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Application of the coastal and marine ecological classification standard using satellite-derived and modeled data products for pelagic habitats in the Northern Gulf of Mexico

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ABSTRACT

The expansive and dynamic nature of the ocean's water column may limit the feasibility of the frequent *in situ* sampling that would be necessary to monitor these habitats and produce region-wide map products with any regularity. Alternatives to *in situ* sampling such as remote sensing and classification offer a means of routinely characterizing the environmental forcing functions that shape and determine habitat suitability and distribution. Four products derived from Moderate Resolution Imaging Spectroradiometer (MODIS)-aqua satellite (chlorophyll concentration, salinity, sea-surface temperature, and euphotic depth) and a hydrodynamic modeled product for bottom to surface temperature differences (Δt) were evaluated to assess the utility of these products as proxies for *in situ* measurements. MODIS images covering the northern Gulf of Mexico were obtained for a 5-year time period (January 2005 – December 2009; 300 total images) and processed through Automated Processing System. The products were used to classify surface waters in three regions of the northern Gulf of Mexico using subcomponents and modifiers from the Coastal and Marine Ecological Classification Standard (CMECS) Water Column Component (WC) to determine if CMECS categories could be affectively used to categorize the products into meaningful management units. Products were assessed for each month over the five year period. Sea-surface temperature and salinity were classified into CMECS WC temperature and salinity subcomponent categories, respectively. Three modifiers from the WC were also used for the pelagic classification: water column stability, productivity, and turbidity. Δt was used to assign classification for water column stability; surface chlorophyll was used to determine phytoplankton productivity; and euphotic depth was used to indicate the level of turbidity. Statistical analyses of the products compared to the Gulf States Marine Fisheries Commission's Southeast Area Monitoring and Assessment Program *in situ* data indicated that the MODIS and hydrodynamic modeling products were consistently different from the *in situ* data; however, we believe the potential is strong for use of these standard products to enhance water column information. Use of the CMECS WC with appropriate modifiers captures all the significant pelagic environmental parameters which influence habitat and species distributions. Of the parameters evaluated, the sea-surface salinity and temperature, as expected, were most useful for making comparisons. Further research incorporating different types of data is necessary to explore the full potential of this approach. Specifically, resource managers would like to see the incorporation of sediment and bathymetry data. We believe addition of these data layers would result in more robust habitat maps and provide an innovative tool for resource managers.

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1. Introduction

Commercial and recreational fisheries within the Gulf of Mexico contribute significantly to the region's economy making effective management a priority. The goal of fisheries management is to

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optimize the benefits of living marine resources by addressing threats to a resources' sustainability through 'conservation, development, and full utilization of the fishery resources to provide food, employment, income, and recreation' (GSMFC, 2012). Coastal and marine habitats can be significantly and rapidly impacted by a number of anthropogenic actions and natural events such as coastal storms, development and hydrological alterations (NOAA, 2011). With approximately 98% of Gulf of Mexico fisheries dependent on estuarine and nearshore habitats at some point in their life cycle (http://healthygulf.org/our-work/wetlands/wetland-importance), it is critical that resource managers have the ability to quickly and frequently monitor and assess habitat loss and degradation. The Governors' Action Plan for Healthy and Resilient Coasts (GOMA, 2006) identified a priority need to make regionally mapped coastal and marine habitats accessible to resource managers. However, inconsistencies in the approach that various agencies use for categorizing and labeling habitats makes it difficult to develop a region-wide habitat map.

The expansive and dynamic nature of the ocean's water column may limit the feasibility of the frequent *in situ* sampling that would be necessary to monitor these habitats and produce region-wide map products with any regularity. Alternatives to *in situ* sampling such as remote sensing and classification offer a means of routinely characterizing the environmental forcing functions that shape and determine habitat suitability and distribution. A collaboration led by the National Oceanic and Atmospheric Administration (NOAA) and NatureServe, in partnership with the Environmental Protection Agency, the United States Geological Survey, and several academic and non-governmental organizations led to the development of a standard for the classification of coastal and marine ecosystems for use at the local, regional and national levels (FGDC, 2012). The Coastal and Marine Ecological Classification Standard (CMECS), which provides a common terminology for naming ecological units, was endorsed by the Federal Geographic Data Committee (FGDC) in June 2012 as the first national classification standard for U.S. coastal and marine ecosystems.

The concept of a coastal and marine ecological classification standard emerged in the United States with the passage of the Essential Fish Habitat (EFH) requirements under the Magnuson-Stevens Fisheries Conservation and Management Act of 1996 (http://www.nmfs.noaa.gov/sfa/magact/). Federal managers realized soon after EFH designations began that there was a lack of common terminology for characterizing habitats and often regionally specific nomenclature was used. As such, long term monitoring of status and trends at a national level would prove difficult.

Prior to CMECS, the only national classification standard for coastal and marine waters in the United States was the *Classification of Wetlands and Deepwater Habitats in the United States*, FGDC-STD-004 (FGDC, 1996). However, FGDC-STD-004 had limited application for the range of coastal and marine ecosystems under NOAA jurisdiction. Therefore, NOAA, in partnership with NatureServe, the U.S. Environmental Protection Agency, and the U.S. Geological Survey and in consultation with numerous state government agencies, non-governmental organizations and academic groups, undertook development of CMECS to ensure broad application for the full suite of coastal and marine ecosystems of management concern. CMECS is structured to allow users to consistently apply common terminology for the physical, chemical and biological aspects of the coastal and marine environment. The complete history and structure of CMECS is beyond the scope of this manuscript; rather the authors refer readers to the FGDC-endorsed standard for additional information (FGDC, 2012). However, what is key to this paper is one aspect of CMECS, the Water Column Component.

Table 1
Key water column feature of reviewed coastal and marine habitat classification systems.

Reference	Name	Location	Key water column features
Dethier 1990	A Marine and Estuarine Habitat Classification System for Washington State	Washington, United States	- Depth - Energy - Salinity
Brown 1993	A classification system of marine and estuarine habitats in Maine: An ecosystem approach to habitats	Maine, United States	- Depth - Energy - Salinity
Wieland 1993	Marine and Estuarine Habitat Types and Associated Ecological Communities of Mississippi Coast	Mississippi, United States	- Depth - Energy - Salinity
Holthus and Maragos 1995	Marine Ecosystem Classification for the Tropical Island Pacific	Tropical Pacific	- Not applicable
Federal Geographic Data Committee 1996	Classification of Wetlands and Deepwater Habitats in the United States	United States	- Depth - Energy - Salinity
Madley et al., 2002	Development of a System for Classification of Habitats in Estuarine and Marine Environments (SCHEME) for Florida	Florida, United States	- Energy - Salinity
Resource Information Standards Committee 2002	British Columbia Marine Ecological Classification: Marine Ecosections and Ecounits, Version 2.0	British Columbia, Canada	- Depth - Energy - Salinity
Connor et al., 2004	The National Marine Habitat Classification for Britain and Ireland	Britain and Ireland	- Height or depth band - Salinity - Substratum - Tidal currents - Wave exposure - Zone
Department of the Environment and Heritage and CSIRO 2005	Pelagic regionalization: National Marine Bioregionalisation Integration Project	Australia	- Water masses and associated features
Ministry of Fisheries and Department of Conservation (2008)	Marine Protected Areas: Classification, Protection Standard and Implementation Guidelines	New Zealand	- Depth - Mean and max wave height - Sea-surface temperature - Tidal currents
Federal Geographic Data Committee 2012	Coastal and Marine Ecological Classification Standard		- Biogeochemical features - Depth - Hydroforms - Layers - Salinity - Temperature

1.1. Methodology

The goals of this project were twofold: 1) apply the CMECS Water Column Component (WC) to the northern Gulf of Mexico; and 2) assess the utility of Moderate Resolution Imaging Spectroradiometer (MODIS)-Aqua satellite-derived products and modeled data, developed by the Naval Research Laboratory (NRL) at Stennis Space Center, MS, for characterizing pelagic habitats in the absence of temporally and spatially dense *in situ* data. There were several steps involved in this process, including: identifying the most useful physicochemical parameters for characterizing the water column; refining the CMECS WC based on application in the northern Gulf of Mexico; assessing the utility of NRL products to delineate and classify pelagic habitat types in select areas of the northern Gulf of Mexico; comparing the results of CMECS classification of NRL products to CMECS classification of *in situ* SEAMAP data; and querying resource managers for product improvement opportunities.

1.2. Identification of physicochemical parameters for characterizing the water column

Physicochemical parameters representing the essential forcing functions are needed to effectively characterize pelagic habitats. Numerous existing marine classification systems were examined for parameters considered to be important (Table 1); most listed salinity and temperature. A review of the life histories for several marine species indicated that correlations between salinity and species distributions occur and when assessing habitat suitability, salinity is one of the parameters included (U.S. Fish and Wildlife Service, 1983). While only one of the classifications reviewed included temperature, examination of life cycles for various commercial fisheries species suggested many species respond more to temperature than salinity; temperature is also known to significantly influence distribution of marine life (U.S. Fish and Wildlife Service, 1983). Beyond salinity and temperature, the Gulf of Mexico Fisheries Management Council (GMFMC) Essential Fish Habitat (EFH) Amendment identifies characteristics of habitats that influence species distributions to include structures such as turbidity zones, thermoclines, or fronts separating water masses (GMFMC, 2010).

This study was initially modeled after the UKSeamap project, which was undertaken to characterize marine benthic and water column habitats. For analyses of the water column Connor et al. (2006) identified a series of environmental data layers necessary to characterize the water column. Twelve hydrographic datasets representing a variety of parameters were assessed but only surface salinity, surface to bed temperature difference (Δt) and frontal probability (water column stability) were utilized to produce the water column data layers (Connor et al., 2006). Based on our knowledge of environmental factors that influence fisheries distribution, information gathered from the literature, and the findings of the UK Seamap project, we elected to consider sea-surface temperature, salinity, and chlorophyll; euphotic depth; and Δt to categorize NRL products and *in-situ* data into CMECS categories.

1.3. Water column classification standard (CMECS)

Once a preliminary set of essential physicochemical parameters or forcing functions had been agreed upon, a draft water column classification approach (CMECS WC) was developed and distributed to oceanography and marine ecology experts. A working group was formed to evaluate expert comments and the WC was revised accordingly. A workshop was held to further evaluate the WC and develop recommendations for improvement, which were included in the final version of CMECS (FGDC, 2012). CMECS WC contains five subcomponents (Table 2). This study primarily utilized the surface layer (Layer subcomponent) and all categories within the Salinity and Temperature subcomponents, as well as two CMECS modifiers, trophic status (as represented by primary productivity, i.e., chlorophyll) and water column stability.

1.4. MODIS satellite products

Five products were derived from the MODIS-Aqua satellite imagery: chlorophyll concentration, salinity (based on a relationship with the absorption coefficient), sea-surface temperature (SST), and euphotic depth (Z_{eu}). MODIS images covering the northern Gulf of Mexico were obtained for a 5-year time period (January 2005–December 2009; 300 total images). The daily, level-1B image files were downloaded from the National Aeronautics and Space Administration (NASA) Level 1 and Atmosphere Archive and Distribution System (LAADS) website (http://ladsweb.nascom.nasa.gov/data/search.html) and processed through Automated Processing System (APS). NRL developed APS, which includes sensor calibration, atmospheric correction (with near-infrared correction for coastal waters), and bio-optical inversion (Martinolich and Scardino, 2011). APS incorporates, and is consistent with, the latest NASA MODIS code; it was operated in stand-alone, batch-processing mode, allowing for rapid reprocessing of dozens of scenes per day.

Three regions were processed at 1 km spatial resolution: western Gulf of Mexico, central Gulf of Mexico, and eastern Gulf of Mexico. Weekly and monthly composite images were generated from the daily scenes, for each of the five satellite data products, to reduce the effects of cloud cover. Surface chlorophyll concentration was estimated using the OC3 algorithm for MODIS (O'Reilly et al., 2000). It is generally considered to have an accuracy of about 35% (McClain, 2009).

Sea-surface salinity was estimated from the ocean color imagery, based on an empirical relationship between colored dissolved organic matter (CDOM) absorption and salinity. River and bay discharge into coastal areas typically carries high levels of CDOM that can be used as a semi-conservative tracer to follow low-salinity plumes as they mix with offshore waters. Thus salinity varies inversely with CDOM absorption, and CDOM has an optical absorption signature that can be detected by existing ocean color satellite sensors such as SeaWiFS and MODIS. Sea-surface salinity can be empirically estimated from ocean color satellite imagery, since the absorption slope difference between 412 nm and 443 nm can be used as a proxy to estimate the CDOM absorption coefficient:

Table 2
Coastal and Marine Ecological Classification Standard Water Column Component (WC) Classification structure showing the five subcomponents.

Layer	Salinity	Temperature	Hydroform	Biogeochemical feature
Surface Layer Upper Water Column Pycnocline Lower Water Column	Oligohaline, <5 Mesohaline, >5–18 Lower Polyhaline, >18–25 Upper Polyhaline, >25–30 Euhaline, >30	Cold, 0–10 °C Temperate, >10–20 °C Warm, >20–30 °C Hot, >30 °C	Hydroform Class: e.g., Current Hydroform: e.g., Buoyancy Flow Hydroform Type: e.g., Downwelling	List of biogeochemical features: e.g., chlorophyll maximum, chlorophyll minimum, turbidity maximum

$$\text{Salinity} = 36.208 - 46.488x + 27.683x^2 - 8.338x^3 + 0.965x^4$$

In the above equation, x = difference between the absorption coefficients at 412 and 443 nm (a412–a443). The algorithm was developed using *in situ* data from a wide variety of locations and has been validated with independent ship and mooring data (Ladner et al., 2006, 2008). Currently the algorithm has an accuracy of about ± 1 (using the Practical Salinity Scale, which is unitless; UNESCO, 1981) and is valid in coastal waters where salinity is strongly impacted by freshwater discharge (out to approximately mid-shelf). Sea-surface temperature from MODIS-Aqua was calculated with the standard NASA processing algorithm; uncertainties are 0.1 °C or less (Minnett et al., 2004).

The euphotic depth characterizes light attenuation in the water column and was calculated (Lee et al., 2007). Specifically, it was determined as the depth at which photosynthetically available radiation (PAR) drops to 1% of its surface value. It was derived from the inherent optical properties (IOPs) of the water, the absorption and backscattering coefficients, and was dependent on the concentration of dissolved and particulate matter in the water, which varies spatially and temporally. The absorption and backscattering coefficients were estimated satellite remote sensing reflectance (Rrs) values (Lee et al., 2002), and those coefficients were used to estimate Z_{eu} and make associated image products.

1.5. Hydrodynamic model products

The weekly and monthly temperature differences along the Gulf Coast were derived from reanalysis of the Intra-Americas Sea Ocean Nowcast/Forecast System (IASNFS). Such IASNFS reanalyses have been applied to a number of studies (e.g., Arnone et al., 2010; D'Sa and Ko, 2008; Green et al., 2008). The Northern Gulf of Mexico Nowcast/Forecast System (NGOMNFS) was imbedded in the IASNFS, a 3-dimensional circulation model based on the Navy Coast Model (NCOM) (Ko et al., 2003). The model has a 1/24° resolution or about ~5.8 km at the northern Gulf of Mexico and 40 vertical layers. It covers the Gulf of Mexico and Caribbean Sea and uses Navy Global NCOM for the open boundary conditions. IASNFS assimilated satellite altimeter data from GFO, Jason-1, ERS-1/2, EnviSat and TOPEX and sea surface temperature from NOAA AVHRR and MODIS (Ko et al., 2008). The surface forcing included wind, heat fluxes and sea level air-pressure derived from the Navy's Operational Global Atmospheric Prediction System (NOGAPS) global weather forecast model. The NGOMNFS has a 2-km resolution and covers the coastal waters of Texas, Louisiana, Mississippi, Alabama and Florida's Gulf coast (Fig. 1). Open boundary conditions were taken from IASNFS and forced surface fluxes originated from the Navy's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS), a regional weather forecast model. The Δt values were calculated from temperature at surface layer and at bottom layer or to 100 m depth and interpolated onto a 2 min grid for northern Gulf Coast and onto a 0.5 min (~1 km) grid for the Galveston Bay.

1.6. Validation of satellite and model data

The satellite and model-derived products developed by NRL (chlorophyll, salinity, Δt) were assessed for suitability and validity through comparisons to an *in situ* data set obtained from the Gulf States Marine Fisheries Commission's Southeast Area Monitoring and Assessment Program (SEAMAP). SEAMAP is a state/federal/university program for the collection, management and dissemination of fishery-independent data and information in the southeastern United States (http://www.gsmfc.org/). While SEAMAP consists of three operational components (SEAMAP-Gulf of Mexico; SEAMAP-South Atlantic; and SEAMAP-Caribbean) only SEAMAP-Gulf of Mexico was used for the validation assessment. In the Gulf of Mexico, SEAMAP resource surveys include summer and fall shrimp/groundfish, and spring and fall plankton, reef fish, and environmental data. The SEAMAP database for the Gulf of Mexico covers 1984 to the present. SEAMAP data were selected based on temporal and spatial consistency with the NRL products, but were also selected based on the availability of all five parameters (sea-surface temperature, salinity and chlorophyll; euphotic depth as Secchi depth reflecting turbidity; and Δt). Appropriate SEAMAP tables were extracted and imported into an ESRI shapefile format so that comparisons with the NRL products could be made. NRL products and SEAMAP data were reclassified into CMECS categories. Visual comparisons were made by overlaying the reclassified SEAMAP data on the corresponding reclassified NRL product. For example, SEAMAP sea-surface temperature was color coded according to the assigned class then displayed on a reclassified, color coded NRL product for sea-surface temperature.

NRL products were extracted and matched to SEAMAP data locations for the corresponding month and year. Statistical analyses were performed to assess the fit of the NRL products to SEAMAP data using SigmaPlot 12.0 software (http://www.sigmaplot.com/products/sigmaplot/sigmaplot-details.php). The Mann–Whitney *U*-test was used to test whether differences between the *in situ* SEAMAP data and the corresponding NRL data were significant ($p < 0.05$).

2. Results

2.1. Statistical comparisons of NRL products and SEAMAP data

Statistical analyses (Table 3) of the unclassified NRL products indicated that, for the majority of the products, there was a significant difference ($p \leq 0.001$) between the product data and the

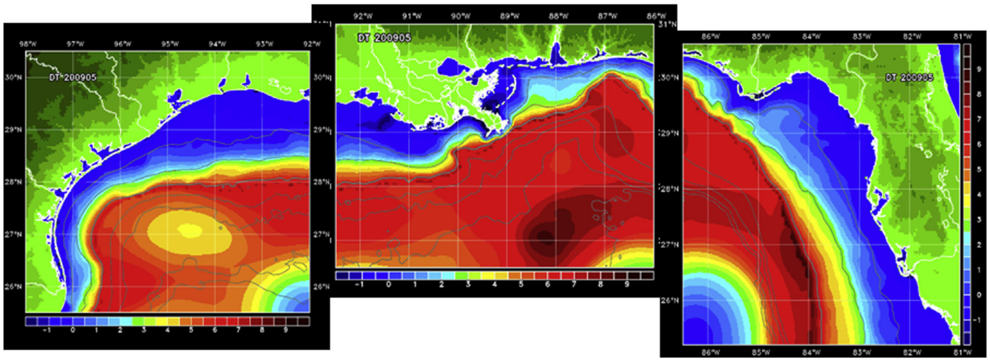


Fig. 1. Northern Gulf of Mexico Nowcast/Forecast System temperature differences along the Gulf Coast derived from reanalysis of the Intra-Americas Sea Ocean Nowcast/Forecast System.

Table 3
Mann–Whitney Rank Sum Test *p* values for pairs of SEAMAP and satellite-derived or modeled data. Satellite data represent monthly composites for the dates shown, e.g., 4-05 is a monthly composite for April, 2005. The bottom row indicates the percentage of *p* values for each parameter that were found to have no significant difference in the median values for each SeaMap and satellite or modeled data pair. Significantly different values are indicated (*).

Date	Sea surface temperature		Δt		Zeu	Sea surface salinity		Surface Chlorophyll	
	NRL	CMECS	NRL	CMECS	CMECS	NRL	CMECS	NRL	CMECS
4-05	<0.001*	<0.001*	<0.001*	<0.001*	1.000	<0.001*	<0.001*	0.262	1.000
5-05	0.470	1.000	<0.001*	<0.001*	1.000	<0.001*	0.704	<0.001*	1.000
6-05	<0.001*	0.002*	<0.001*	<0.001*	1.000	<0.001*	<0.001	N/A	N/A
10-05	0.086	1.000	0.056	0.016*	1.000	0.430	0.436	<0 001*	0.163
6-06	0.039*	<0.001*	<0.001*	<0 001*	1.000	<0 001*	0.054	0.004*	<0.001*
12-06	0.363	0.034*	0.191	<0.001*	1.000	<0.001*	0.005*	<0.001*	0.016*
4-07	<0.001*	1.000	0.012*	0.137	1.000	<0.001*	<0.001*	<0.001*	1.000
5-07	<0.001*	1.000	<0.001*	0.404	1.000	<0.001*	0.361	<0.001*	1.000
6-07	<0.001*	0.012*	<0.001*	0.588	0.162	0.017	0.234	<0.001*	0.079
6-08	<0.001*	<0.001*	<0.001*	<0.001*	0.141	0.003	<0.001*	<0.001*	<0.001*
7-08	0.355	1.000	<0.001*	0.242	1.000	<0.001	<0.001*	0.228	0.020*
6-09	0.062	0.062	<0.001*	<0.001*	1.000	<0.001	<0.001*	0.284	0.185
7-09	0.001*	0.165	0.168	0.329	1.000	0.241	0.319	0.112	0.316
10-09	0.661	<0.001*	0.232	0.018*	0.188	0.304	<0.001*	0.604	0.269
Total %	43	50	29	36	100	21	43	38	64

unclassified *in situ* SEAMAP data (noted below as *in situ*:NRL). However, when the NRL product data were reclassified into CMECS categories and then compared statistically to the SEAMAP *in situ* data, the results were more promising, indicating less significant differences between CMECS categories and SEAMAP *in situ* data.

Sea-surface temperature *in situ*:NRL data had no significant differences 35% of the time. After reclassification to CMECS categories, that percentage increased to 47%. Δt results were 24% and 29% for *in situ*:NRL data and CMECS reclassified categories, respectively. Sea-surface salinity results were 24% and 35% for *in situ*:NRL data and CMECS reclassified categories, respectively. Surface chlorophyll *in situ*:NRL data returned a result of 35%; however, CMECS reclassified categories for *in situ* and NRL product data produced much better results; 69% of the examples tested demonstrated no significant differences. With respect to analysis of the euphotic depth data, we were unable to run statistical analyses to compare the NRL data to SEAMAP data. SEAMAP data for light penetration are measured by Secchi depth. There is no universally accepted, direct conversion between these two measurement approaches though many robust regional algorithms do exist. Analyses of the NRL products and SEAMAP data failed to unveil any statistical algorithm development that could be used to convert euphotic depth to a Secchi depth equivalency. We believe there were two primary reasons for this. First, available Secchi depth data are quite limited within the SEAMAP database. For many of the dates examined, there were no data reported for Secchi depth. Secondly, SEAMAP data are reflecting a single point in time whereas the NRL products represented a monthly average. It is possible that a more in depth analysis of the daily NRL products might prove more fruitful in development of an acceptable algorithm for euphotic depth conservancy to Secchi depth.

3. Discussion

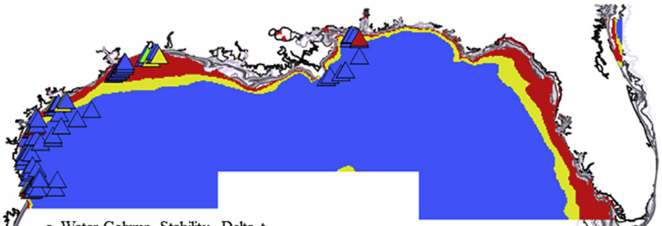
Our first goal for this project was to apply the CMECS WC to the northern Gulf of Mexico. In so doing, we first had to identify useful physicochemical parameters for characterizing the water column, develop a draft framework incorporating those parameters, and then present our proposal to experts to solicit advice for refining the WC. While this project's design was initially modeled after the UKSeaMap work (Connor et al., 2006), it was refined based on the finalized CMECS WC. The UKSeaMap classification system was undertaken to characterize the region's marine benthic and water column habitats. Only surface salinity, surface to bed temperature difference and frontal probability were utilized to produce the water column data layers. In order to stay true to our goal to apply the CMECS WC, we built off the work of Connor et al. (2006) (e.g., surface salinity, Δt, water column stability) while incorporating other parameters identified in CMECS as important water column classifiers. We expanded on the parameters used by Connor et al. (2006), to include surface chlorophyll and euphotic depth in our analyses for two reasons: 1) both are easily attainable through remote sensing; and 2) we were interested in assessing whether these datasets had potential for developing estimates of fish species distributions.

Our second goal was to assess the utility of NRL products for characterizing pelagic habitats in the absence of temporally and spatially dense *in situ* data. The first step toward achieving this goal was to assess the match of NRL products to available *in situ* data. The statistical analyses of the NRL products showed a suitable relationship for large, time series *in situ* data collections. Even though there were statistically significant differences found within the data, we believe there is no biological relevance within these differences. An examination of the data will help explain this conclusion. In April 2005, while there is a statistically significant difference within the data, the average sea-surface temperature within the SEAMAP data was 22.1 °C; the NRL sea-surface temperature average was 20.5 °C, a difference of less than 2 °C. That holds true for 13 of the 14 months evaluated. The one month which had an average difference greater than 2 °C was June 2005, but that difference was less than 2.5 °C. In most of the months, the average differences were less than 1 °C. Most marine species have relatively wide temperature ranges, e.g., Gulf Menhaden spawn in Gulf waters ranging from 18 to 25 °C (Christmas et al., 1982), red snapper have been taken at temperatures ranging from 13 to 32 °C (Moran, 1988), brown shrimp can survive in temperatures as low as 10 °C and as high as 35 °C (Lassuy, 1983) and therefore we conclude would not be impacted by these narrow ranges of difference. Similar results were found when comparing averages for sea-surface salinity and surface chlorophyll with the exception of two months where sea-surface salinity values were considerably different, July 2008 and June 2009.

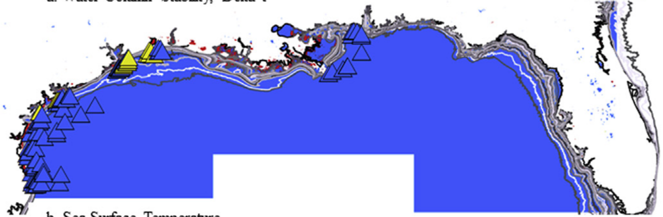
In July 2008, the SEAMAP salinity average was 24.5 whereas the NRL average was 30.3. Many living marine resources would likely not be affected by a difference in salinity at this range but the difference does occur at the upper end of the preferred optimal habitat for some species such as shrimp (Zein-Eldin and Renaud, 1986). The more notable difference was for June 2009 when

SEAMAP salinity averaged 19.9 while the NRL salinity averaged 31. This is a considerable difference but we must note that the NRL data are monthly averages whereas the SEAMAP data are single points in time. Several of the SEAMAP stations sampled in June 2009 measured salinity levels <5. This appears to be atypical for waters in the northern Gulf of Mexico; however, these specific stations were near the mouth of the Mississippi River and we hypothesize that the SEAMAP measurements may have been taken following a large rain or flood event. A review of precipitation records for this period may further support this hypothesis.

Finally, we wanted to delineate and classify pelagic habitat types using CMECS WC categories and present those outputs to resource managers. Using ArcGIS we were able to produce seasonally-averaged maps depicting CMECS categories for sea-surface temperature, salinity, and chlorophyll; euphotic depth; and Δt. CMECS categories for four of the five parameters evaluated are shown in Fig. 2. The three UK SeaMap water column stability classes (Connor et al., 2006) included thermally stratified, well-mixed waters, and an intermediate transition zone. Similarly, Δt was used in this project to reclassify the Δt data into water column stability classes; stability is a modifier in CMECS. CMECS modifiers represent a consistent set of characteristics and definitions to describe the nature and extent of observed variability within ecological units, allowing users to customize the application of the classification in a standardized manner (FGDC, 2012). Fig. 2a illustrates CMECS classified Δt using the NRL hydrodynamic modeled product and SEAMAP data for April 2005. The Salinity and Temperature Subcomponents of the CMECS WC were included because they each indicate the dynamic nature of mixing within the water body, and are both defining features of habitat suitability. Also, as previously noted, most aquatic organisms function optimally within a defined range of salinities and temperature has a considerable impact on ecosystem functioning, affecting photosynthesis, growth, metabolism, and mobility of organisms. Fig. 2b illustrates CMECS classified sea-surface temperatures using NRL products and SEAMAP data for June 2005 and Fig. 2c illustrates CMECS classified sea-surface salinity using NRL products and SEAMAP data, also for June 2005. Trophic status (a CMECS modifier) represented as phytoplankton productivity (i.e., surface chlorophyll) helps define species habitat. Surface chlorophyll is easily estimated through satellite remote sensing. Fig. 2d illustrates CMECS classified surface chlorophyll using NRL products and SEAMAP data for June 2008. The last aspect of the WC that was evaluated for this study was turbidity (a CMECS modifier) as determined by the depth of light penetration, i.e., ambient light is >1% of surface light (i.e., euphotic depth). Initially, we intended to assign a photic level to the NRL euphotic depth product. However, the availability of comparable *in situ* data was insufficient to allow for evaluating the NRL product as a suitable proxy for *in situ* data. For the purposes of this study, we decided to simply use the euphotic depth product as a proxy for turbidity. The remaining two WC Subcomponents, Hydroform and Biogeochemical Feature, were out of the scope of this project but additional analyses inclusive of these components could improve product utility.

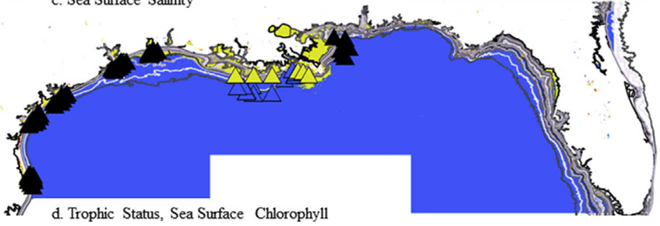


a. Water Column Stability, Delta t



b. Sea Surface Temperature

c. Sea Surface Salinity



d. Trophic Status, Sea Surface Chlorophyll

Fig. 2. Examples of the CMECS classified NRL products and SEAMAP data for select months in 2005 and 2008. Triangles on the images indicate the locations of SEAMAP stations for the respective months reported for each parameter. Triangle colors correspond to the NRL CMECS categories as described below for each image. The contour lines in the images represent bathymetry. Image 3a illustrates water column stability (Delta t) for April 2005; blue represents stratified waters where surface temperatures are >2.0 °C higher than bottom temperatures, yellow represents likelihood of frontal development with surface temperatures between 0.5 and 2.0 °C higher than bottom temperatures, and red areas represent mixed waters, i.e., the difference between surface and bottom temperatures is <0.5 °C. Image 3b illustrates sea-surface temperatures (SST) for June 2005; blue represents SST 20–30 °C, red represents SST > 30 °C. Image 3c illustrates sea-surface salinity for June 2005; blue represents salinity >30 (euhaline), yellow represents salinity > 25–30 (upper polyhaline), and pink represents salinity >18–25 (lower polyhaline). Image 3d illustrates surface chlorophyll for June 2008; blue represents chlorophyll <5 μg, yellow represents chlorophyll >5–30 μg, and red represents chlorophyll >30 μg.

We were able to present the maps to resources managers of the five U.S. Gulf states and document their reactions regarding the utility of these maps. One application explored using these maps was to identify optimum habitat conditions for select managed species. Using a combination of the map layers might allow resources managers to identify favorable environmental conditions which might then be used to determine areas to consider fisheries closures during spawning or ideal sites for restoration activities. An example of this application was developed for Galveston Bay using high resolution data to identify favorable water conditions for brown shrimp and incorporating additional data layers that would help better define suitable habitat, i.e., substrate and intertidal vegetation.

Comments from resource managers requested products incorporating bathymetry and sediment data. To further build on the Galveston Bay management scenario, we were able to secure additional data layers. Nelson (1992) indicated that ‘a combination of habitat characteristics, such as bottom type, water temperature, and bathymetry, would more accurately indicate species’ spatial and temporal distributions.’ Since substrate and availability of intertidal vegetation are other key factors in successful movement into the estuary for brown shrimp, both of these data were overlain on the favorable water conditions raster in ArcMap. National Wetlands Inventory data (vector polygon) was the source of the location and distribution of intertidal vegetation. The NWI classes EEM1 and EEM2 are the two classes into which intertidal vegetation falls in Galveston. On the ground these are generally *Spartina alterniflora* marshes with their normal associates. The U.S. Geological Survey maintains a rich database of grab samples for all

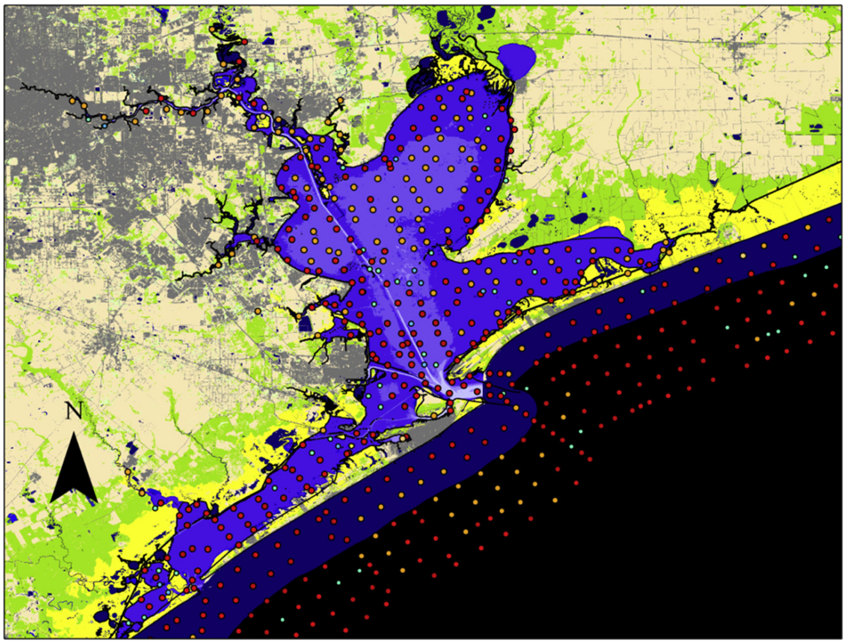


Fig. 3. Substrate and coastal wetland distribution for Galveston Bay and nearshore Gulf of Mexico.

three continental US coasts through the usSEABED database (http://walrus.wr.usgs.gov/usseabed/). Over 1800 samples were available within Galveston Bay and the adjacent nearshore Gulf of Mexico. Although some of the samples did not record sediment type, over 400 samples fell into the sand or sandy mud categories favored by brown shrimp. Most of the other samples in the area showed other unconsolidated bottom classes so although not optimal they indicate that the great majority of Galveston Bay as at least acceptable substrate the shrimp. Fig. 3 shows the distribution of optimal sand and sandy mud samples in the area as well as their relationship to coastal estuarine and palustrine wetlands, uplands, and urban areas. Optimal sediment samples (sands and sandy muds) are shown as red points; other fine unconsolidated sediment samples are shown in orange; estuarine emergent wetlands are shown in yellow and palustrine wetlands in green. The surrounding uplands and the urban areas of Houston, Pasadena, and Galveston are shown in tan and gray respectively.

Bringing the sediment, bathymetry and intertidal vegetation data into this exercise, thereby expanding on the use of CMECS by informing other components (i.e., Substrate Component, Biotic Component), demonstrated that CMECS can be used by resource managers to identify priority areas for restoration or protection. However, since this project was focused on the water column, we did not consider data layers for bottom type or bathymetry beyond the Galveston Bay case study.

4. Conclusions

NRL products such as those assessed in this study have the potential to contribute water column information for use with habitat assessments and management decision-making processes. The high temporal resolution and near-real-time availability of the remotely sensed data can be used to characterize the dynamic pelagic environment and allows for monitoring and response to discrete events such as freezes, large releases of freshwater due to coastal flooding, and spill events. Although there were statistically significant differences between the NRL products and the SEAMAP *in situ* data, we believe the potential is strong for use of standard NRL products to add water column information. The large coverage and high temporal resolution likely would provide more benefit than what may be lost due to the slight variability we noted amongst the results.

In addition, this project has affectively demonstrated the utility of CMECS. The CMECS WC with appropriate modifiers captures all the significant pelagic environmental parameters which influence habitat and species distributions. Reclassifying NRL products and *in situ* SEAMAP data into CMECS categories produced a better match between the two data sources without the loss of biologically relevant differences within those data. Of the parameters evaluated, the NRL sea-surface salinity and temperature, as expected, were most useful for making comparisons. Further research and different types of data are still needed to explore the full potential of this approach. Specifically, resource managers would like to see the incorporation of sediment and bathymetry data. We believe addition of these data layers would result in more robust habitat maps and provide an innovative tool for resource managers. The CMECS categorized NRL maps have been made publicly available at http://gulfatlas.noaa.gov/.

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