Executive Summary

Billions of dollars will be spent on the management and restoration of Northern Gulf of Mexico (NGoM) ecosystems over the next twenty years. Resource managers and restoration practitioners must monitor ecologically appropriate indicators to effectively evaluate the performance and impacts of their activities and guide adaptive management of living marine resources (LMRs). They need access to baseline data and trends in the condition of sites to help them set ecologically valid restoration goals and monitor the performance of their projects. Decision makers need synthesized data to make decisions within timelines set by politics and law. Grant makers need data to evaluate whether proposed restoration and management activities are appropriate for the proposed sites and to measure the impacts of their investments across multiple sites.

This report recommends a comprehensive set of ecologically-informed ecological resilience indicators for salt marsh, mangrove, seagrass, oyster, and coral ecosystems in the NGoM that can be used to inform sustainable ecosystem and LMR management (Tables 1–5). These indicators address both the ecological integrity and ecosystem services of these ecosystems. Application of these indicators will provide critical information relevant to damage assessment and recovery planning, restoration planning and evaluation, and ecosystem health assessment.

To develop the indicators, we applied an innovative Ecological Resilience Framework (ERF [Figure 1]) that integrates information on ecosystem drivers, ecological integrity and ecosystem service provision. We linked this framework with a comprehensive programmatic and spatial analysis to assess the degree to which the recommended indicators are currently being monitored by existing programs in the NGoM, and thereby identify gaps in monitoring opportunities for additional data collection.

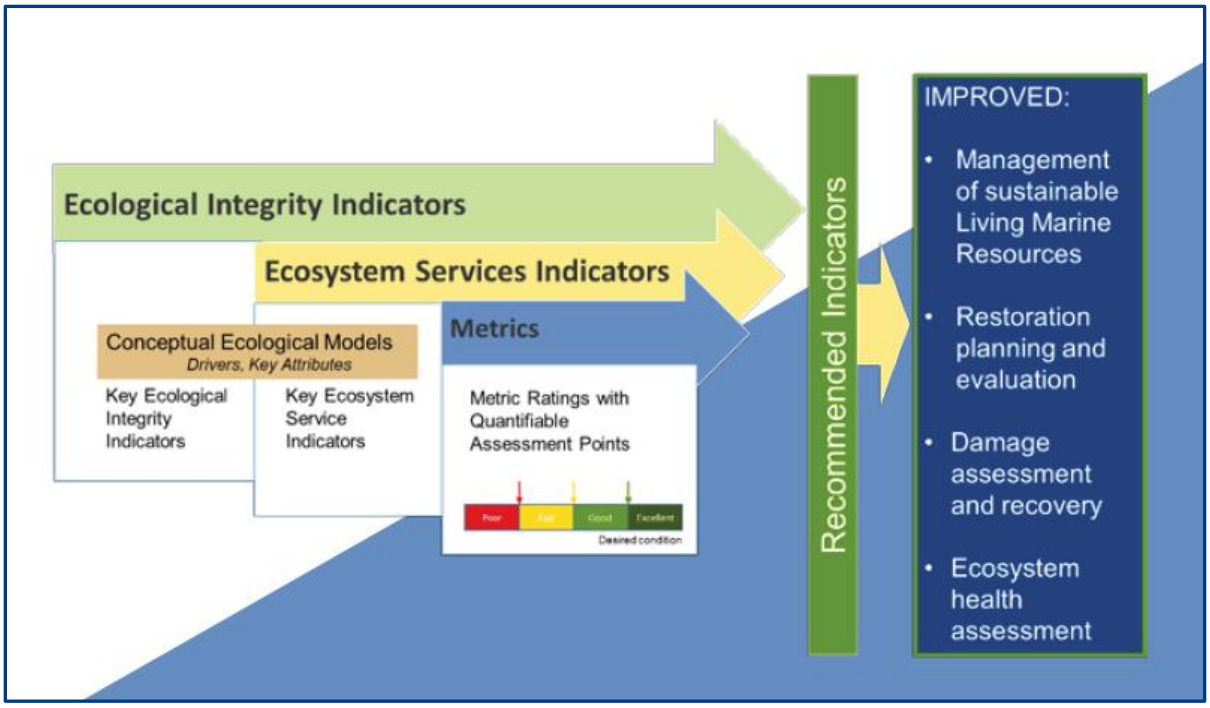

Figure 1. *Ecological Resilience Framework used to identify ecosystem integrity and ecosystem service indicators*

Using the ERF to develop the recommended set of ecosystem indicators, we:

- created Conceptual Ecological Models (CEMs) that identify the critical ecosystem drivers and functions and specify the linkages between them that ultimately effect ecosystem services.
- used the CEM to identify indicators with specific metrics that can be monitored to assess the ecological integrity of the ecosystem and its capacity to provide ecosystem services.
- developed metric ratings with quantifiable assessment points that allow evaluation of ecological condition and capacity for provision of ecosystem services across sites and over time.

To assess the degree to which the recommended indicators for each ecosystem are currently being collected by monitoring programs across the NGoM, we:

- compiled ecosystem range maps, and created a distribution map of each ecosystem across the NGoM.
- inventoried existing monitoring programs and identified the data that they collect
- analyzed the metadata of indicators from the monitoring programs to identify the programs that collect data on our recommended indicators
- completed a spatial analysis of the monitoring programs that collect data for each indicator to assess the degree of implementation of the indicators geographically across the NGoM
- published the spatial analyses and supporting data for each indicator of each ecosystem via the Coastal Resilience Decision Support Tool (CRDST) (http://maps.coastalresilience.org/gulfmex/).

The challenge to collect, aggregate, and share data on these ecologically appropriate indicators has been a major impediment to ensuring maximum impact and return on investments in the NGoM. Agreement on the indicators and data that are needed to monitor the health of NGoM ecosystems is the first step towards addressing the challenge. The ecological resilience indicators recommended here represent a major step towards achieving the goal of coordinating the monitoring efforts in the NGoM to support effective management of sustainable ecosystems and LMRs. Deployment of these indicator as a standard by multiple monitoring sites across the region and aggregation of the data would allow for Gulf-wide condition and trend assessment to help ensure that investments in resource management and restoration significantly improve and sustain the ecological condition of the NGoM, its LMRs and the ecosystem services it provides.

The summary list of indicators and their metrics is presented here in the context of the key factors from the conceptual models.

***Table 1**. Summary of Salt Marsh Metrics Based on the Conceptual Ecological Model*

SALT MARSH ECOSYSTEMS			
Function & Services	**Major Ecological Factor or Service**	**Key Ecological Attribute or Service**	**Indicator/*Metric***
Sustaining/ Ecological Integrity	Abiotic Factors	Hydrologic Regime: Flood Depth/Duration/Frequency	--
		Water Quality	Eutrophication/*Basin-wide Nutrient Load (Total Nitrogen, Total Phosphorus)*
		Soil Physicochemistry	--
	Ecosystem Structure	Marsh Morphology	Land Aggregation/*Aggregation Index (AI)*
			Lateral Migration/*Shoreline Migration*
		Plant Community Structure	--
		Microbial Community Structure	--
	Ecosystem Function	Elevation Change	Submergence Vulnerability/*Wetland Relative Sea Level Rise ($RSLR_{wet}$) and Submergence Vulnerability Index (SVI)*
		Primary Production	Above Ground Primary Production/ *Aboveground Live Biomass Stock*
			Below Ground Primary Production/*Soil Shear Stress*
		Secondary Production	Specialist Birds/*Clapper Rail and Seaside Sparrow Density*
		Decomposition	--
		Biogeochemical Cycling	--
Ecosystem Services	Supporting	Habitat	Specialist Birds/*Clapper Rail and Seaside Sparrow Density*
	Regulating	Coastal Protection	Wave Attenuation/*Percent Wave Height Reduction per Unit Distance*
		Water Quality	Nutrient Reduction/*Basin-wide Nutrient Load (Total Nitrogen, Total Phosphorus)*
		Carbon Sequestration	Soil Carbon Density/*Soil Carbon Density*
	Cultural	Aesthetics-Recreational Opportunities	Recreational Fishery/*Spotted Seatrout Density and Recreational Landings of Spotted Seatrout*

Table 2. *Summary of Mangrove Metrics Based on the Conceptual Ecological Model*

MANGROVE ECOSYSTEMS			
Function & Services	**Major Ecological Factor or Service**	**Key Ecological Attribute or Service**	**Indicator/*Metric***
Sustaining/ Ecological Integrity	Abiotic Factors	Minimum Temperatures	--
		Soil Physicochemistry	--
		Hydrologic Setting	Eutrophication/*Basin-wide Nutrient Load (Total Nitrogen, Total Phosphorus)*
			Connectivity/*Multi-metric*
	Ecosystem Structure	Plant Community Structure	Stand Health/*Foliage Transparency*
			Regeneration Potential/*Propagule, Seedling, Sapling Presence*
		Landscape Structure	Land Aggregation/*Aggregation Index (AI)*
			Land Cover Change/*Land Cover Change Rate*
		Microbial Community Structure	--
	Ecosystem Function	Elevation Change	Submergence Vulnerability/*Wetland Relative Sea Level Rise ($RSLR_{wet}$) and Submergence Vulnerability Index (SVI)*
		Primary Production	--
		Decomposition	--
		Secondary Production	Fish Habitat/*Killifish Species Diversity*
			Invasive Species/*Presence (Multiple Species)*
		Biogeochemical Cycling	--
Ecosystem Services	Supporting	Habitat	Status of Macrofauna Populations/*Density of Juvenile Common Snook*
	Provisioning	Food	Status of Snapper-Grouper Complex Commercial Fishery/*Density of Gray Snapper* and *Annual Commercially Landed Weight of Gray Snapper* (Lutjanus griseus*) in the Gulf of Mexico States and/or Federal Waters*
	Regulating	Coastal Protection	Erosion Reduction/*Shoreline Change*
		Water Quality	Nutrient Reduction/*Basin-wide Nutrient Load (Total Nitrogen, Total Phosphorus)*
		Carbon Sequestration	Soil Carbon Storage/*Mangrove Height*
	Cultural	Aesthetics-Recreational Opportunities	Recreational Fishery/*Density of Juvenile Common Snook*

Table 3. *Summary of Seagrass Metrics Based on the Conceptual Ecological Model*

SEAGRASS ECOSYSTEMS			
Function & Services	**Major Ecological Factor or Service**	**Key Ecological Attribute or Service**	**Indicator/*Metric***
Sustaining/ Ecological Integrity	Abiotic Factors	Water Quality	Transparency/*Percent Surface Irradiance*
			Phytoplankton Biomass/*Chlorophyll* a *concentration*
			Sediment Load/*Total Suspended Solids*
		Soil Physicochemistry	--
	Ecosystem Structure	Abundance	Change in Areal Extent/*Areal Extent*
			Change in Cover/*Percent Cover*
		Plant Community Structure	Seagrass Species Composition/*Species Dominance Index*
		Morphology	Shoot Allometry/*Leaf Length*
			Shoot Allometry/*Leaf Width*
		Chemical Constituents	Nutrient Content/*Nutrient Limitation Index*
			Stable Isotope Ratios/$\delta^{13}C$ *and* $\delta^{15}N$
	Ecosystem Function	Secondary Production	Scallop Abundance/*Scallop Density*
		Carbon and Nutrient Sequestration	--
		Biogeochemical Cycling	--
		Primary Production	--
Ecosystem Services	Supporting	Habitat	Scallop Abundance/*Scallop Density*
	Provisioning	Food	Scallop Abundance/*Scallop Density*
	Regulating	Coastal Protection	Erosion Reduction/*Shoreline Change*
		Water Quality	--
		Carbon Sequestration	--
	Cultural	Aesthetics-Recreational Opportunities	Recreational Fishery/*Spotted Seatrout Density* and *Recreational Landings of Spotted Seatrout*

Table 4. *Summary of Oyster Metrics Based on the Conceptual Ecological Model*

OYSTER ECOSYSTEMS			
Function & Services	**Major Ecological Factor or Service**	**Key Ecological Attribute or Service**	**Indicator/*Metric***
Sustaining/ Ecological Integrity	Abiotic Factors	Water Quality	Salinity/*Salinity*
			Dissolved Oxygen/*Dissolved Oxygen*
		Substrate Availability	Change in Percent Cover of Reef Substrate/*Percent Cover of Reef Substrate*
		Acidification	--
	Ecosystem Structure	Disease	Disease Prevalence (Dermo)/*Weighted Prevalence*
		Food Availability	--
		Reef Structure	Change in Reef Area/*Area*
			Change in Reef Height/*Height*
			Density of Live Oysters/*Density of Live Oysters Relative to the Regional Mean*
		Oyster Larvae	--
		Predation	--
	Ecosystem Function	Habitat Provisioning	Species Richness/*Number of Species per Unit Area*
			Resident Species/*Biomass of Resident Species*
		Filtration	--
		Condition of Adjacent Habitat	--
		Nitrogen Removal	--
Ecosystem Services	Supporting	Habitat	Status of Macrofaunal Populations/*Density of Naked Goby*
	Provisioning	Food	Oyster Fishery/*Site Harvest Status and Commercial Oyster Landings*
	Regulating	Coastal Protection	Erosion Reduction/*Shoreline Change*
		Water Quality	--
	Cultural	Aesthetics-Recreational Opportunities	Recreational Fishery/*Perception of Recreational Anglers Fishing in the Area of Influence of Oyster Reefs*

Table 5. *Summary of Coral Reef Metrics Based on the Conceptual Ecological Model*

CORAL ECOSYSTEMS			
Function & Services	**Major Ecological Factor or Service**	**Key Ecological Attribute or Service**	**Indicator/*Metric***
Sustaining/ Ecological Integrity	Abiotic Factors	Water Quality	Nutrient Enrichment/*Chlorophyll* a *Concentration*
			Light Attenuation/*Water Transparency*
			Temperature Regime/*Temperature Range*
			Carbonate Chemistry/*Aragonite Saturation State*
		Substrate Attributes	--
	Ecosystem Structure	Benthic Community Structure	Epibenthic Sessile Community Structure/*Living Biota Percent Cover*
			Grazing/*Echinoid Abundance*
		Infaunal Community Structure	--
	Ecosystem Function	Benthic Community Condition	Macroalgae/*Macroalgal Percent Cover*
			Coral Disease/*Disease Prevalence*
			Coral Bleaching/*Bleaching Prevalence*
			Coral Mortality/*Recent Mortality Prevalence and Old Mortality Prevalence*
		Connectivity	--
		Primary Production	--
		Secondary Production	--
		Tertiary Production	--
		Nutrient Cycling	--
		Environmental Condition	--
Ecosystem Services	Supporting	Habitat	Status of Macrofauna Populations/*Live Stony Coral Cover*
	Provisioning	Food	Status of Snapper-Grouper Complex Commercial Fishery/*Density of Red Snapper*
	Cultural	Aesthetics-Recreational Opportunities	Recreational Fishery/*Density of Juvenile Common Snook*
		Educational Opportunities	Educational Program Participation/*Number of Visitors of a Coral Reef Participating in an Education Program*