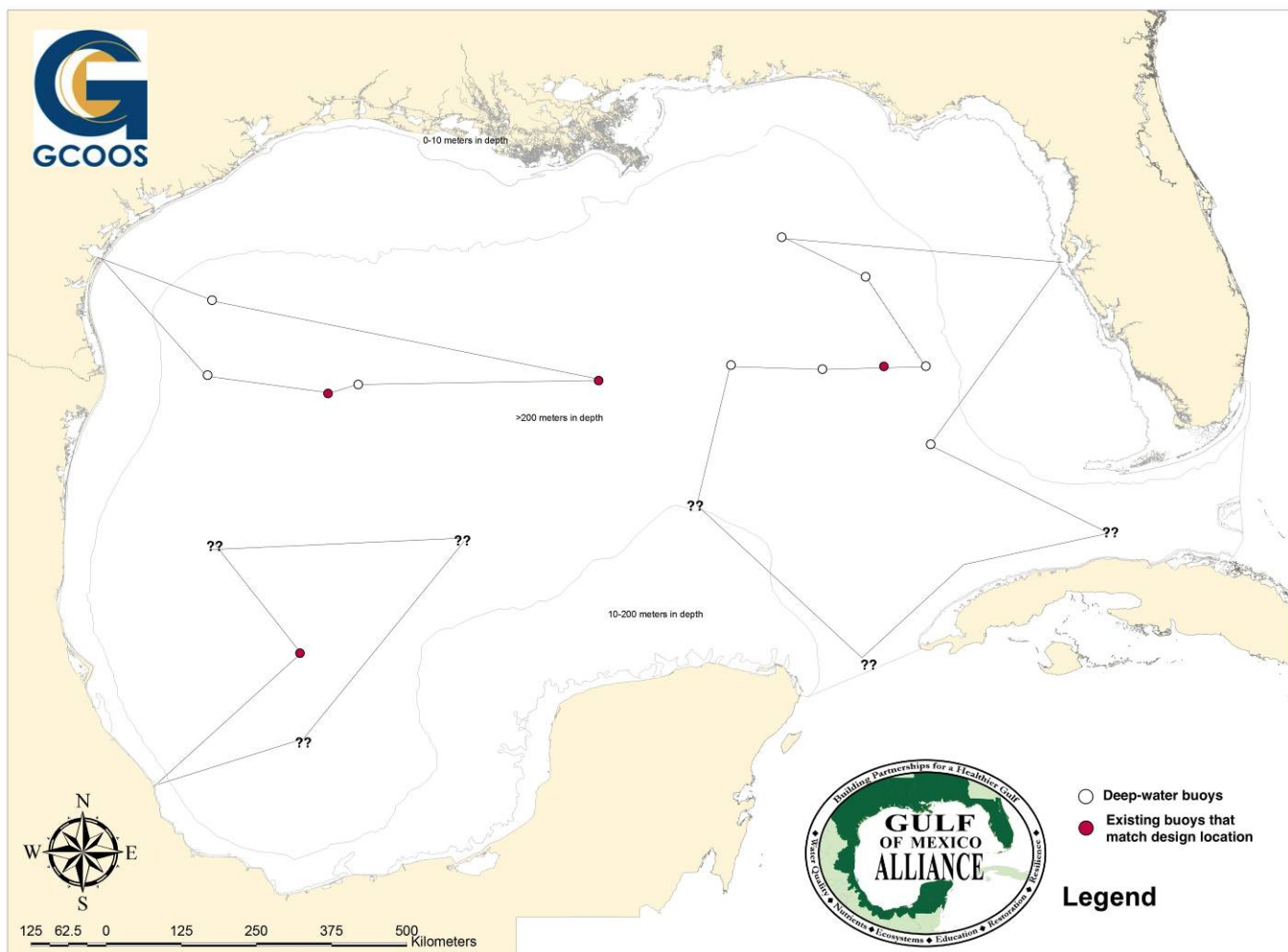
Figure 12. Examples of buoy-maintenance tracks during which flow-through and fixed-station sampling will take place.

 Of critical interest is the need to characterize inflows and outflows/cross sections (between Yucatan and Cuba and between Florida and Cuba) to understand patterns and magnitude of nutrients flowing into and out of the Gulf (*Fig, 4*). The proposed placement of the more centrally-located stations informs the effort to understand basic fate and transport mechanisms within the major Gulf Loop Current and its large eddies. Proposed stations are situated to capture key upwelling zones along the deep-water shelf interfaces in the Gulf which may constitute significant nutrient sources and to understand transport mechanisms by which nutrients move horizontally and vertically. The instrumentation of the shelf-edge moorings is to collect meteorological data important to shelf-edge upwelling dynamics. One major source of upwelling is associated with wind-driven circulation; the other upwelling feature of concern is that of the cold-core eddies that spin up around the Loop Current's warm-core eddies or cold-core eddies that spin up at the shelf edge from other processes. Cold-core eddies bring nutrient-rich water from depth to the surface or near-surface.

In addition to the required field measurements of temperature, pH, conductivity, salinity and dissolved oxygen (D.O.), the analyte list includes the basic suite of marine nutrient analytes as well as supporting parameters and isotopes needed for understanding nutrient processes (see link in *Appendix 2*).

Aerial deposition sampling for nutrients is important, as this forms a significant source of nutrients finding their way into Gulf waters. Sampling can take place during maintenance cruises and some buoys may be suitable as well. Intensive monitoring may be needed initially, followed by evaluation of resulting datasets to determine necessary locations and sampling frequency.

The design includes same-station monitoring of sediments once every five years for nutrients and information on the overlying phyto- and zooplankton communities to establish background sediment oxygen demand, nutrient flux, and nutrient-based changes in community composition and abundance.

The stations displayed in deep Mexican waters are tentative awaiting input from Mexican oceanographers. It is the intent to encourage location of similar stations in that area following the same rationales.

Mercury-specific design aspects for the deep Gulf
The water-sampling design for mercury in the Deep Gulf continues to closely match that for nutrients. However, sampling for *in-situ* mercury species is also needed at the pycnocline and oxycline at each station. The addition of mercury parameters (listed at link in *Appendix 2*) to the nutrient-sampling regime provides the necessary information.

If feasible, atmospheric deposition measurements for the mercury species should take place at selected stations in conjunction with the nutrient-deposition sampling. If the frequency of maintenance visits to the buoys is inconsistent with the monitoring duration needed for bulk rainfall, ship-based atmospheric monitoring during the visits should be explored. This sampling should coordinate with the National Atmospheric Deposition Program. Intensive monitoring may

be needed initially (in conjunction with nutrient deposition efforts), followed by evaluation of datasets to determine necessary locations and sampling frequency.

Sampling of seafood and food-web organism tissues is necessary to assess trends in mercury concentration. Key species to include in the deep Gulf are yellowfin tuna and sharks, with tissue samples collected annually using standard protocols for size and age class. Their collection should coincide with routine water quality sampling where possible.

Annual benthic infauna and sediment sampling are also needed to measure mercury and methylmercury in sediment and infauna. This sampling should be conducted at the fixed stations between buoys in conjunction with routine water-quality sampling.

HABs-specific design aspects for the deep Gulf
The deep Gulf stations are important to inform HAB transport, assess the locations of source populations; and identify phytoplankton end-members for models. The locations of permanent buoys and the sensors required for nutrients will generally suit the needs of HAB monitoring. As technologies improve (e.g., lower power and space requirements, less frequent servicing intervals; lower detection limits), buoys should incorporate sensors appropriate for phytoplankton biomass, community composition, and dissolved nutrients. During the quarterly maintenance trips to the buoys, additional samples and measurement, laid out at the link in Appendix 2, are needed. Existing detection limits for some nutrients are higher than concentrations in the deep Gulf, but all relevant nutrients are included at the link in Appendix 2 for addition as technologies improve. Samples should be collected at the surface and at discrete depths to target the chlorophyll maximum layer and layers above and below this depth. Profiling the vertical water column structure before sampling will be necessary (e.g., using fluorometry).

As a general practice, duplicate samples should be processed and archived in anticipation of more sensitive HAB cell and toxin detection technologies. Also, while underway between stations, data should be collected with flow-through sampling to map surface phytoplankton biomass; phytoplankton community composition; and key physical parameters (Appendix 2). Samples should be taken during mapping for ground-truthing flow-through data.

Pathogen-specific design aspects for the deep Gulf
The design for pathogen sampling in the Deep Gulf is simple and fits well with the other monitoring priorities. Sampling is the same as on the shelf outside the 25 m contour. The three pathogenic *Vibrio* species are sampled quarterly at the buoy locations. Additionally, opportunistic sampling of weed lines, hurricane paths, and similar events—selected by remote sensing before the cruise if necessary—is taken to establish baseline populations of these *Vibrio* species.

Next Steps

The next steps in the process of developing a Gulf-wide monitoring network include:

- Submitting a white paper on the status and recommendations for Gulf monitoring to the Gulf Restoration Council, the Centers for Excellence and other potential funding pathways.
- Holding a third joint workshop to refine the Gulf-wide Monitoring Network by collaborating with additional Gulf partners to develop an implementation plan for the network. This implementation planning will include responsibility for data handling, analysis, and interpretation (this has been initiated).
- Facilitating the Gulf States' development of estuarine and coastal segment monitoring plans.

Implementation Challenges

Implementation challenges include:

Design
- Establish sampling location, frequency, and parameters
- Selection of equipment and sensors
- Local designs construction
- Monitoring program evaluation and design revision
- Model development/calibration/validation

Identifying and engaging monitoring entities as participants (in each scale or region)
- Personnel
  - Identifying the appropriate agency/entity by location
  - Training

Infrastructure
- Vessels
- Platforms
- Equipment and consumables

Coordination and logistics

Computer resources
- Data storage and access & archiving
- Modeling
- Data analysis
- Data visualization
- Data transmission

- Data dissemination

Satellite
- Time
- Algorithm development
- Product development
- Satellite maintenance and replacement

Formalizing GMN organization
- External review board (technical) to make recommendations, with coordinating "council" authorizing final decisions based on those recommendations
- Consideration of redundancy planning for unexpected 'departures' by collaborating programs
- Identification and coordination of GMN infunding
- Identification and management of outfunding
- Network status and reporting

Appropriate analytical capacity

Data comparability
- QA/QC & protocol development

Equip purchase and maintenance
- Purchase from endowment or through separate equipment funding

Physical sample archival

Coordinating sampling and sampling resources
- Ensure that the schedule is publicly accessible once GMN is operational to help other entities coordinate monitoring

Data handling
- Identification of entity to manage and maintain data, and conduct QA/QC on data received from monitoring network (data management)
- Identification of entity to perform data analysis and assessment for inclusion in reporting

Literature Cited

GCOOS Regional Association Board of Directors. 2011. A Sustained, Integrated Ocean Observing System for the Gulf of Mexico (GCOOS): Infrastructure for Decision-making, Version 1. Dec 2011. available for download at http://gcoos.tamu.edu/BuildOut/GCOOS_BuildoutPlan_V1.pdf

Appendix 1. GOMA Monitoring Priorities and Associated Monitoring Questions

Monitoring Priority #1: Nutrients [1]

Monitoring Questions at the Estuary or Coastal Segment scale

High priority
1) What is the spatial and temporal variation in nutrient (carbon, nitrogen, phosphorus, silicate) concentrations in the estuary or coastal segment?

2) What is the long-term trend in nutrient loading to the estuary or coastal segment?

3) Which biological/chemical/physical indicators are most susceptible to nutrient enrichment in the estuary or coastal segment?

4) What is the long-term trend in nutrient export from the estuary or coastal segment?

Medium priority
1) Are nutrients contributing to harmful algal blooms (HABs) within the estuary or coastal segment?

2) What is the temporal variation in nutrient loading to the estuary or coastal segment?

3) What is the long-term trend in biological or chemical responses to nutrients in the estuary or coastal segment?

Low priority
1) Is groundwater a significant source of nutrients to the estuary or coastal segment?

2) Which nutrient(s) is limiting the biological/chemical/physical response within the estuary or coastal segment?

Monitoring Questions at the Regional scale (In order of priority)

1) What is the spatial and temporal variation and trends of nutrient loadings and concentrations within the region?

2) Which biological/chemical/physical indicators are most susceptible to nutrient enrichment within the region?

3) What is the long-term trend in biological/chemical/physical responses to nutrients in the region?

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[1] The GOMA Nutrients Team developed the list of the nutrient questions that are best addressed through monitoring and their order of priority.

4) What is the relationship between nutrient loadings and the development of hypoxic zones within the region?

5) What are the trends in the size, frequency, and duration of hypoxic water within the region?

6) Are nutrients contributing to harmful algal blooms (HABs) within the region?

Monitoring Questions at the Gulf-wide scale (In order of priority)

1) Which biological/chemical/physical indicators are most susceptible to nutrient enrichment in the Gulf of Mexico?

2) What is the spatial and temporal variation and trends in nutrient concentrations within the Gulf of Mexico?

3) How do circulation patterns in the Gulf of Mexico affect nutrient concentrations?

Monitoring Priority #2a: Harmful Algal Blooms [2]

Overarching question: How do the frequency, distribution and duration of Harmful Algal Blooms compare to phytoplankton community during non-bloom periods and what are the linkages to environmental and climatic factors?

All Scales:

1. – What is the spatial and temporal distribution of HAB species?

2. – What are the frequency, distribution, and duration of bloom events?

3. – What is the linkage between environmental (and other) conditions and HAB development/maintenance?

Continental Shelf and Deep Water scales: What is the presence/persistence of HAB toxins in all matrices?

Monitoring Priority#2b: Pathogens [3]

Overarching question: What are the sources, distributions, and fates of pathogens of public health concern, and are there environmental factors related to climate change that influence these patterns?

All Scales: How do pathogens of public health concern vary spatially and temporally and what are their associated environmental factors across the Gulf?

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[2] The HABs Workgroup of the GOMA WQ Team developed the list of HAB questions that are best addressed through monitoring and their order of priority.

[3] The Pathogens Workgroup of the GOMA Water Quality Team developed the list of pathogen questions that are best addressed through monitoring and their order of priority.

Estuary and Coastal Segment scales: How do pathogens of public health concern vary spatially and temporally and what are their associated environmental factors across the Gulf, especially in shellfish harvesting areas and human swimming areas (e.g., bathing beaches)?

Monitoring Priority #2c: Mercury [4]

Overarching areas of monitoring need:

A. Status and trends of mercury in fish tissue to determine if management efforts are effective

B. Status and trends in critical food web components

C. Data to develop the Gulf of Mexico mercury model (to identify the sources of mercury in Gulf seafood).

    a. Atmospheric fluxes to the Gulf mercury model

    b. Riverine fluxes to the Gulf mercury model

    c. Transport and fluxes of mercury across the Gulf (circulation)

    d. What is the spatial variation in sediment and water column methylation rates taking place between the flux boundaries

Atmospheric monitoring questions

1. What is the wet and net dry surface exchange flux of elemental mercury, particulate mercury, gaseous oxidized mercury, and methylmercury between the atmosphere and the waters of the Gulf of Mexico, and how do these fluxes vary spatially and temporally?

2. What is the wet and net dry surface exchange flux of elemental mercury, particulate mercury, gaseous oxidized mercury, and methylmercury between the atmosphere and Gulf of Mexico watersheds, and how do these fluxes vary spatially and temporally?

Estuary Monitoring Questions

1. What are the fluxes of dissolved and particulate mercury and methylmercury from rivers to estuaries around the GOM?

2. How do estuarine processes (e.g., scavenging, Hg methylation) alter the concentrations of these Hg species?

3. What are the net fluxes of mercury and methylmercury from estuaries to coastal waters of the GOM?

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[4] The Mercury Workgroup of the GOMA Water Quality Team developed the list of mercury questions that are best addressed through monitoring and their order of priority.

Appendix 2. GOMA GMN, Monitoring System Metadata (sampling locations, timing, parameters, etc.)

For information on sample locations, timing, analytical parameters, and similar metadata about the Gulf Monitoring Network, go the the *GOMA Catalog of Monitoring Programs* at the link below. Use the GoM*onitor* application to display the desired information for the organization named "GOMA" and the program named "Gulf Monitoring Network".

http://gcoos2.tamu.edu:8080/goma/

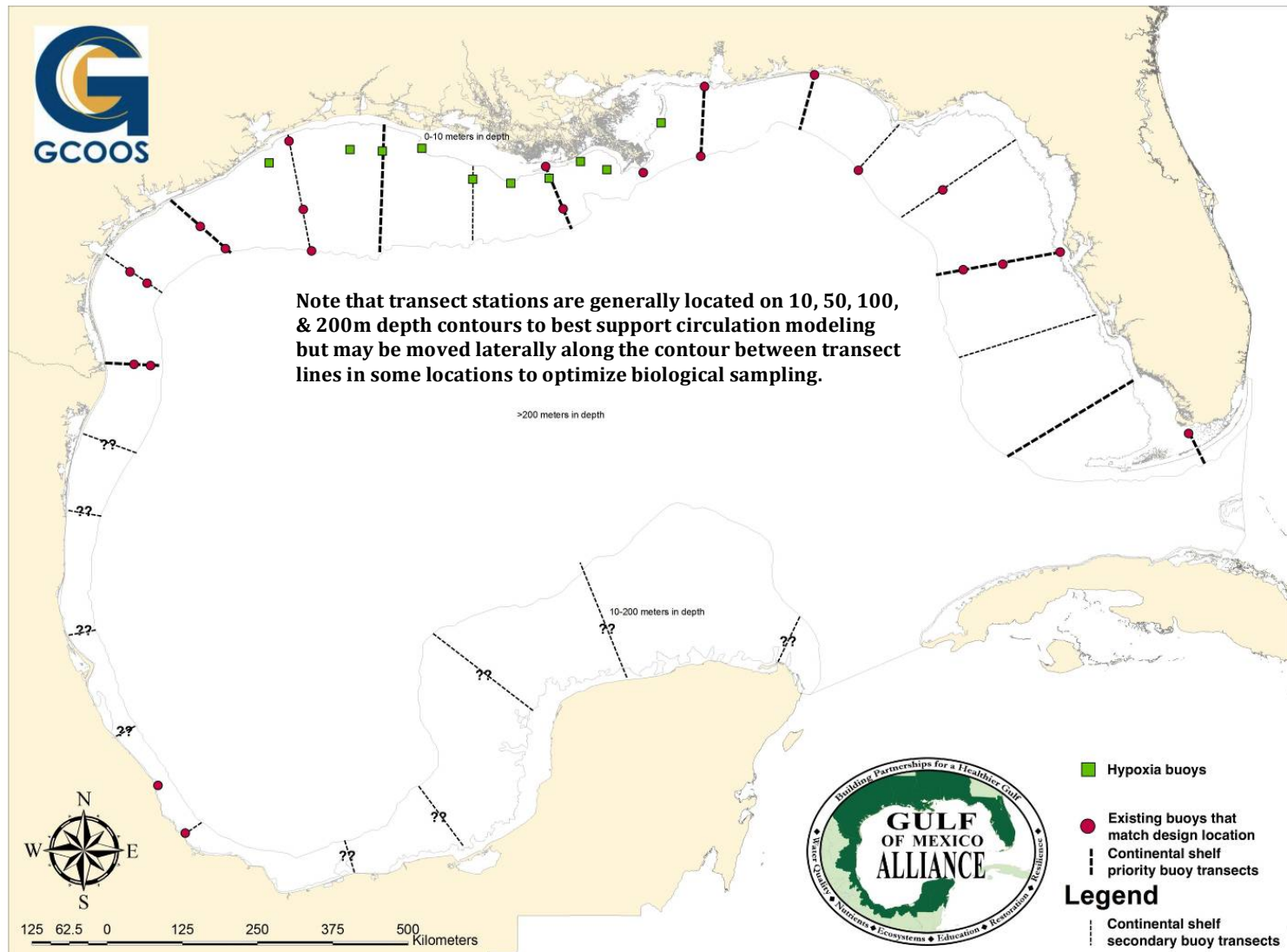# Appendix 3. Enlargements of Key Maps of Monitoring Areas
Appendix 3a. GOMA GMN, Estuary Template
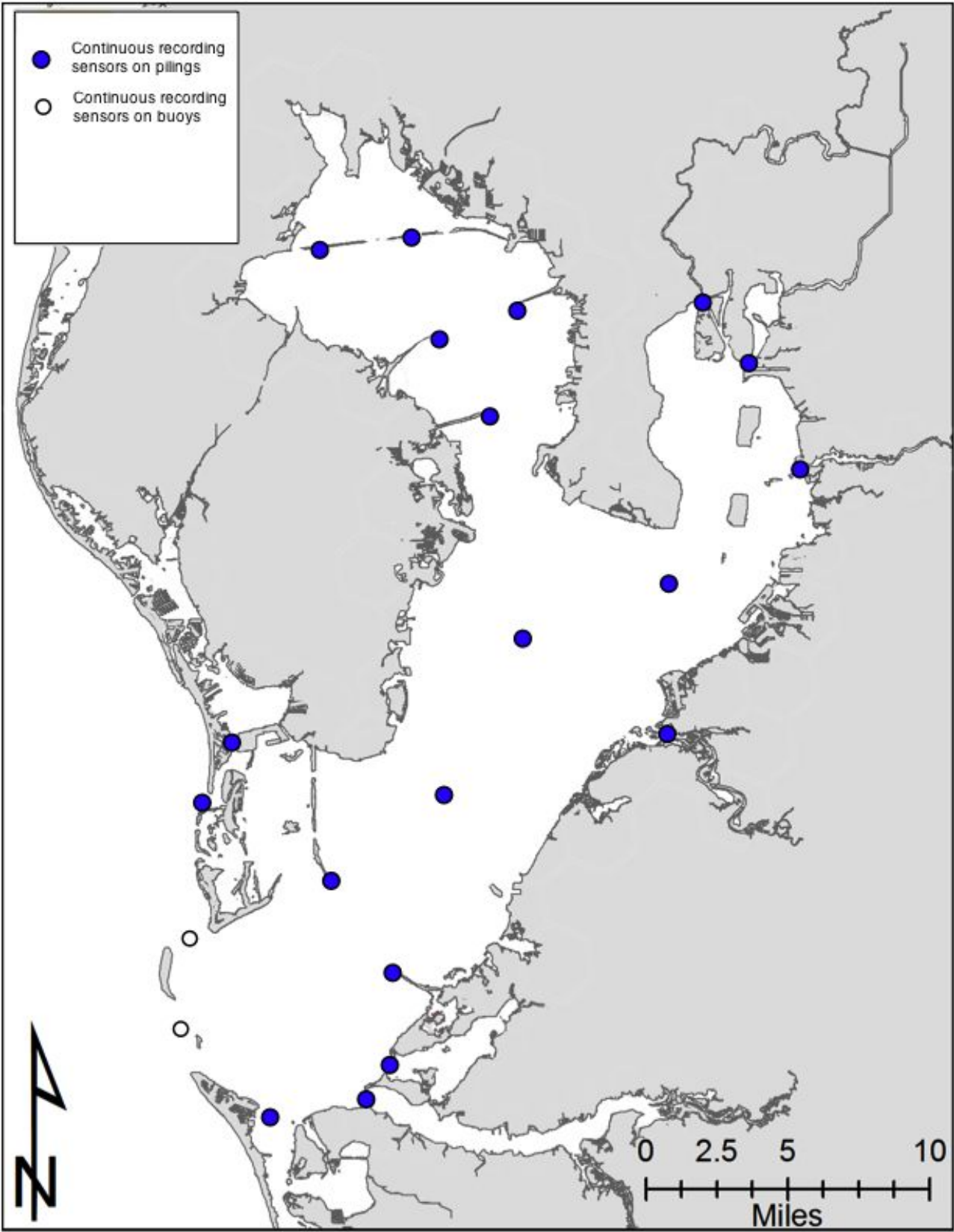
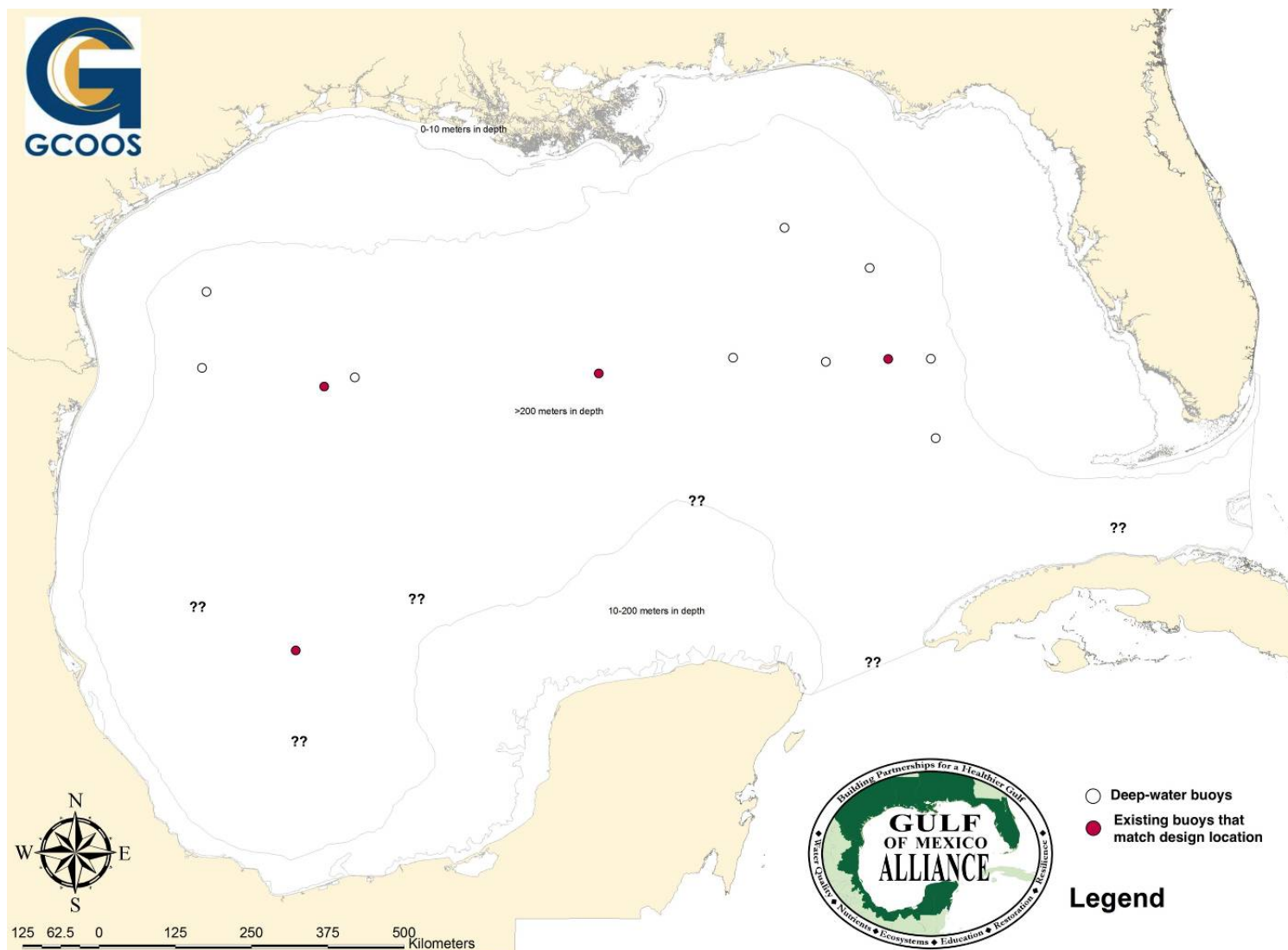## Appendix 3b. GOMA GMN, Coastal Segment Template

Appendix 3c. GOMA GMN, Shelf Transects

Location of buoy transects on the Continental Shelf and additional buoys for monitoring of the Gulf Hypoxic Zone (after GCOOS).

Appendix 3d. GOMA GMN, Deep Gulf Fixed Stations

Locations of fixed deep-Gulf stations with buoys bearing continuous-recording equipment.