

# Framework for Developing a Reference-based Assessment Approach for Evaluating the Ecological Condition of Coastal Watersheds

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## **1.0 Introduction**

### **1.1 Background**

In 2003, North Carolina established the Ecosystem Enhancement Program (EEP) in order to become more proactive in restoring, enhancing and protecting its aquatic resources (lakes, rivers, estuaries, and wetlands) from further degradation. To contribute toward this effort, EEP contracted with East Carolina University (ECU) scientists to develop an assessment approach that would enable EEP and its contractors to evaluate and monitor the condition of streams and riparian zones in the coastal plain at both the site and watershed scales. The intent was that EEP would use this channel-riparian assessment approach to help develop detailed watershed plans and to better implement and track the effectiveness of ecological restoration efforts in the coastal plain.

By 2005, ECU had created channel-riparian assessment protocols for four types of inland coastal plain streams: rural low (1<sup>st</sup>-2<sup>nd</sup>) order, rural high (3<sup>rd</sup>-4<sup>th</sup>) order, urban low order, and urban high order (Rheinhardt et al. 2005, Brinson et al. 2006). ECU also developed an approach for aggregating data from a random selection of reaches within a small watershed for use in estimating the condition of a stream network. These procedures were tested in six small inland coastal plain watersheds in 2005 and further refined (Rheinhardt et al. 2007b).

The rural assessment procedures, based on several years of research involving the use of reference sites, were repeatable and sensitive to alterations at a scale appropriate for use by resource managers (Rheinhardt et al. 2007b). However, results of the field tests suggested that additional refinement was needed for the urban protocol to make it both more sensitive to urban situations and the results more repeatable among users. Further research by ECU scientists is underway in urban reference sites to provide data for refining the two urban assessment protocols.

Although the channel-riparian protocols and stream network assessments have been shown to work reasonably well in estimating the condition of aquatic resources of inland riparian ecosystems, North Carolina has many coastal watersheds that are not only influenced by the offsite condition of contributing tributary streams, but are also influenced by the condition of their shorelines, shoreline buffers, and subtidal areas where they interface with the estuary proper. Thus, it is apparent that coastal watersheds require a separate, but complementary, assessment approach into which the assessment protocols developed for inland stream networks could be a part. The focus of this report is (1) to summarize some of the literature on potential estuarine and shoreline indicators of condition and (2) to suggest a framework for creating a comprehensive, reference-based, ecological condition assessment approach for small coastal watersheds and connected subestuaries.

Small coastal watersheds are defined here as those that originate in the coastal plain, that are large enough to include at least one perennial stream, and that discharge directly into an estuary or subestuary that is influenced by sea level through the influence of

astronomic or wind-generated tides. This is similar to the “estuarine segments” of King et al. (2005) and Brooks et al. (2006) except that their definition of estuarine segment for the Chesapeake Bay required that the drainage be large enough to include one perennial stream, discharge into a mesohaline estuary, and include brackish tidal wetlands. The latter two of these criteria are too restrictive for North Carolina since many small coastal watersheds discharge into freshwater portions of estuaries and thus do not have brackish tidal marshes. Such conditions are common in the Albemarle Sound region and as well as near the heads of the Neuse and Pamlico Rivers. It is probably not advisable at this point to create more restrictive criteria until further details are worked out.

## **1.2 The need for coastal watershed assessments**

Fifty-three percent of the US population lives in coastal counties (Pew Oceans Commission 2003) and that percentage is increasing due to a proliferation of retirement/golfing communities being built near the coast. Sixty-five percent of monitored estuaries in the U.S. exhibit moderate to high signs of eutrophication (Bricker et al. 1999, Howarth et al. 2000), a direct result of human population pressures. Coastal land use affects estuarine condition; development leads a wide variety of problems, from bioaccumulation of toxic chemicals in estuarine fish (King et al. 2004) to a decline in the integrity of marsh bird communities (DeLuca et al. 2004) and benthic communities (Dauer et al. 2000, Lerberg et al. 2000). Many coastal estuaries in North Carolina are particularly susceptible to problems associated with pollution and eutrophication (e.g., hypoxia, algal blooms, fish kills, shellfish closures) because they exhibit high residence times (>1 yr) due to the limited flushing capacity afforded by only a few, narrow, barrier inlets (Christian et al. 1991, Giese et al. 1985, Mallin 1994). Thus, nutrients (particularly nitrate) can and do remain available for long periods before being exported, denitrified, or buried in sediment. Fertilizer application to cropland, channelization of streams, large-scale animal rearing operations, and the widespread use of septic systems in expanding suburbs have all contributed to the increased pollution and eutrophication of streams and estuaries. A myriad of other problems, such as destructive or unsustainable fishing pressure and destruction of nearshore and shoreline habitats have magnified the deterioration of estuaries throughout coastal North Carolina (Street et al. 2005). The effects of these problems have been accumulating for some time and have detrimentally affected certain sectors of the economy of North Carolina and the health of its citizens.

Numerous anthropogenic stressors detrimentally affect coastal watersheds. Identifying stressor-specific indicators of estuarine health would be useful in developing approaches that could be used by resource managers to monitor, control, and restore estuarine ecosystems (Niemi et al. 2004, APNEP at <http://www.apnep.org/>). A major challenge is to identify key indicators of condition that could be used to diagnose problems and guide decisions toward solving them.

Estuarine condition can be evaluated by measuring water quality parameters (Niemi et al. 2004) or with IBI-type approaches that assess communities of fish and benthic fauna (Overton 2001, Hale et al., 2004, Bilkovic et al. 2005, 2006; King et al. 2005). These approaches can show correlations between species composition and overall watershed

condition, particularly for types of land use and especially the proportion of impervious surface. For restoration purposes, indicators are needed to identify a range of alterations and quantify their effects. Further, analyses should be effective at revealing on-site conditions (reach, individual shoreline) as well as aggregated conditions at small watershed scales.

Environmental stressors resulting from alterations tend to vary in magnitude, timing, and spatial arrangement (Stoms et al. 2005). Indicators must respond to such variation to be useful. Due to the complexity of estuarine ecosystems and the types of alterations that affect them, there are probably many indicators that respond to changes in condition, but only a subset of those are likely to be useful for resource managers. The most useful indicators are (1) related to an important ecosystem function, (2) related to a specific problem or class of problems affecting a function or functions, (3) scientifically defensible, (4) capable of differentiating levels of condition, from best to worst based on local reference conditions, (5) easily and rapidly measured, and (6) repeatable when measured by different people and/or at different times. A major challenge is to identify indicators that meet all or most of these criteria and tie them together into a comprehensive management package.

First steps in meeting this challenge are to define coastal watersheds and identify the key stressors related to altered coastal watershed condition. Ideally, condition should be quantitatively or logically related to one or more ecosystem functions. The magnitude, timing, and spatial arrangement of the stressors can then be used to identify indicators that respond to varying degrees and sources of human influence that affect ecosystem functions. The indicators could then be put into an assessment framework for evaluating the condition of an estuarine watershed, similar to the approach used in the channel-riparian protocol.

## **2.0 Complementary efforts**

Several complementary efforts have been underway, both nationally and in North Carolina, that provide the basis for developing a coastal watershed assessment approach for determining coastal watershed condition. The array of approaches discussed in this section varies widely in spatial complexity and temporal scales. The challenge is to integrate this information to develop an assessment framework that is scientifically sound, rapid to apply, reference-based, and can be used to diagnose watershed problems. We describe them under the categories of classification and inventory, ecological condition assessments, and restoration-oriented efforts. In some cases, a given procedure falls into more than one category. For example, NCCREWS has been developed to address all three (<http://dcm2.enr.state.nc.us/Wetlands/nccrews.htm>).

### **2.1 Classification and Inventory**

#### **2.1.1 Riggs and Ames classification of shoreline types.**

Riggs and Ames (2003) provide a comprehensive classification of shoreline types found

along North Carolina estuaries. Each type differs in its geologic and physical attributes, which together determine its relative vulnerability to storm-driven erosion. Several shoreline subtypes were identified within each of four basic shoreline categories (Table 1). Note that Riggs and Ames classified all human-modified shorelines as a unique subtype within a Combination Shoreline category, regardless of their original subtype prior to modification. These human-modified shoreline types were not classified further, presumably because the authors were most interested in the evolution and fate of natural shoreline features than in identifying the original class from which altered shorelines were modified. However, in developing a condition assessment, it would be useful to identify the various types of modifications to shorelines, perhaps in reference to their natural or historic conditions.

**Table 1. Natural shoreline types in North Carolina estuaries (Riggs and Ames 2003).**

SHORELINE CATEGORIES		SUBTYPES	DEFINING PARAMETERS
Sediment Bank Shorelines	Bluff		>20 ft high
	High Bank		5-20 ft high
	Low Bank		<5 ft high
Organic Shorelines	Swamp Forest		Freshwater riverine floodplains and freshwater pocosins
	Marsh		Fresh, brackish, and salt water
Combination Shorelines	Sediment Bank with Cypress Fringe		
	Sediment Bank with Marsh Fringe		
	Sediment Bank with Fringe of Large Down Wood		
	Low Sediment Bank with Stumps		
	Swamp Forest with Strandplain Beach		
	Marsh with Strandplain Beach		
Back-barrier Shorelines	Overwash Barriers		Mixed sand fans and marsh platforms
	Complex Barriers		Sediment banks and organic banks
	Inlet		Flood tide deltas

### 2.1.1 NCCREWS wetland classification

The NCCREWS developed a wetland classification approach for North Carolina that could also be used as a Level-1 assessment (i.e., without a field visit) (<http://dcm2.enr.state.nc.us/Wetlands/nccrews.htm>). It incorporates a spatial data layer that provides the abundance and distribution of wetlands, both inland and as part of estuaries. All of the wetland classes of the NCCREWS method can be found in small coastal watersheds. They include Salt/Brackish Marsh, Freshwater, Marsh, Estuarine Shrub Scrub, Pocosin, Bottomland Hardwood, Riverine Swamp Forest, Depressional Swamp Forest, Hardwood Flat, Pine Flat, Managed Pineland, Estuarine Forest, Maritime Swamp Forest, and Headwater Swamp Forest. The Human Impacted class would be considered here as an altered example of one of the foregoing classes. The use of NCCREWS as a Level 1 functional assessment method is described in section 2.2.4.

## 2.2 Ecological Condition Assessments

### 2.2.1 EPA Estuarine and Great Lakes (EaGLe) Coastal Initiative

The EaGLe initiative (<http://eagle.nrri.umn.edu/pubdefault.htm>) by EPA was established to develop a new generation of environmental indicators to assess the biological health of coastal ecosystems. The initiative encompassed five regional research centers in the U.S., including the Atlantic Slope Consortium (ASC) and the Atlantic Coast Environmental Indicators Consortium (ACE INC), both of which involved the study of watersheds and estuaries of Albemarle-Pamlico Sound. One goal of the ASC (<http://www.asc.psu.edu>), of which ECU scientists were contributing members, was to identify indicators that would “link conditions in upstream watersheds to downstream estuaries” (Brooks et al. 2006). Much of the direction ECU scientists took in developing channel-riparian assessment protocol for headwater reaches of coastal plain streams was initially influenced by a parallel ASC effort in inland watersheds (Rheinhardt et al. 2007b).

In a series of studies, ASC scientists identified 10 potential nearshore indicators associated with key ecosystem properties in estuarine segments (small watersheds) of Chesapeake Bay (Table 2). Although the 10 indicators were based on in-depth studies of Chesapeake Bay estuarine segments, only three indicators (water column light extinction, abundance of common reed, and estuarine shoreline condition) are reasonably adaptable to a rapid assessment approach similar to the channel-riparian protocol for riparian ecosystem assessment. However, none of the three indicators have been regionally calibrated to North Carolina estuaries. These three potential indicators and their likely implementation in a management framework will be discussed in more detail below.

**Table 2. Potential estuarine near shore indicators identified by the Atlantic Slope Consortium ([www.asc.psu.edu/overview.asp](http://www.asc.psu.edu/overview.asp)) (Brooks et al. 2006, Appendix A). The three indicators with potential for rapid assessment are indicated with (\*).**

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1. Bio-optical model of habitat suitability for submerged aquatic vegetation (SAV)\*
  2. Abundance of common reed (*Phragmites australis*)\*
  3. Polychlorinated biphenyls (PCBs) concentration in white perch
  4. Blue crab (*Callinectes sapidus*) abundance
  5. Nitrate, total N, and total P concentrations
  6. Index of marsh bird community integrity
  7. Index of waterbird community integrity
  8. Fish community index
  9. Macrobenthic community indices
  10. Estuarine shoreline condition\*
-

In Chesapeake Bay, which is a relatively well-mixed estuary with turnover periods on the order of months, an indicator of light absorption capacity was shown to be related to land use (Gallegos and Biber 2004). Light attenuation is important to the growth of submerged aquatic vegetation (SAV), particularly during the growing season (Gallegos et al. 2005), because SAV requires relatively clear water. Thus, this indicator of water clarity was shown to be a useful indicator of the potential for SAV habitat. A physical indicator similar to this one might prove to be useful in NC estuaries as well. However, light attenuation is highly variable depending on suspended sediments and phytoplankton density, so repeated measurements would likely be necessary.

Another useful indicator in Chesapeake Bay was the abundance of common reed (*Phragmites australis*), an aggressive invasive species that forms monotypic stands that enable it to outcompete native brackish wetland vegetation (Chambers et al. 1999). *Phragmites* is an indicator of poor aquatic health because it dominates marshes following land disturbance and increased nitrogen loads. An ASC study found that the abundance of *Phragmites* was related to the type, amount, and proximity of landuse (Brooks et al. 2006). Proximity of various landuse types was an important variable related to condition when inversely weighted relative to distance (e.g., if development A was located 10 times further away than development B, A was weighted 1/10 as much as development B). *Phragmites* is not yet as problematic in North Carolina estuaries as it is in Chesapeake Bay, but it likely will follow a similarly invasive pattern as development in North Carolina coastal watersheds increases in intensity and area. Thus, the presence and abundance of *Phragmites* may be an early warning signal of deteriorating estuarine condition and so would probably be a useful indicator in North Carolina estuaries.

The third potentially useful indicator identified by the ASC was shoreline condition. Human alterations of shorelines are usually an attempt to prevent loss of waterfront land and real estate. However, alterations of shoreline and nearshore habitat have been shown to detrimentally affect estuarine benthic and fish communities (Bilkovic et al. 2005). The specific mechanisms for how degradation of shoreline and nearshore habitat (e.g., wetlands, SAV, shellfish beds, mudflats) affects nearshore communities are unclear, except where shoreline modifications directly eliminate shoreline habitat (Table 3). However, such modifications of nearshore habitat may also alter sediment transport and local current patterns that provide foraging, spawning, and nursery areas for a wide variety of estuarine-dependant species. There also appears to be a relationship between the amount of watershed development and the condition of estuarine macrobenthic communities (Bilkovic et al. 2006), particularly in highly developed watersheds. Because increased developments in small coastal watersheds are usually also associated with increased shoreline development and shoreline modifications, the effects of the two on biota are not easily distinguished.

**Table 3. Common categories of structural modifications to shorelines. They are listed from least (top) to most (bottom) ecologically detrimental. Modified slightly from NC-DCM (2006). "Land Planning" is not included because it avoids the need for modification.**

<b>Structure Type</b>	<b>Aliases</b>	<b>Typical Construction Materials</b>	<b>Characteristics</b>	<b>Erosion Control Purpose</b>
Vegetation Control	Wetland or upland plantings	Wetland or upland vegetation	Planting, replanting, or conserving existing vegetation	Creates a buffer to dissipate wave energy.
Beach Fill	Beach nourishment	Sediment/sand similar to the native beach	Placing sand on the shoreline	Acts as a sacrificial erosive barrier.
Sill	Marsh sill, wooden breakwater, wave board timber	Rock, concrete pieces, vinyl	Parallel and close to shore, low elevation, usually to protect wetland vegetation	Reduces wave energy on the shoreline. Traps sediment landward to rebuild/protect wetlands.
Groin/jetty	Groin: designed to trap sand to build a beach Jetty: usually longer than groin, designed to prevent infilling of a channel	Timber, rock, concrete, vinyl	Solid or permeable. Perpendicular to shore	Designed to trap sand on the updrift side to build out a beach.
Breakwater	Wave attenuator	Timber, concrete, rock	Parallel to shore, larger and further offshore than sills, floating or fixed	Reduces wave energy on the shoreline. Traps sand between the shore and breakwater.
Sloped Structure	Riprap, revetment, sloped seawall	Concrete, rock	Watertight or porous, sloped against a bank	Protect land from erosion and absorb wave energy without reflecting waves.
Vertical Structure	Bulkhead, seawall, gravity wall	Timber, steel, vinyl, rock, concrete	Watertight, vertical, parallel to shore	Designed to hold back land.

Shoreline condition, as measured by the ASC study, was not a single indicator, but consisted of mapped estuarine segments showing various shoreline alterations that together summarized condition. The mapping protocol, originally developed to monitor land use changes along Chesapeake Bay's coastline, is administered by the Comprehensive Coastal Inventory (CCI) Program of the Center for Coastal Resources Management (CCRM) at the Virginia Institute of Marine Science (VIMS) (<http://ccrm.vims.edu/cci.html>). Remotely sensed imagery is taken at low altitude by fixed-wing aircraft and then field verified from a small boat cruising the shoreline. The mapped categories are upland, forested, scrub-shrub, grass, residential, commercial, bare, bank height (3 categories), bank erosion (2 levels), marsh (absent, eroding, not eroding), beach (as for marsh), bathhouse, dock, ramp, bulkhead, riprap, groin, and breakwater. The remotely-sensed and ground-truthed data sets are integrated and published online, by county, as Shoreline Situation Reports (<http://ccrm.vims.edu/gisdatabases.html>). The data are used for monitoring changes in shoreline condition, for regulatory enforcement, for locating potential restoration sites, and for contributing to ecological assessments (Bilkovic et al. 2006).

The CCI Program recently surveyed shorelines along the Chowan River estuary in North Carolina for the APNEP program (Dean Carpenter, APNEP, personal communication, 2006). Those data are available online as maps and aerial photographs ([http://ccrm.vims.edu/chowan/chowan\\_disclaimer.htm](http://ccrm.vims.edu/chowan/chowan_disclaimer.htm)), but the GIS layers from which the maps were made provide detailed data on locations and types of shoreline structures (groins, jetties, piers, revetments, etc.), all of which affect shoreline condition to varying degrees. None of the CCRM shoreline data have yet been used to estimate changes in nearshore functions nor have they been used to develop specific indicators that could be used to rapidly assess estuarine condition of specific watersheds. However, the data appear to be sufficiently robust to be useful as a part of an integrative shoreline assessment method and could be adapted to condition assessments in North Carolina estuaries.

### **2.2.2 North Carolina Strategic Habitat Area (SHA) Designation Process**

As part of a comprehensive Coastal Habitat Protection Plan (CHPP), North Carolina recognized that certain types of coastal habitats were critical for insuring sustainable coastal fishery resources. The habitats are water column, shell bottom (e.g., oyster beds, clam beds), submerged aquatic vegetation (e.g., eel grass, widgeon grass), soft bottom, hard bottom, and wetlands (e.g., salt marsh, tidal swamp). In the CHPP, locations of these critical habitats were termed strategic habitat areas (SHAs), defined as "specific locations of individual fish habitats or systems of habitats that were identified to provide exceptional habitat functions or that are particularly at risk due to imminent threats, vulnerability, or rarity" (Street et al. AP4). To provide guidance in identifying SHAs, the Strategic Habitat Area (SHA) Scientific Advisory Committee was established to "recommend a scientifically based process and criteria to identify Strategic Habitat Areas throughout coastal North Carolina" (Deaton et al. 2006).

The Advisory Committee recommended that the Marine Fisheries Commission (MFC) modify its definition of SHAs to include a more functionally based habitat designation (Table 4). The Division of Marine Fisheries (DMF) plans to recommend that the MFC reorganize and modify their habitat definitions and associated rules to reflect a comprehensive habitat classification/protection approach that includes SHAs as one of several tools to protect, enhance and restore fish habitat. Habitats that would be reorganized under the overall category of “Fish Habitat Areas” would include: (1) Anadromous Fish Spawning Areas - MFC designation and rules pending, (2) Anadromous Fish Nursery Areas – not currently designated in rules, (3) Submerged Aquatic Vegetation– not currently designated in rules, but is close, (4) Shellfish Producing Habitat – not currently designated in rules, (5) Crab Spawning Sanctuaries - MFC rules already in place, (6) Primary Nursery Areas - MFC, Environmental Management Commission (EMC), Coastal Resources Commission (CRC) rules already in place, and (7) Strategic Habitat Areas – MFC, CRC, and EMC rules to be established, but has been adopted by the MFC. SHAs may include habitat complexes consisting of any combination of the above, as well as other habitats.

**Table 4. Types of fishery habitats included as part of a comprehensive habitat designation (Deaton et al. 2006).**

- 
1. Anadromous spawning areas
  2. Anadromous nursery areas
  3. Submerged aquatic vegetation (SAV)
  4. Shellfish producing area
  5. Crab spawning sanctuaries
  6. Primary nursery areas
  7. Strategic habitat areas (SHAs)
- 

Figure 1 outlines the process for identification of SHAs by defining the scope of a project and utilizing available information to specify their geographic boundaries. These SHAs provide one or more of the following ecological functions for important estuarine fishery species: refuge from predation, spawning conditions, refuge and foraging conditions for juveniles (nursery areas), foraging opportunities, and safe passageways (corridors) among foraging areas, refuges, and spawning grounds. Of course, not all areas can provide all functions for all species. For example, a prime refuge for one species should, by definition, be a poor foraging area for its predator. Likewise, a prime nursery area for one species would be a poor refuge for its prey. The main impetus of the SHA designation process was to collate as much information as possible about ideal habitat parameters, functions, and locations of habitats needed for various estuarine species. That information would then be used to design a network of protected habitats that would most efficiently maintain and enhance coastal fisheries. To do this, the Scientific Advisory Committee used an algorithm called MARXAN (Ball and Possingham 2000) as a tool to organize information on habitat locations and threats to create an optimal spatial configuration for protecting an array of habitats.

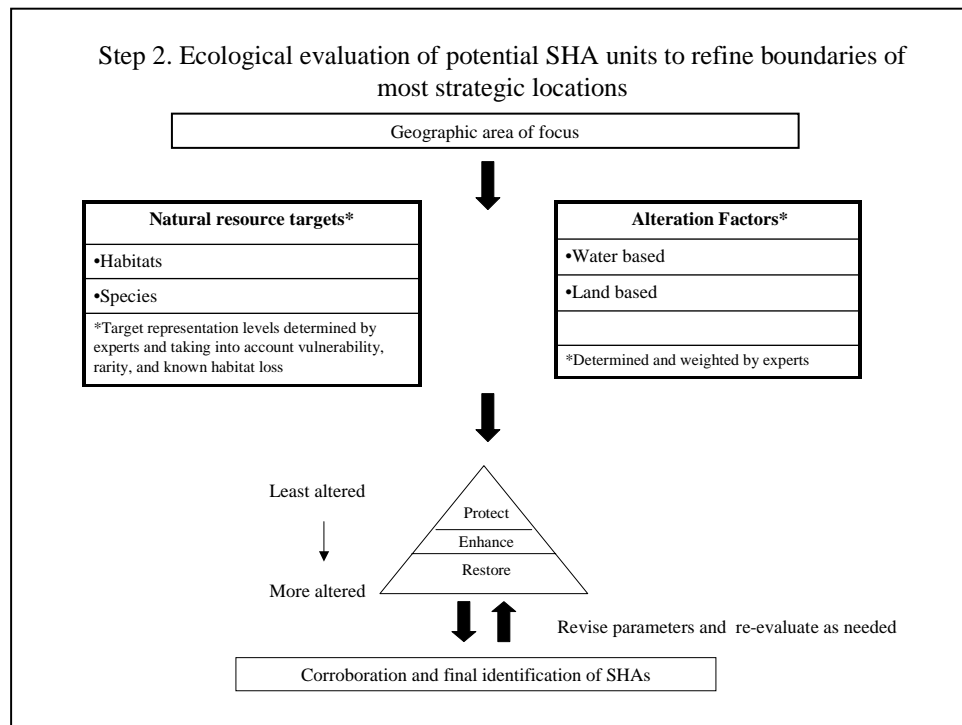
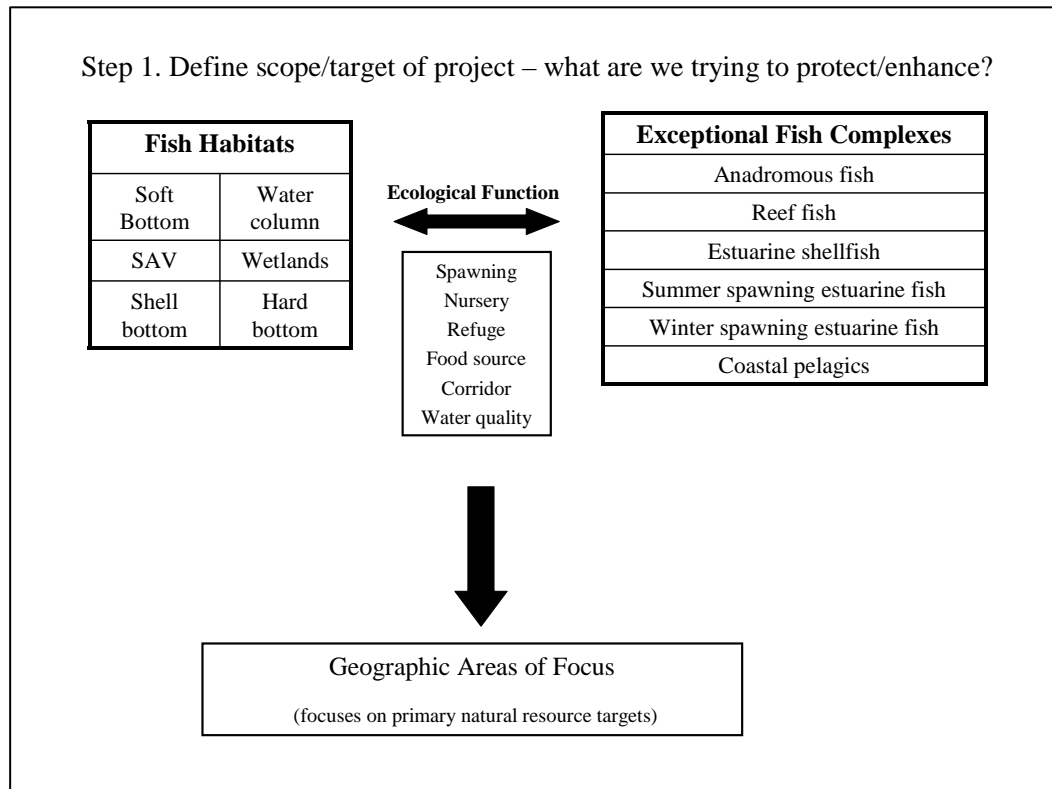


Figure 1. Template for SHA identification process (Deaton et al. 2006).

The optimal spatial configuration for SHA designation is created as a GIS layer that could provide office-based data of potential shoreline habitat condition. For detailed assessments, field verification would probably be required as well, in a manner similar to field verification of shoreline surveys.

At the very least, habitat types as defined by CHPP, and appropriate subtypes (Table 4), could be incorporated into indicator development of nearshore and shoreline components of an assessment. In fact, the data layers of locations of other fish habitats in Table 4 as well as the Alteration Factors in Figure 1 represent useful information for assessing estuarine condition. A partial list of alteration factors that indicate relatively high (severe) effects on SHAs (depending on habitat type) are dams, urban stormwater runoff, urban/suburban construction activities, shoreline stabilization, marina and dock construction, and various water quality indicators (use support of shellfish harvest, etc., biotic indices, ambient water quality data, sediment toxicity.). In addition to identifying SHAs, DMF could be a useful source of these data for routine estuarine assessments in part because the data have been collated in a single GIS platform.

### **2.2.3 Recommendations to the North Carolina Coastal Resources Commission Shoreline Stabilization Subcommittee**

Shoreline stabilization structures are the primary human alteration to natural shorelines. Many of the shoreline modifications in Table 5 are designed to inhibit shoreline erosion, a widespread and naturally recurring process. Each modification has its own effect on the functioning of shoreline processes. As such, it could be used to help estimate relative shoreline condition. All these modifications require regulatory permits in North Carolina, but until recently there has been little guidance to support permit decisions.

To help make permit decisions more scientifically-based, the North Carolina Estuarine Biological and Physical Processes Work Group was convened to craft a science-based ranking of the relative ecological effects of various shoreline stabilization methods permitted in North Carolina. The report (NC-DCM 2006) identified 13 shoreline ecological functions, 11 natural shoreline types (based on Riggs and Ames 2003; Table 5), and 8 common stabilization methods. Each natural shoreline type was ranked as (0) minimal, (1) moderate, or (2) exceptional in its characteristic ability to perform each of the 13 functions. Potential changes in nearshore ecosystem functioning was identified for each type of stabilization method. Using the functional rankings of each shoreline and the potential changes in function in response to each stabilization method, the shoreline stabilization methods were ranked, by shoreline type, based on the degree to which they would affect the natural functions typically provided by shorelines.

**Table 5. Natural estuarine shoreline types modified from those developed by Riggs and Ames (2003). These shoreline types were used by the North Carolina Estuarine Biological and Physical Processes Workgroup (NC-DCM 2006) to rank by type the degree to which they modified functions relative to natural shorelines (listed in Table 1).**

- 
1. Swamp Forest
  2. Marsh
  3. Marsh with Oysters
  4. Marsh with Mud Flats
  5. High and Low Sediment Bank with Marsh
  6. High and Low Sediment Bank with Swamp Forest
  7. High and Low Sediment Bank with Oysters /SAV
  8. High and Low Sediment Bank with Woody Debris
  9. High and Low Sediment Bank with Sand Bluff
  10. Overwash Barrier/Inlet Areas
- 

Differences in rankings of shoreline stabilization methods were intended to estimate the degree to which they may impair estuarine functions. However, the degree to which a particular method alters ecosystem processes depends on the type of shoreline on which it is constructed. For example, both high sediment bank and swamp forest shorelines were considered exceptional at dissipating wave energy, but swamp forest was considered to be better in providing habitat for juvenile fish. The committee determined that the least detrimental stabilization method for both shoreline types was properly planned shoreline development (i.e., “land planning”) wherein infrastructure is built far enough landward so that it is not threatened by erosion (an avoidance approach). For swamp forest shorelines without adequate buffers, “vegetation control” was considered the next least damaging stabilization option available. In contrast, for high sediment bank shorelines with inadequate buffers, supplying sand to the beach front (“beach fill”) was considered the least damaging stabilization option.

The rankings of stabilization methods, by shoreline type, were not based on any specific research, but were instead based on professional opinions of the technical workgroup. The Stabilization Subcommittee hoped that recommendations of the workgroup would eventually be used to guide policy decisions on permitted shoreline stabilization activities. Although based on a collective best scientific judgment, these rankings could be used as a basis for developing indicators of shoreline condition. Rankings could be coupled with a shoreline database derived from shoreline surveys, like those conducted by VIMS-CCI Program (described above, Section 2.2.1) coupled with field data.

#### **2.2.4 Use of NCCREWS as a Level-1 assessment**

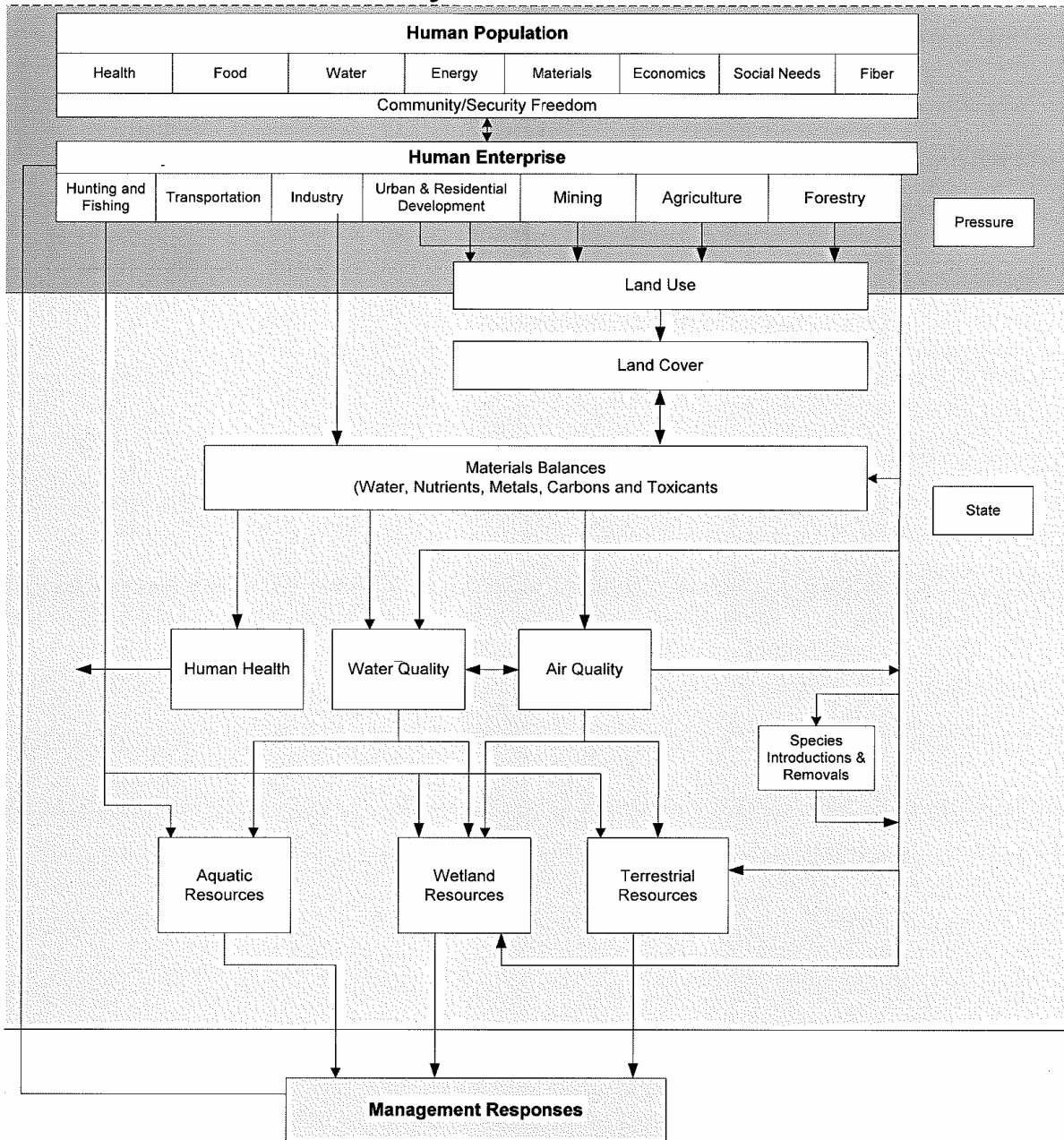
Data generated by NCCREWS has a number of potential uses including identification of wetland type and location, identification of the most ecologically significant wetlands, improved avoidance and minimization of wetland impacts, improved impact analysis for development projects, improved land use planning, and identification of potential wetland mitigation sites. GIS data layers provide information on the location of wetland classes for the 20 coastal counties as well as 17 inner coastal plain counties. The information can be used as a framework for a Level-1 assessment. As described on the NCCREWS web site (<http://dcm2.enr.state.nc.us/Wetlands/nccrews.htm>), the hierarchical structure provides four levels of information: (1) overall functional significance of the wetland, (2) specific functions and potential risk of wetland loss, (3) subfunctions, and (4) parameters and subparameters evaluated to determine the level and extent of functions.

The NCCREWS model evaluates 39 separate characteristics of a wetland and its watershed (14-digit hydrologic units). Using GIS analysis, a High, Medium, or Low rating is assigned to each of the subparameters that describe the landscape and internal wetland characteristics. The subparameter ratings are successively combined to produce ratings for parameters; parameter ratings are combined to produce ratings for subfunctions; subfunction ratings are combined to produce ratings for primary functions. The primary functions are combined to form an overall wetland rating of the wetland's ecological significance. NC-CREWS produces three possible overall wetland rating scores: Exceptional Significance, Substantial Significance, or Beneficial Significance. Since the output is dependent on remote sensing, a field visit would be necessary for verification. The method is not reference based, so level of functioning (or subfunctions) is more dependent upon the wetland class than it is on whether a particular wetland has been altered.

#### **2.2.5 Albemarle-Pamlico National Estuarine Program (APNEP)**

Indicators of condition for the Albemarle-Pamlico region are being developed by a group of committees. While the work is not yet complete, the scope of this project is broad, and indicators that are developed should be considered for coastal watersheds. Figure 2 shows the conceptual approach taken whereby pressures identified for the Albemarle-Pamlico system influence the state of its natural resources. As an example, APNEP is structured by first identifying the indicator (e.g., living wetlands resources), an indicator category (e.g., wetlands), importance (e.g., represents sentinel and charismatic species), measurement units (e.g., bird species assemblages by wetland type: presence/absence (per wetland type); abundance (number/area), data sets (e.g., official bird counts of waterfowl and colonial water birds), and various contacts (e.g., state and government agencies, non-governmental organization, etc.). It is not yet known how indicators would be used to evaluate estuarine resources. Work is still in progress at this time, and a report is expected within a few months.

# Albemarle-Pamlico Ecosystem Environmental Indicators



**Figure 2. Relationship between pressures and the state of natural resources for the Albemarle-Pamlico. The study is in progress.**

## 2.3 Restoration

### 2.3.1 White Papers by the North Carolina Habitat Priorities Advisory Committee and the Implementation Advisory Committee (2006)

This work was developed under an EEP project, “An approach to coordinating compensatory mitigation requirements to meet the goals of the Coastal Habitat Protection Plan.” Two committees were formed and white papers were drafted for each committee’s review, input, and adoption. The first was the Priorities Advisory Committee that produced a draft white paper stating as its objective, to present “a scientific rationale and framework for an alternative approach to compensatory mitigation that will improve the effectiveness and scope of ecological restoration in the coastal region of North Carolina” (available as a combined report with the Implementation Advisory Committee’s report at <http://www.treefrogresources.com/coastalmitigation/docs/papers.html>). The habitat paper provides extensive evidence of the shortcomings of current mitigation policy and its implementation in achieving federal no-net-loss goals. For example, mitigation of environmental impacts upstream has not adequately protected and restored downstream “receptor habitats” in estuaries. Part of the failure was attributed to “in-kind and on-site” mitigation policies, but much of the problem was also shown to be due to unregulated or insufficiently regulated human activities in uplands and along the coast. One example provided was the commercial extinction of river herring (*Alosa aestivalis* and *A. pseudoharengus*) populations. The collapse of the fishery was a combined result of poor fisheries management and habitat loss, especially the loss of habitat resulting from stream channelization in upstream spawning and nursery areas.

The report includes a list of human stressors that adversely impact coastal ecosystem functions and habitats of fishery species. It points out that many of these stressors have been present for centuries and have been responsible in part for the degraded condition of estuaries and associated fisheries resources. While it is not possible to specify how individual stressors have altered a given estuarine resource, it is broadly accepted that watershed-based restoration practices will benefit estuarine conditions. The report suggested that innovative approaches could be accomplished by integrating compensatory mitigation into the CHPP process, which will require a much broader perspective regarding mitigation options than is currently practiced. It would allow for out-of-kind and off-site compensatory mitigation of downstream “receptor habitats.” This “big picture” approach will require better infusion of available science into the process, a functionally-sound inventory and classification of coastal resources, and methods for quantifying resource condition with quantitative reference-based assessments. Concurrent with developing reference-based assessment methods is the need for establishing a tracking system (scorecard approach) that would allow resource managers to follow changes in resource (e.g., CHPP habitat) condition over time. Given that estuarine condition is already degraded by all accounts, a challenge is not only to reverse this trend, but also to offset newly developing stressors.

Using the Habitat Priorities Advisory Committee white paper as the technical foundation, the Implementations Advisory Committee developed and endorsed a range of mitigation strategies that go beyond the in-kind, on-site wetland replacement that has been used for many years. In broad terms, such an approach assumes a 2:1 replacement has been traditionally/historically accepted, and recommends that instead mitigation be broken into two parts: (1) allocating a 1:1 replacement for the habitat altered, as a way to be consistent with a 'no net loss' policy and (2) using the remainder of the 2:1 ratio to restore functions in the watershed and the estuary. This second part consists of a list of activities that would provide improvement in estuarine habitat through detaining stormwater runoff, reducing nutrient loading of estuaries, and restoring estuarine habitat directly, in addition to others (<http://www.treefrogresources.com/coastalmitigation/docs/papers.html>),

A key element in moving toward an ecosystem approach for coastal mitigation policy is the development of a reference-based, ecosystem approach for assessing the condition of coastal resources. This should be based on a functional approach that incorporates the best available science with quantitative output that could be used with a scoring mechanism to track resource condition over time. The channel-riparian condition assessment procedure (Rheinhardt et al. 2005) that EEP has applied to several coastal plain watersheds could serve as a model. Through the use of structural measures, this approach identified key components (processes) that control channel-riparian ecosystem functioning and then identified indicators that were sensitive to alterations of those components. Reference data from a range of stream reaches from least altered to most altered were used to develop a protocol to score the condition of the indicators relative the least altered reaches, and from those scores to estimate ecological condition. Scores from a randomly chosen set of reaches were then used to estimate the condition of an entire stream network. This information is available for use by NC-EEP in its restoration planning process.

An approach similar to the channel-riparian assessment approach could be used to develop coastal watershed assessment protocols. Although the channel and riparian zone were functionally interdependent, the two components differed enough that they were scored independently, thus enabling managers a practical means for diagnosing the source of problems. A similar approach could be used for components of coastal watersheds.

### **2.3.2 NOAA Coastal Ocean Program coastal habitat restoration guidelines.**

The National Oceanographic and Atmospheric Administration (NOAA) produced a 2-volume series on monitoring guidelines for coastal habitat restoration (Thayer et al. 2003, 2005). Volume 2 (Thayer et al. 2005) focused on major types of habitats that included some of the important habitats that occur in North Carolina estuaries, including oyster reef, shoreline, soft bottom, SAV, and marsh. Although this volume concentrated on restoration monitoring guidelines, some of the criteria identified for measuring success might be useful as indicators as part of a rapid assessment protocol when based on reference conditions in North Carolina. At the very least, information in this report could

be used to support the use of various indicators and provide a rationale for functional relationships.

### **3.0 Partitioning an estuarine segment into functional units**

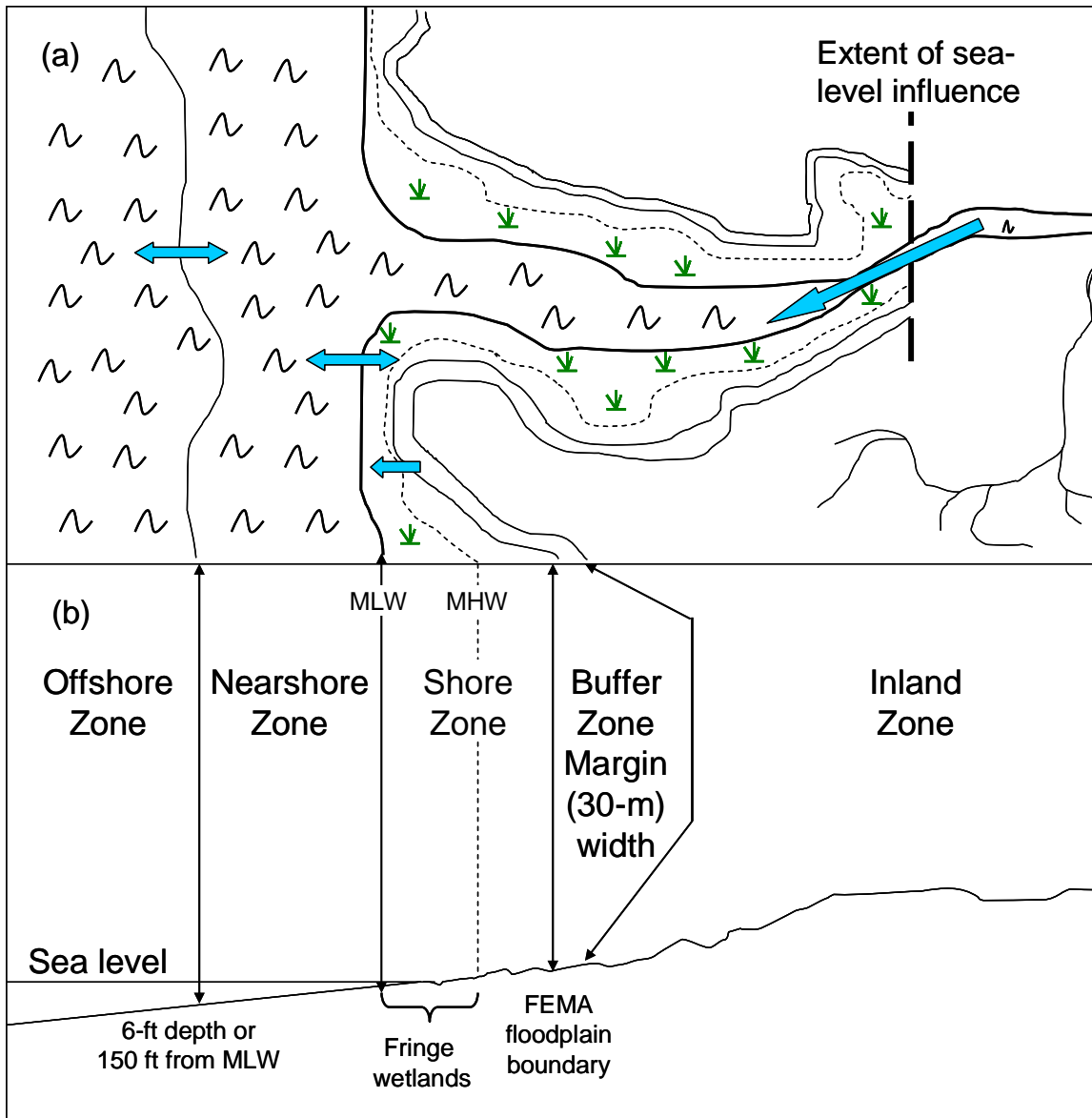
In this section we identify (1) the major functional units of coastal watersheds from which indicators could be derived and (2) a framework for developing a referenced-based assessment protocol that incorporates the wealth of information already being gathered by state agencies in mapping and inventorying coastal resources. For the purposes of developing a condition assessment, we build upon the small coastal watershed definition (i.e., the estuarine segment of Brooks et al. (2006)). The seaward boundary would terminate at the 6-ft (2 m) contour (relative to mean low water (MLW)) and thus would encompass the lower limit of most SAV beds, or 150 ft (50 m) offshore from the MLW contour, whichever is closest to shore. Nautical charts have all depths measured relative to MLW, so the 6-ft depth can be obtained from NOAA charts. Other defining factors, such as constricted openings of an embayment connected to a larger portion of an estuary, may be more useful than a 6-ft contour.

The condition of coastal watersheds is affected not only by the condition of their tributary streams, but also by factors originating in or near the estuary proper. To aid in developing an assessment protocol that can be used to evaluate the condition of resources in coastal watersheds, it would be useful to partition the estuarine segment into functional zones from which separate suites of indicators could be derived (Figure 3), analogous to the way channel and riparian zones were partitioned in stream reach assessments (Rheinhardt et al. 2005). This approach would be consistent with the “receptor habitat” concept.

Each estuarine zone possesses a different, but interdependent, set of functions. A distinct suite of indicators should be identified for each zone, which then could be used to evaluate the condition of each zone independently before combining as part of a coastal watershed assessment. Each of the zones shown in Figure 3 is discussed below, including an explanation of how each zone relates to estuarine functioning, typical human alterations to the zone, how it links (interfaces) with other zones, and how a relatively unaltered zone would look. Information from the above referenced protocol was used to help characterize the zones, their functions, and typical alterations to them.

#### **3.1 Offshore Zone**

The Offshore Zone (deep subtidal area) incorporates the mainstem, open water area of estuaries. It is located beyond the boundaries of the estuarine segment (>150 ft from MLW or >6-ft depth contour). This zone exchanges water and biota with the Nearshore Zone (see below). The condition of this zone is affected by the water quality of all the large and small watersheds that contribute to it. Sewage outfalls, stormwater outfalls, sediment plumes, toxic chemicals, and nonpoint pollution all mix in the estuary proper to cause shellfish closures, dieback of SAV (submerged aquatic vegetation) in the adjacent Nearshore Zones, and invasion of aggressive exotic species. None of the Offshore Zones in North Carolina is completely unaltered because they are affected by contributions from



**Figure 3. Functional zones of coastal watersheds: (a) plan and (b) cross-section views. The widths of the Nearshore and Shore Zones vary depending upon shoreline type and local bathymetry or elevation. The Offshore Zone extends offshore to the Nearshore Zone. The Nearshore Zone (subtidal) extends to a distance of 150 ft (50 m) beyond MLW (mean low water) or to the 6-ft (2-m) depth contour, whichever is closest to shore. The Shore Zone (intertidal to supratidal) extends from MLW to the FEMA 100-yr flood zone boundary (wetlands are within this zone). The Buffer Zone margin extends 100 ft (30 m) inland from the Shore Zone. The Inland Zone represents landuse patterns: its condition is reflected by the condition of the network of tributary streams that drain from the coastal watershed to sea level. The thick arrows depict where one zone affects the functioning of another zone.**

large watersheds. By definition, the Offshore Zone is not a part of the small coastal watershed (estuarine segment), but its condition does affect the condition of coastal watersheds. For example, sewage and stormwater outfalls from densely populated communities in an adjacent watershed could cause closure of shellfish beds in the estuarine segment even if the segment is otherwise in relatively good condition. Thus, an assessment of an estuarine segment should incorporate some evaluation of the condition of the estuary in which the segment is imbedded.

### **3.2 Nearshore Zone**

The Nearshore Zone (shallow, subtidal areas) is located shoreward of the Offshore Zone and is adjacent to the offshore side of the Shore Zone (see below). This zone is part of the estuarine segment (from MLW (mean low water) to the 6-ft depth contour or to a distance of 150 ft, whichever is closest to MLW). Submerged aquatic habitat occurs in this zone, including SAV beds, mudflats, and oyster reefs. In much of western Pamlico Sound where tides are negligible, intertidal mudflats and oyster reefs are virtually absent. The Nearshore Zone supplies abundant foraging, spawning, and nursery habitat for estuarine-dependent species (Scott-Denton 1999, Wyda et al. 2002, Street et al. 2005). The most common alterations to this zone are breakwaters, sills, piers, and wharves, damage by propellers, dredging, and placement of dredge spoil. The Nearshore Zone is linked to both the Shore Zone (see below) and the Offshore Zone by currents and movement of biota. The least altered Nearshore Zones would be those without any the above types of structures or damages.

### **3.3 Shore Zone**

The Shore Zone (intertidal to supratidal area) occurs between the MLW contour and the FEMA (Federal Emergency Management Agency) 100 year flood height. Variation in physical/environmental factors is most pronounced in this zone, ranging from intertidal mudflats, oyster beds, marshes, and swamps, to upland areas including the base of bluffs and high banks. This is the zone most responsible for dissipating storm surges. Many estuarine-dependent species utilize this zone as spawning and nursery areas. Estuarine wetlands in the Shore Zone are noted for their contributions to estuarine food webs (Boesch and Turner 1984). Human modifications are also most intense in this zone, which include revetments and seawalls constructed to protect property and infrastructure from erosion, bulkheads to increase waterfront lot sizes by placing fill behind them, groins to trap sand, and water-dependent infrastructure such as marinas, docks, and boat ramps. All of these alterations, and others, affect the integrity of the Shore Zone. The Shore Zone is linked to the condition of the Nearshore Zone via wind and lunar-driven tides and the exchange of biota. The least altered Shore Zones lack any man-made structures; they consist of only natural vegetation (swamp, marsh, forest) or substrate (mudflat, beach, oyster reef, etc.).

### **3.4 Buffer Zone Margin**

The most landward zone of the coastal margin is the Buffer Zone margin. When unaltered, this zone provides a buffer to the Shore Zone by protecting it from various non-forest land uses (human alterations) that occur in the Inland Zone (see below). The Buffer Zone margin extends 100 ft (30 m) inland from the most landward extent of the Shore Zone (i.e., 100 ft landward of the FEMA 100-yr flood zone) and interfaces most directly with the Inland Zone. One hundred feet was chosen as the width of the buffer margin because mature trees (approx. 100 ft tall) within the zone would have some chance of falling into the Shore Zone where they could potentially provide detritus and habitat structure for estuarine organisms. The least altered condition of the Buffer Zone would be old or mature forest.

### **3.5 Inland Zone**

This zone is located inland of the coastal margin. It is a part of an estuarine segment in that land use affects the condition of tributary streams that flow to the coast. Stormwater runoff to riparian zones, groundwater discharge to channels and riparian zones, and channelization of inland streams all contribute to the water quality of tributary streams. Dams, channelization, and removal of large down wood (LDW) in channels detrimentally impact anadromous fish by changing the timing, rate, and quality of water shunted to downstream estuaries. Tributary streams eventually discharge into the Nearshore Zone of the estuary at sea level. If all inland streams were adequately-buffered, unchannelized, and had no pollution from point sources, then watershed landuse would not detrimentally impact estuarine condition. However, most tributary streams have been altered to varying degrees and so contribute nutrients, sediments, and toxic chemicals to the estuary via freshwater tributaries. Excess nutrients and sediments in estuaries lead to eutrophication and increased turbidity, which in turn cause algal blooms, loss of SAV beds, and closure of shellfish beds. Toxic chemicals directly or indirectly (through biomagnification) stress aquatic organisms and increase mortality (Comeleo et al. 1996).

## **4.0 Design of a reference-based approach to estimate ecological condition**

The ecological condition of each of the zones in Figure 3 can range from unaltered to severely along the same scale that was developed for the channel-riparian assessment of Rheinhardt et al. (2005). For example, a shoreline type (Table 1) that has a Shorezone dominated by cypress fringe, commonly found in the Albemarle Sound, may be altered by construction of a bulkhead and backfilling the wetlands. The result is elimination of the wetland behind the bulkhead and the loss of its associated functions. This would result in a severely altered condition. The area in front of the bulkhead, as part of the Nearshore Zone, would still retain some of its functioning, but may be degraded due to the erosive environment caused by reflective waves from the bulkhead. In this latter case, habitat of the Nearshore Zone is less likely to support SAVs and would eliminate the exchange of water between the Nearshore Zone swamp forest of the former Shore Zone environment. The loss of SAVs would be a degradation of habitat functioning and loss of water exchange may have biogeochemical consequences. Less severe alterations, such as

cutting the cypress fringe, would have serious consequences for habitat, but probably would have minimal effects on hydrologic functions, as long as the forest were allowed to re-establish.

Table 6 lists a number of alterations that may be applicable to one or more of the zones of Figure 3. At the same time, the alterations can be related to effects on major functional categories, i.e., hydrologic, biogeochemical, and habitat. Similar approaches have been used as a basis for estimating compensatory mitigation requirements and for tracking mitigation success. The EEP protocol for estimating headwater channel-riparian ecosystem condition used such a functional approach. An equivalent program for compensating for impacts to coastal resources could be developed, first by assessing the effects of alterations on functions in each of the zones described above, and then aggregating scores by estuarine segment and/or coastal watershed.

Rapid assessment approaches require the use of indicators to evaluate condition relative to some benchmark, ideally an unaltered or relatively unaltered standard (Brinson and Rheinhardt 1996). Since an estuarine segment can be partitioned into several functionally different, but interdependent components (zones), indicators can be identified that allow a ranking of the condition for each component. A series of in-depth study would be needed to identify the usefulness of these indicators and identify others. Indicators would also have to be calibrated against reference standard conditions and arranged along a gradient of degrees of alteration. The paragraphs below identify some examples of potential indicators of condition for each of the estuarine zones previously identified.

For the Offshore Zone, indicators for determining the ecological condition would likely be related to water quality constituents in the mainstem estuary and the proximity of development in nearby watersheds. The Offshore Zone is not a part of an estuarine segment, but its condition may affect it. For example, in the Lockwoods Folly basin, dense residential and commercial development on the barrier islands is an important factor related to shellfish closures in the estuary. Stormwater runoff from barrier island towns such as Long Beach and Holden Beach flowing to the backside of the islands detrimentally affect water quality. Thus, any indicators of offshore condition must take into account factors in the estuary that occur outside the estuarine segment under consideration.

For the Nearshore Zone, indicators that evaluate the condition of subtidal habitats, such as oyster reefs and SAV beds, would be useful. Maps of the Strategic Habitat Areas, Primary Nursery Areas, and other designated uses would provide Level 1 information (without a field visit). Field surveys of alterations such as breakwaters, jetties, and groins should be conducted.

For the Shore Zone, there a number of anthropogenic alterations are commonplace. Databases on shoreline condition, shoreline surveys, and remotely sensed images are potential sources of data.

**Table 6. Common alterations partitioned by their effects on functions. Modifications commonly affect more than one function. Most of these modifications are to the Nearshore, Shore, and Buffer Zones.**

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**Hydrologic functions (modifications that alter the ability of the shoreline to trap sediments)**

- Cutting of living cypress trees (loss of knees that baffle currents)
- Removal of large down wood (LDW) and wrack
- Removal of trees along bank (eliminates the main source for LDW)
- Construction of a bulkhead or revetment along the shoreline
- Construction of groins up current
- Excavation to construct navigation channels or mosquito ditching
- Diking to retain water (e.g., for rice cultivation)

**Biogeochemical alterations**

- Removal of wrack
- Removal of LDW
- Filling of wetlands or benthos
- Removal or cutting of wetland vegetation
- Diking to retain water (e.g., for rice cultivation)

**Habitat alterations**

- Mowing submerged aquatic vegetation (SAV)
- Thinning or clearing of understory along shoreline
- Cutting or removal of trees or snags onshore and offshore
- Removal of LDW onshore and offshore
- Filling of wetlands or benthos
- Excavation to construct navigation channels or mosquito ditching
- Diking to retain water (e.g., for rice cultivation)

**Modifications to upland buffer**

- Impervious surface
  - Rowcrop
  - Managed lawn
  - Fallow field
  - Man-made structure (pier, deck, building)
- 

For the Buffer Zone margin, recent aerial photographs may be the most effective way to determine condition because of the difficulty in accessing sites from a boat, walking shorelines, or having road access to make observations. Land use / land cover could be ranked by intensity of alteration, similar to the scale devised by Brown and Vivas (2005). For the Offshore Zone, indicators for determining the ecological condition would likely be related to water quality constituents in the mainstem estuary and the proximity of development in nearby watersheds. The Offshore Zone is not a part of an estuarine segment, but its condition may affect it. For example, in the Lockwoods Folly basin,

dense residential and commercial development on the barrier islands is an important factor related to shellfish closures in the estuary. Stormwater runoff from barrier island towns such as Long Beach and Holden Beach flowing to the backside of the islands detrimentally affect water quality. Thus, any indicators of offshore condition must take into account factors in the estuary that occur outside the estuarine segment.

For the Inland Zone, it is reasonable to assume the channel-riparian protocols developed for assessing the condition of inland riparian ecosystems would be also useful for assessing inland stream networks of coastal watersheds. The protocols were not calibrated for the sea level reaches of rivers, however, so as part of the Shore Zone, development of a reference set would be necessary as a framework to estimate condition. In the Lockwoods Folly coastal watershed, tidal portions of rivers (the Shore Zone) were separated from the inland network because the indicators were not calibrated for tidal swamps. However, channel-riparian protocols conducted in the upstream, nontidal reaches were shown to be adequate for assessing stream networks in Lockwoods Folly, suggesting that aggregated scores for inland stream networks could be used as indicators of condition for inland zones of coastal watersheds.

## **5.0 Summary and Recommendations**

Developing a reference-based assessment approach for coastal watersheds will require a preliminary research-level effort to identify appropriate indicators and to determine the relationships between the indicators and ecosystem condition. Calibration of indicators should be based on the range of conditions caused by the types of alterations common to the region (Table 6). Many of the studies described in this document can be used to provide a source of data that could be useful in developing indicators and the scientific rationale for choosing functionally-based indicators.

Scoring of indicators could be designed to range between zero (worst condition) to 100 (best condition) to make it compatible with the EEP channel-riparian assessment format already in use. Assessing functional units by zones would enable resource managers to diagnose the source of problems, identify restoration needs, measure the effectiveness of restoration efforts, and better communicate management decisions with stakeholders. Scores aggregated by watershed could be used to quantitatively evaluate watershed condition, develop watershed plans, and track the effectiveness of watershed-wide planning efforts. Ultimately, the results could contribute to the scorecard concept proposed by the North Carolina Habitat Priorities Advisory Committee.

Here we summarize how we addressed each of the subtasks in Task 3 under contract D06025 and provide answers to questions raised by EEP reviewers.

### **Task 3: Summarize available data useful for assessing coastal watersheds**

**Subtask (a). Field test the VIMS CCI shoreline development index to determine which components might be usefully incorporated into a coastal watershed assessment protocol.**

We determined that the VIMS CCI index is not sufficient for assessing nearshore and shore zone conditions the way that it is currently framed. Although all of the VIMS CCI inventory categories have relevance for reference-based assessments, they contain a mix of potentially natural features (forested, etc.) and modifications (dock, ramp, etc.). Therefore, the categories are not consistent with a reference-based approach. Further, the categories related to modifications have not been ranked in terms of their degree of alteration. However, the shoreline stabilization categories (bulkhead, etc.) could be examined in terms of their effects on ecological condition and ranked using the rationale as described in the NC CRC Shoreline Stabilization Subcommittee report (NC-DCM (2006); Section 2.2.3 above).

The method that VIMS CCI uses for transferring field data to a GIS platform is an efficient way to reconcile indicators observed in the field with remote sensing. This would consist of using recent, high resolution aerial photographs as the mapping platform (1999 DOQQ images are too out-of-date, although the resolution is probably adequate). The images would supplement what could not be observed inland during a field survey from a boat. The information could be incorporated as part of the mapping developed for the SHA designation process, and would be mutually beneficial to both the DMF-SHA and a protocol developed for EEP in assessing small coastal watersheds. The collection of field data from a small boat could be supplemented with a determination of shoreline type (Riggs and Ames as reported in NC-DCM 2006) as a way of understanding the degree of alteration, thus lending itself to a more reference-based gradient of alteration. In short, we recommend that a VIMS CCI-like data management approach be examined for its application to the database management of the SHA effort.

**Subtask (b). Provide a classification system for estuarine watersheds based on geomorphic and landscape characteristics that could be used to stratify coastal watersheds for developing a watershed reference set.**

Given the natural variation in estuarine habitat, ranging from tidal to non-tidal, from fresh to nearly full strength seawater, and from exposed to protected shoreline, we recommend that small coastal watersheds be stratified, as necessary, according to these sources of variation. The purposed of such an effort would be to partition natural variation in a way that allows an ecological assessment method to be more sensitive to variation caused by human activities.

The SHA approach (Deaton et al. 2006) has adopted a fairly broad classification that would likely be adequate for developing distinct reference sets. These are the Northern Region (non-tidal Albemarle Sound and tributaries), western Pamlico Sound (nontidal Neuse and Pamlico River estuaries), eastern Pamlico Sound (high salinity, extensive SAV beds, back-barrier marshes, inlets), and the southeastern estuaries (Core Sound and southward) affected by astronomic tides. The Cape Fear River and its extensive freshwater tidal wetlands should be treated separately from those just listed. Such stratification would in large measure control for variables of salinity, tide, and fetch.

Within each of these geographic regions, unaltered shoreline type (Tables 1 or 5) would be identified and partitioned according to zones in Figure 3. The feasibility of these alternatives needs to be field-tested before evaluations are made on the degree of alteration.

**Subtask (c). Provide a synopsis on pertinent NC data sets that could be incorporated into indicator development for coastal catchments.**

A decision has to be made on whether EEP finds useful both Level-1 (no field visits) and Level-2 assessments. Using the SHA effort as a baseline and working toward a Level-1 assessment, the data would have to be transformed to accommodate a watershed perspective (“looking upstream”) rather than an estuarine habitat resource perspective (“looking downstream”), the latter being the current SHA approach. The advantage of using SHA data as the primary source is that same information could be used for both approaches, but in different ways. The largest point of departure between the two approaches is the scaling of variables. If the zonation approach of Figure 3 is used for small watershed assessments, a small coastal watershed assessment would not focus on a specific SHA resource (SAVs, oyster reefs, etc.) in the estuary, but would target assessment zones irrespective of particular SHA habitats. This level of data synthesis and evaluation would be equivalent to a Preliminary Watershed Assessments conducted by EEP.

A Level-2 assessment, as outlined in Section 4.0, would require fieldwork on both land and water. In brief, this would consist of (1) a channel-riparian zone assessment of ecological condition of the watershed, using randomized sampling points as an indication of upland (and stream) quality, (2) a shoreline survey, in combination with remote sensing, to evaluate the condition of the Nearshore Zone and the Shore Zone. Because the channel-riparian protocol has not been designed to assess the Buffer Zone downstream from sea level influence (Figure 3), the approach may have to rely on a combination of remote sensing and a boat survey. Details of this need to be worked out with a series of field trials. The Nearshore Zone and the Shore Zone would be evaluated while conducting the boat survey. Condition of the Offshore Zone would rely on water quality data sets for the biogeographic regions identified for the SHA approach (Deaton et al. 2006).

**Subtask (d). (1) Provide an outline on how to best approach developing a protocol that could be used for assessing coastal watersheds. (2) Identify potential indicators for tidal forested reaches and estuarine shorelines. (3) Provide a potential framework for an assessment protocol for estuarine shoreline condition. (4) Provide a summary of research needs for identifying and calibrating coastal indicators.**

**Items 1 and 3: Protocol for assessing coastal watersheds and a framework for assessing shoreline condition.**

- a) Identify the coastal watershed to be assessed for ecological condition
  - 1) Delineate watershed using the best available elevation data; where ditches cross interstream divides, field visits are recommended.

- 2) Ensure that the watershed contains one perennial stream (3<sup>rd</sup> order or higher or equivalent flow or catchment).
- 3) In outer coastal plain east of Suffolk Scarp where natural channels are scarce, ditches and canals have replaced natural drainages. At this time, we do not have recommendations on how to identify small watersheds in this region.
- b) Office preparation (essentially a Level-1 assessment)
  - 1) Acquire DMF data layers developed for SHAs, NCCREWS attributes, bathymetry, etc.
  - 2) Reconfigure the data layers so they conform to watershed assessment, rather than the strictly SHA-oriented approach (e.g., a MARXAM run would not be necessary).
  - 3) Calculate impervious surface, alteration of wetlands, land use/land covers, etc. in a way that feeds into the indicators of both Level-1 and Level-2 assessments.
  - 4) Write a brief report equivalent to a Preliminary Watershed Plan for EEP, but with emphasis on documentation rather than analysis.
- c) Conduct the terrestrial portion of the assessment in the field
  - 1) Identify the downstream boundary of sea level control.
  - 2) Use the channel-riparian protocol to select and evaluate randomly chosen sites at a density equivalent to earlier surveys (protocol for ‘streams’ in the tidewater region east of the Suffolk Scarp may require substantial modification; we recommend a research-level effort to work out the kinks).
- d) Conduct the aquatic/wetland portion of the assessment that is under sea level influence
  - 1) From the terrestrial side, gain access to sites to verify land uses of buffer zone margin from aerial photographs (may be conducted simultaneously with the channel-riparian work, with sites chosen randomly, if feasible).
  - 2) From the aquatic side, survey the shore to evaluate indicators of alterations of the Nearshore and Shore Zones.
- e) Aggregate indicator information into three master ecosystem functions: hydrologic, biogeochemical, and habitat. Assess the condition of the small watershed to yield a summary score for the terrestrial part (from channel-riparian work), and a summary score for each of the coastal aquatic/wetland zones.
- f) Identify subwatersheds at a scale consistent with coordinated restoration activities.
  - 1) Use indicators to identify hotspots of degradation of ecosystem functions for both terrestrial and aquatic components.
  - 2) Calculate ecological conditions for each component using three scenarios: current conditions, reference standard condition (to have a reference point for estimating degree of degradation), and “built-out” condition based on current zoning maps.

**Item 2. Identify potential indicators for tidal forested reaches and estuarine shorelines.**

Tidal or sea-level controlled forests are exposed to some of the same anthropogenic stresses as other estuarine ecosystems (Table 6), but alterations that specifically affect forest growth and regeneration also affect functioning. Alterations such as timber harvesting, upriver impoundments, sediment and nutrient loading, ditching, and regional

groundwater withdrawal (causing local subsidence) are particularly stressful for tidal swamps (Table 7).

**Table 7. Potential metrics and associated functions for tidal freshwater swamps. Details for measuring and calibrating would need to be determined from studies of reference sites.**

<i>Function</i>	<i>Sub-functions</i>	<i>Condition metric</i>
Hydrologic regime	Energy dissipation Hydrologic fluctuations Surface water storage Subsurface water storage	Shoreline modification Drainage ditches Fill in microtopography Soil compaction
Biogeochemistry	Nutrient cycling Biogeochemical transformations Salinity regime	Contaminants, Living & detrital biomass Upstream impoundments and channel dredging
Plant and animal habitat	Mixture of light regimes controlling microhabitats for plants Spawning, nursery, & foraging habitat for aquatic and terrestrial animals	Species composition and richness for plants, leaf area index (LAI) Animal species composition, trophic structure Obstructions to passage (tide gates, culverts, etc.)

**Item 4. Provide a summary of research needs for identifying and calibrating coastal indicators.**

1. Establish reference sets and sites for a range of shore types, including freshwater tidal wetlands. A pilot study could be conducted with all shoreline types in one or two of the five biogeographic regions identified in the SHA approach (Deaton et al. 2006). For example, reference sets for Western Pamlico Sound and Cape Fear estuaries could be used as a test case for developing a functional assessment framework.
2. Develop protocols for delineating watersheds east of the Suffolk Scarp where natural streams are rare or so severely altered by ditching that it is difficult to determine where natural streams or sloughs originally occurred.

3. Develop a complete list of indicators for tidal swamps. A preliminary list of potential indicators was provided in Table 7, but more in-depth study is need in tidal freshwater portions.
4. Develop and scale indicators for each of the zones. A series of in-depth studies would be needed to identify the usefulness of the potential indicators identified in this report (Tables 2, 3, and 6) and to identify others. Indicators would also have to be calibrated against reference standard conditions and arranged along a gradient of degrees of alteration for each zone.
5. Validate this Level-2, rapid assessment using Level-3 methods of King et al. (2005) and Bilkovic et al. (2005), where appropriate.
6. Conduct training and field-testing at a pilot-study scale, similar to those previously conducted in the Little Contentnea and other inner coastal plain watersheds. This would initially be restricted to the watersheds where we establish reference data sets, but could be expanded (with appropriate testing) to other watersheds and biogeographic coastal regions in North Carolina (Deaton et al. 2006).

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