1. Introduction

Marine coastal habitats have been identified as some of the most vitally important on Earth. Their high productivity and high biodiversity make them valuable areas for human food production, carbon sequestration, nutrient and contaminant retention and processing, and species conservation (Duarte et al. 2009). Many of the ecosystem services provided by coastal habitats represent greater contributions than might be surmised from their mere physical extent. For example, these relatively sheltered, highly productive areas such as salt marshes and tidal creeks are important nursery and transient habitats for many species that spend most of their lives in other areas. As transition zones between land and water, coastal habitats often help to stabilize sediments and protect coastlines from wave energy while also providing accessible food resources, aesthetic views and recreational opportunities. All of these characteristics help to create jobs as people seek to live, work, and play in coastal areas (NOAA 2009).

The Georgia coast includes several important habitat types. An almost continuous chain of barrier islands separates the nearshore coastal waters from the open waters of the Atlantic Ocean. Between the islands and the mainland the high tidal amplitude interacts with the low slope of the land to create extensive intertidal zones. These areas are protected but subject to periods of inundation by salt water, which creates conditions suitable for several species of marsh grass such as *Spartina alterniflora*. The combination of these physical conditions on the Georgia coast supports one third of the total area of tidal marsh on the U.S. east coast (Wiegert and Freeman, 1990). Between the barrier islands, several medium to large rivers empty into semi-protected sounds. These riverine estuaries provide areas of more variable salinity where fresh water, nutrients, sediments, and sometimes contaminants are delivered to the coastal zone from the land. Tidal creeks allow for bidirectional flow between the highly productive marshes and the riverine estuaries and more saline lagoons, while the inlets between the islands provide connections to the open ocean. The seaward sides of the barrier islands are subject to higher wave energy, higher salinities, and generally lower nutrient concentrations than the landward side. The beaches are popular recreational areas and also provide important nesting habitat for sea turtles and shorebirds. Georgia’s coastal waters are home to commercially and recreationally important species such as fish, shrimp, crabs and oysters as well as the smaller organisms on which they feed. They are also important areas for nutrient cycling and the treatment of waste and runoff.

The desirable characteristics of coastal areas have spurred increasing levels of human development near coasts, and increasing nutrient input is a prime concern for coastal systems worldwide (Bricker et al. 1999; Howarth et al. 2000; NRC 2000). Excess inputs of nitrogen and phosphorus can lead to eutrophication, or the accelerated production of organic matter. The classic pathway of eutrophication occurs when nutrients stimulate phytoplankton growth (and hence accelerate the production of organic matter). As this organic material gets consumed or dies, it sinks to the bottom where it is decomposed by microbes. The decomposition process uses up oxygen via respiration; hence, enhanced decomposition can result in a reduction of the oxygen concentrations (hypoxia) in bottom water. The consequences of hypoxia can include death of benthic organisms, fish kills, reduced growth and reproduction, physiologic stress, forced migration, reduction of spawning grounds and nursery habitats, increased vulnerability to predation, and disruption of life cycles. Diaz and Rosenberg (2008) called decreasing dissolved oxygen levels the most serious threat from eutrophication in coastal areas and noted that dead zones have now been reported from more than 400 marine ecosystems. Other potential impacts of eutrophication include the stimulation of nuisance and toxic algal blooms, increases in turbidity, losses of submerged aquatic vegetation, and changes in the food web (Howarth 1988; Rabalais 2002).

Georgia does not have submerged aquatic vegetation and has not had serious problems with harmful algae. The most compelling evidence for eutrophication in Georgia comes from the long-term (10-19 yr) studies of Peter Verity (Verity 2002 a,b; Verity et al. 2006; Verity and Borkman 2010), who documented increasing levels of nutrients (ammonium, nitrate, dissolved organic nitrogen, orthophosphate and silica) in the Skidaway River estuary, as well as changes in response variables (increases in chlorophyll *a*,

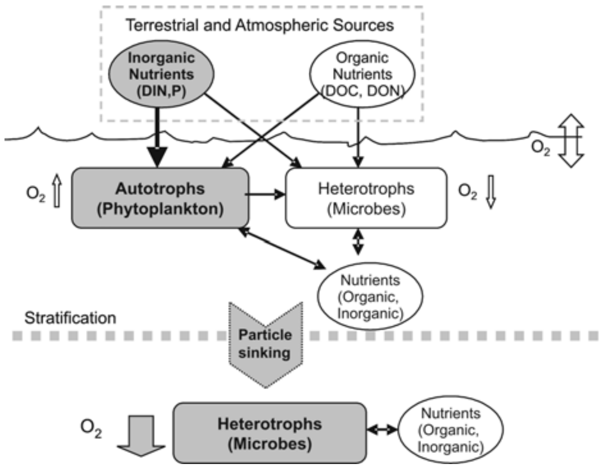

Figure 1-1. Pathways of eutrophication. (left) The classic pathway, wherein inorganic nutrients fuel phytoplankton production, which then sinks to the bottom in a stratified water column where it is consumed by microbes, leading to decreased oxygen concentrations in bottom water. (right) An alternative pathway, wherein organic nutrients fuel microbial activity, which leads to decreased oxygen concentrations throughout a well-mixed water column. Modified from Verity et al. 2006.

particulate organic carbon and nitrogen, and bacteria concentrations; decreases in dissolved oxygen; and changes in plankton community composition). Verity et al. (2006) proposed an alternative pathway for eutrophication in these waters, wherein excess nutrients stimulate microbial respiration directly (Figure 1-1). Although both pathways lead to low oxygen, there are important differences between them: phytoplankton are involved in the classic pathway but are bypassed in the alternative; it is generally inorganic nutrients that fuel phytoplankton growth and organic nutrients that fuel microbes; the classic pathway occurs in stratified water, such that the reduction in dissolved oxygen is in the bottom, whereas in the Skidaway River low dissolved oxygen is observed in well-mixed water. Verity's data suggest that both of these pathways may be occurring at this site, as there have been increases in both inorganic and organic nutrient concentrations and both phytoplankton and microbe concentrations over time.

In response to concerns over eutrophication and its consequences, there have been several national-level efforts to assess the status of U.S. coastal waters. The National Estuarine Eutrophication Assessments (NEEA) found that approximately two-thirds of the U.S. estuaries for which data were available exhibited moderate to high expressions of eutrophic conditions, with most estuaries being highly influenced by human-related activities (Bricker et al. 1999, 2007). Georgia estuaries included in these studies rated low to moderate in eutrophic conditions, but the criteria were not always appropriate (e.g. the status of sea grass is irrelevant because sea grasses are not found in Georgia waters). The National Coastal Condition Reports (NCCR) have consistently rated water quality in continental U.S. estuaries as "fair" overall, while the southeast as a whole has been rated on the high side of "fair" (U.S. EPA 2001a, 2004, 2008). Assessments for individual states are not generally provided, but a report by GA DNR CRD using data collected for the U.S. EPA National Coastal Assessment program classified 80% of Georgia estuarine waters as having "fair" water quality, 18% as "poor", and only 1% as "good" based on the NCCR indicators (Guadagnoli et al. 2005).

The U.S. EPA's water quality regulations require States to develop quantifiable targets for nutrients in order to ensure that waters meet their designated uses. The EPA is currently working with the States to establish numeric nutrient water quality standards for U.S. waters. (Georgia's criteria will be developed and adopted under agreement with EPA in 2014.) Current national guidance calls for criteria that address nutrient pollution in terms of both causal (nutrients) and response variables (chlorophyll, transparency) (Grumbles 2007). The EPA also points out the value of monitoring water quality, saying "we can't effectively manage what we can't measure" (Grumbles 2007).

The Coastal Resources Division (CRD) of the Georgia Dept. of Natural Resources (GA DNR) has collected water quality data for over 30 years in support of a variety of programs (i.e. Shellfish Sanitation, Nutrient Monitoring, and Beach Water Quality). These programs have been in existence for varying amounts of time, have sampled in different locations, and have measured different water and resource quality parameters in order to meet the goals of a diverse array of programs. Parameters measured include fecal bacteria, temperature, salinity, dissolved oxygen, nitrogen, phosphorus, and pH. These data have not previously been integrated or analyzed in a common framework. They also have not been evaluated with the goal of identifying those measurements that might be useful indicators of the status of Georgia coastal waters. Ideal water quality indicators are parameters that are sensitive to change, are well-correlated with status, and are readily measured.

This project had two main objectives: 1) to compile coastal water quality data collected by GA DNR CRD into an integrated database and analyze it for long-term and seasonal trends, and 2) to identify an appropriate suite of indicator parameters for Georgia waters. The following sections of this report address these objectives: Section 2 is a summary of the CRD data sets and a description of the database that we developed to evaluate them; Section 3 presents maps of the CRD data along with an analysis of temporal and spatial trends; Section 4 describes correlations among the measured parameters; Section 5 provides the rationale and criteria for the indicators we propose for Georgia coastal waters; Section 6 provides initial information on the status of Georgia waters with respect to these indicators; and Section 7 provides recommendations for improving the CRD monitoring programs in the future.