Vegetated Buffers in the Coastal Zone
Prepared for GA DNR – Coastal Resources Division

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Introduction

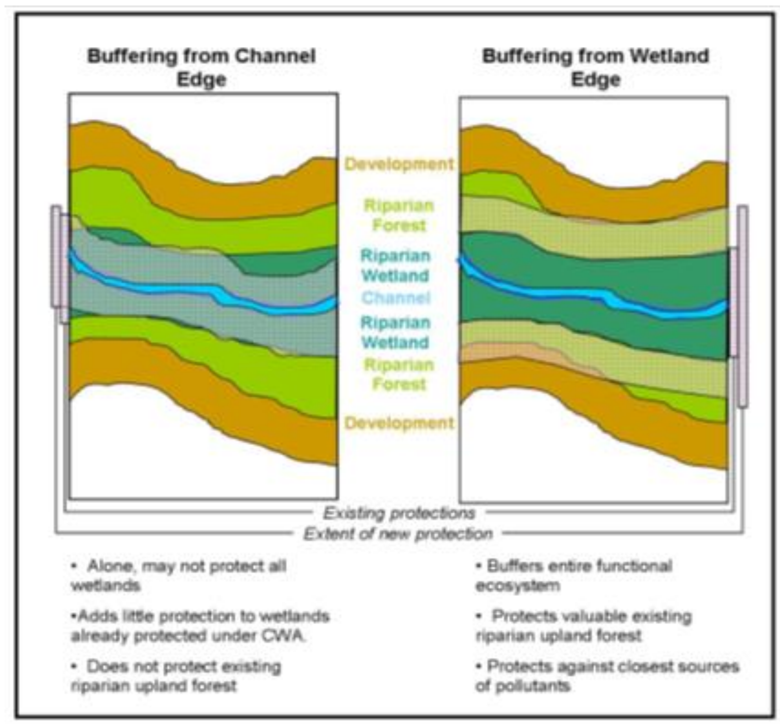

Figure 1. The effect of buffering from channel or wetland edge in riparian areas. CWA = federal Clean Water Act. Reproduced from Bason (2008) their Figure 7.

Vegetated buffers are continuous areas of vegetation bordering streams or wetlands, separating them from surrounding land uses. Riparian buffers, which may be vegetated, are adjacent to water bodies such as creeks and streams. For the purposes of this report, we distinguish riparian buffers from “wetland buffers”, which we use to refer specifically to vegetated buffers that are adjacent to wetlands. Wetland buffers are measured from the upland/wetland boundary as opposed to the edge of the water body (Fig. 1). Establishing a buffer from this location helps to eliminate potential pollutants from entering wetlands and also protects them from development impacts such as filling, grading, and sediment runoff (Bason 2008).

Wetland buffers are managed for the primary purposes of: “(1)sustainable removal and retention of excess nutrients entering wetlands; (2) protecting wetlands against encroachment and physical alterations; and (3) allowing wetlands themselves to maximize their own capacity to ameliorate pollution” (Bason 2008). In 2005, the Georgia Coastal Research Council prepared a report for the Coastal Resources Division of Georgia DNR that described research on vegetated buffers, with a focus on the coastal zone. Although there had been many studies conducted on buffers, most of this activity was focused on riparian buffers adjacent to streams. In addition to reviewing existing information on riparian buffers, GCRC's previous report also described studies that evaluated runoff to coastal systems. Since that time, there has been additional research on these topics including a few reports that address the use of buffers adjacent to wetlands. However, there have still been no studies that we are aware of that have directly evaluated the use of buffers adjacent to tidal wetlands such as salt marshes.

This updated report contains a summary of recent research on wetland buffers that is relevant to estuarine ecosystems. Part One describes the functions of vegetated buffers adjacent to wetlands. Part Two provides updated information on studies conducted on vegetated buffers (primarily riparian buffers) related to water quality maintenance and habitat protection. These areas are relevant to this report because the manner in which buffers protect and maintain these functions is similar whether the buffers are adjacent to streams or wetlands. Part Two also presents recent research about marsh migration and the role wetland buffers could play in protecting marsh functions. Part Three summarizes new research on the effect of upland land use on coastal systems, which suggests that intertidal marshes alone are not necessarily sufficient to protect water quality. Part Four discusses examples of the application of wetland buffers in other states. At the end of the document are conclusions and a bibliography.

Part One – Functions of Vegetated Buffers Adjacent to Wetlands

Wetland buffers maintain and protect the porous vegetated connections between wetlands and upland areas while preserving wetland ecological functions. In addition to protecting wetlands, these buffers perform many of the same beneficial services as the wetland itself. In marshes, this includes: slowing and spreading out stormwater runoff; filtering sediment, nutrients and pollutants; stabilizing the shoreline and preventing erosion; providing wildlife habitat; and moderating flooding from storm surges. Buffers adjacent to tidal marshes also provide potential migration space for areas affected by sea level rise (i.e., coastal squeeze) (Adamus 2007, Bason 2008).

Water quality protection

Improving and maintaining water quality is one of the most important functions of wetland buffers. Where a vegetated buffer adjoins a wetland, it provides an opportunity for the buffer to filter out any pollutants it receives, thus reducing the odds that the wetland itself will become a source of pollution. Vegetated buffers protect and maintain the water quality of adjacent wetlands by removing sediment, nutrients, toxic substances, and pathogens from incoming runoff (Adamus 2007). Removal efficiency is affected by a variety of physical characteristics of the buffer. For example, buffers with moderately coarse soils and shallow slopes slow down water flow, allowing time and space for runoff to infiltrate and move through the soil rather than remain on the surface. Buffer vegetation (particularly the root zone), the soil itself, and their associated microorganisms can all remove contaminants from runoff before it passes into the adjacent wetland (Adamus 2007, Sheldon et al. 2005).

Habitat protection

Wetland buffers protect and preserve wildlife habitat by providing an ecological transition area between upland and wetland habitats. This can include critical habitat (e.g., breeding and nesting sites) necessary for many wildlife species that also use and/or require wetlands. For example, forested wetland buffers are a source of woody debris and organic matter that act as a food source and moderate the water temperature of adjacent wetlands, thus supporting temperature sensitive species such as fish and amphibians (Sheldon et al. 2005). The intrusion of noise, light, domestic animal predators such as cats and dogs as well as direct human disturbance can have a significant adverse impact on wildlife use of wetlands, including disruption in the feeding, sleeping, and reproductive habits of certain species (McMillan 2000).

Marsh migration space

Salt marshes are extremely productive intertidal wetland habitats that provide many ecosystem functions, including storm surge attenuation, organic carbon storage, water filtration, habitat provisioning and the support of landscape biodiversity. They also provide food and nursery grounds for a variety of organisms including oysters, crabs, shrimp and fish (Fig. 2). Regulations that are in place to protect marshes also serve to protect and preserve these functions. However, marshes are affected by sea level rise. The additional flooding caused by an increase in sea level can drown the vegetation at the seaward edge, converting it to open water. At the same time, the higher water level floods additional areas that were formerly high ground. If there are no barriers (e.g. sea walls), the upland edge converts to marsh vegetation and the entire area moves inland. If there is no area available for this migration to occur the marsh is lost due to a decrease in the intertidal area, a phenomenon known as "coastal squeeze". Coastal marshes are particularly susceptible to this loss because they have gradual slopes, so a small change in the vertical dimension due to sea level rise translates to a relatively larger change in the horizontal dimension.

Figure 2.Ecosystem services provided by salt marshes
Source: Kate Wade, Coastal Biodiversity & Ecosystem Service Sustainability**;** synergy.st-andrews.ac.uk

Part Two – Recent Research on the Effectiveness of Buffers

In our literature search we found very few papers focused on wetland buffers and none on wetland buffers in tidal areas. However, we did find several recent reviews of studies relevant to vegetated buffers. Although the location of the studies included in these reviews was not always specified, we assume they were generally conducted on riparian rather than wetland buffers. As indicated above, the manner in which buffers protect and maintain water quality and habitat functions is similar whether the buffers are adjacent to streams or wetlands. These studies are therefore summarized here as an update to our earlier report.

Water quality protection

Buffer effectiveness is influenced by a variety of factors including buffer width, soil characteristics, and vegetation type. Below we summarize the findings from three meta-analyses. Mayer et al. (2007) conducted a literature review of 45 papers that evaluated a total of 89 buffer sites. Bason (2008) analyzed the results from 17 studies of Atlantic coastal plain buffers, including a subset of the papers included in Mayer et al. (2007). The meta-analysis by Zhang et al. (2010) was specifically focused on riparian buffers in agricultural settings and synthesized data from 73 studies.

Width

Width is a key factor that is evaluated when determining buffer effectiveness at protecting water quality. A wide buffer provides more space and time for nutrients (i.e., nitrogen, phosphorus) and contaminants (i.e., sediments, pesticides) from runoff to be captured. There is not one optimal width for a wetland buffer. Instead, widths are dependent on specific buffer functions along with local conditions such as topography (Adamus 2007). For example, a report prepared by the Environmental Law Institute recommends general buffer widths ranging from 100 to 1000 ft for wildlife habitat protection; 30 to 100 ft for sediment removal; 100 to 180 ft for nitrogen removal, and 30 to 100 ft for phosphorus removal (McElfish et al. 2008). In contrast, McMillan (2000) concluded that an appropriate riparian buffer to maintain wildlife habitat functions for all but the most highly degraded wetlands would be comprised of native tree and/or shrub vegetation and range from 100 to 330 ft.

The studies described below look at how a specific variable (i.e., soil) affects the amount of width needed to achieve a desired buffer function. For example, Mayer et al. (2007) sorted the 89 buffer sites included in his review by width, water flow path, and vegetation type (Table 1). He then analyzed how each of these variables affected the efficacy of the buffer by measuring nitrogen removal.

Table 1.Percent effectiveness of riparian buffers at removing nitrogen. Buffer widths necessary to achieve a given present effectiveness (50%, 75%, 90%) are approximate values predicted by the nonlinear model, $y = ax^b$. Effectiveness was not predicted (np) for models withR^2Values<0.2 except for “all studies” model.
[Adapted from Table 1 by Mayer et al. (2007)]

Buffer variable		**Number of studies analyzed**	**Mean nitrogen removal effectiveness (%)**	**R^2**	**Approximate buffer width (meters) by predicted effectiveness**		
					50%	**75%**	**90%**
All studies		88	67.5 ± 4.0	0.09	4	49	149
Width (meters)	0-25	45	57.9 ± 6.0	0.01	np	np	np
	26-50	24	71.4 ± 7.8	0.00	np	np	np
	>50	19	85.2 ± 4.8	0.03	np	np	np
Flow path	Surface	23	41.6 ± 7.1	0.21	27	81	131
	Subsurface	65	76.7 ± 4.3	0.02	np	np	np
Vegetation type	Forest	31	72.2 ± 6.9	0.04	np	np	np
	Forested wetland	7	85.0 ± 5.2	0.00	np	np	np
	Wetland	7	72.3 ± 11.9	0.01	np	np	np
	Grass	32	54.0 ± 7.3	0.21	17	51	84
	Grass/Forest	11	79.5 ± 7.3	0.39	3	18	44

Below are the findings from the three meta-analyses described above with respect to removal of nitrogen, phosphorus, sediment, and pesticides.

- Nitrogen removal
  - Mayer et al. (2007) found that a small but significant proportion of nitrogen removal could be explained by buffer width. Nitrogen removal effectiveness of buffers ≥ 50 m (165 ft) wide (85%) was greater than that of buffers ≤25 m (82 ft; 58%). Based on the authors’ non-linear regression model, 50%, 75%, and 90% removal efficiencies would occur in buffers with widths of approximately 4 m (13 ft), 49 m (161 ft), and 149 m (490 ft), respectively (Table 1) (Mayer et al. 2007).
  - Bason (2008) found that the amount of nitrogen input to coastal plain streams increased along with buffer width. Eighty to 90-foot buffers removed approximately 80% of the nitrogen, with 2% greater nitrogen removal attained per additional foot of buffer width. The study also found that buffer widths of 150 feet or greater are more likely to consistently achieve their maximum potential for nitrogen removal.
  - Zhang et al. (2010) found that riparian buffer width explained 44% of the total variance in removal effectiveness for nitrogen. The median removal efficacy was 68% when calculated across a range of widths (2–115 ft) and slopes (2–16%).

- Phosphorus removal
  - Zhang et al. (2010) found that riparian buffer width alone explained 35% of the total variance in removal effectiveness for phosphorus. The median removal efficacy for phosphorous was 72% when calculated across a range of widths (2–115 ft) and slopes (2–16%).

- Bason's analysis (2008) showed that factors other than width may be more influential in determining degree of phosphorus removal. In general, phosphorus removal increased with width in a similar but more variable manner than nitrogen removal. However, this relationship was not statistically significant. The data did show a threshold near a width of 80 feet where buffers more consistently removed phosphorus. At this width, phosphorus removal averaged 66% with approximately 50% removal occurring for most buffers.

- Sediment
  - Zhang et al. (2010) found that riparian buffer width alone explained 37% of the total variance in removal effectiveness for sediments. The median removal efficacy for sediment was 86% when calculated across a range of widths (2–115 ft) and slopes (2–16%). When calculating the effects of buffer slope on sediment removal proficiency, the results showed removal increased when the riparian buffer slope was ≤ 10%. Based on this analysis, the authors concluded that a 100-foot riparian buffer under favorable slope conditions (≈ 10%) would remove more than 85% of all the studied pollutants.

- Pesticides
  - Zhang et al. (2010) found that riparian buffer width alone explained 60% of the total variance in removal efficacy for pesticides. The median removal effectiveness for pesticides was 88% when calculated across a range of widths (2–115 ft) and slopes (2–16%).

<u>Other factors</u>

Other factors in addition to width also play a role in determining buffer effectiveness, including the loading rate of the pollutant, runoff flow patterns, the characteristics of the buffer soil, and the type of vegetation present in the buffer. Upland characteristics such as the proximity of development, developmental density and permanency, and management practices will also affect buffers (Adamus 2007).

- Loading rate
  - A buffer's effectiveness at reducing pollution is usually greater when incoming polluted runoff or groundwater arrives in small amounts (low loading rates) (Adamus 2007). Mayer et al. (2007) found that in general, buffer effectiveness declined when nitrogen loads were high relative to buffer width. However, they did find five studies that showed little or no nitrogen removal even when loads were small relative to buffer width. The authors concluded this pattern was due to the ineffectiveness of nitrogen removal in surface flows.

- Flow path
  Buffers are most effective in protecting water quality when runoff entering the buffer is distributed across a wide area rather than in concentrated flow such as channels. This is because the pollutant filtering function that buffers provide is dependent upon the proportion of surface runoff crossing the buffer via sheet flow (Adamus 2007).

- Mayer et al. (2007) found that nitrogen removal effectiveness was affected by water flow pattern. Buffers were much more effective at subsurface removal of nitrogen (77%) than surface removal (42%). An analysis of the effectiveness of nitrogen removal based on buffer width and flow path indicated that subsurface removal of nitrogen did not appear to be related to buffer width, whereas wider buffers removed more nitrogen in surface runoff. While some narrow buffers (3-49 ft) removed significant proportions of nitrogen, a non-linear regression model found that 50%, 75%, and 90% nitrogen removal efficiencies in surface flow would occur in buffers approximately 27 m (89 ft), 81 m (266 ft), and 131 m (430 ft) wide, respectively (Mayer et al. 2007) (Table 1).

➢ Soil characteristics

Nutrient and pollutant movement in the buffer subsurface is dependent on the hydraulic characteristics of the underlying soil. Therefore, the effectiveness of a buffer may be disrupted if subsurface flow occurs below the plant roots, in areas of preferential flow, or in soils with rapid infiltration (Polyakov et al. 2005). Buffers on moderately coarse soil are generally more effective in protecting water quality. Finer-textured soils may become quickly saturated, allowing incoming pollutants to drift above the root zone where most pollutant processing occurs. However, if soils are so coarse that water infiltration occurs very rapidly through the roots, there may be too little time for pollutants to be fully processed. Due to their associated physical and chemical properties, coarser-textured soils, especially those with minimal organic content, also tend to be less effective in retaining pollutants (Adamus 2007).

- A study of eight sites on glacial channel and outwash landscapes in southern Ontario, Canada, found that riparian buffers with widths of 82 to 577 feet were required to remove 90% of nitrate due to a geologic confining layer located beneath very coarse soils (Vidon and Hill 2004).

➢ Vegetation type

Vegetation composition can also have a significant effect on the function and effectiveness of buffers.

- Mayer et al. (2007) found that grass buffers were significantly less effective than forest buffers at removing nitrogen. However, grass buffer effectiveness increased non-linearly with buffer width. Nitrogen removal efficiencies of 50%, 75%, and 90% were predicted for grass buffers approximately 17 m (56 ft), 51 m (167 ft), and 84 m (276 ft) wide and for grass/forest buffers approximately 3 m (10 ft), 18 m (60 ft), and 44 (144 ft) wide, respectively (Table 1).
- Zhang et al. (2010) found that riparian buffers with trees have higher nitrogen and phosphorus removal efficacy than buffers composed of grasses or mixtures of grasses and trees.

Habitat protection

In general, larger vegetated buffers are required to protect the wildlife habitat functions of wetlands than to protect water quality functions (Hruby 2013). However, buffer effectiveness in habitat protection is highly dependent on factors such as adjacent land use activities, type of vegetation within the buffer, and the species of wildlife that uses the surrounding area (McMillan 2000). Wildlife species have varying needs for different types of adjacent habitat for activities such as breeding, foraging, and resting, which makes it difficult to recommend one particular type of buffer habitat as best suited for all species of wildlife.

Shorebirds

- DeLuca et al. (2004) developed an index of marsh bird community integrity to evaluate the relationship between marsh bird communities and estuarine wetland conditions in the Chesapeake Bay area. During this process they surveyed 30 bird species at 219 locations distributed among 96 tidal marshes. Index scores for each marsh were used to determine whether land use intensity (i.e., urban/suburban development, agriculture, and forest) influenced marsh bird community integrity within a 1000-m (3281 ft) buffer and 500-m (1640 ft) buffer. Their results indicated that marsh bird community integrity was significantly reduced when the amount of urban/suburban development within 500 m and 1000 m of the marsh exceeded 14% and 25%, respectively.
- Using the index of bird community integrity developed in their 2004 study, DeLuca et al. (2008) examined how development impacted estuarine waterbird communities within 28 watersheds and associated sub-estuaries of Chesapeake Bay. Waterbirds were defined as all species that forage exclusively or opportunistically on aquatic estuarine organisms (i.e., gulls, terns, and waterfowl). Of particular relevance for this report is their evaluation of waterbirds in comparison to local land cover within 500 m (1640 ft) of the coastline. In 2002 (a dry year), change point analysis indicated a > 85% probability that shorebird community integrity would be negatively impacted when 4.1% of local land cover was urban. In 2003 (normal rainfall), there was a 50% chance of a shorebird community threshold response when 2.1% of the local land cover was urban and a 99.9% probability of a threshold at 3.9% urban development. The authors concluded that, "of the landscape stressors we examined, development near estuarine coastlines is the primary stressor to estuarine waterbird community integrity, and that estuarine ecosystem integrity may be impaired by even extremely low levels of coastal urbanization" (DeLuca et al. 2008).

Application to Georgia

Georgia's 2005 State Wildlife Action Plan categorized 26 bird, reptile, fish, and mammal species found in estuaries as high priority species (see Appendix A for a complete list and habitat information). This designation

Table 2: Status of High Priority Estuarine Wildlife Species in Georgia (GA-DNR, WRD; http://www.georgiawildlife.com/node/1366)

Species Name	Official Designation	
	State	Federal
Red Knot (SE Winter Population)	Rare	Proposed Threatened
Piping Plover	Threatened	Threatened
Wilson's Plover	Threatened	
Swallow-tailed Kite	Rare	
American Oystercatcher	Rare	
Bald Eagle	Threatened	
Black-necked Stilt		Endangered
Wood Stork	Endangered	Threatened
Black Skimmer	Rare	
Least Tern	Rare	Endangered
Gull-billed Tern	Threatened	
Shortnose Sturgeon	Endangered	Endangered
Bluefin Killifish	Rare	
West Indian Manatee	Endangered	Endangered
Loggerhead	Threatened	Threatened
Green Sea Turtle	Threatened	Threatened
Leatherback Sea Turtle	Endangered	Endangered
Kemp's or Atlantic Ridley	Endangered	Endangered

includes "critically imperiled species, habitat indicator species known to be in decline, species endemic to Georgia, and rare or uncommon species in need of further research to determine conservation objectives" (GA-WRD 2005). Eighteen of these species are also listed as imperiled in Georgia and ten are listed as endangered or threatened under the federal Endangered Species Act (Table 2).

Research into the buffer habitat requirements of animals found in or near Georgia's tidal marshes shows that a variety of species make use of more than one habitat type in the course of their lifecycles.

- Using stable isotope analysis, Brittain et al. (2012) examined the proportional use of salt marsh vegetation in four Georgia high-priority coastal terrestrial bird species: the White-eyed Vireo, the Painted Bunting, the Northern Parula, and the Brown-headed Nuthatch. Based on plant, invertebrate, and bird samples collected from salt marsh, maritime scrub-shrub, oak forest, and pine forest habitats on Sapelo Island, they found that salt marsh vegetation was the carbon source for 47 to 94% of the diets of Painted Buntings. White-eyed Vireos and Brown-headed Nuthatches also relied on the marsh for a portion of their diets (12–43%), whereas there was no evidence that the Northern Parula obtained food that originated in the marsh. These findings suggest that Painted Buntings rely as much on saltmarsh habitat for food as on the forest and shrub habitats where they are usually found. Based on these results the authors recommend that habitat management on Georgia's barrier islands include saltmarsh habitat within 700 m (2300 ft) of forests that have <75% canopy, >50% ground cover, and patches of shrubs in the understory.
- A recent study by Byers, Kneib, and Altman investigated the effectiveness of different methods used to delineate the upland boundary of Georgia marshes (e.g., elevation, vegetation). As part of their research, the project team documented how the square-back marsh crab *(Armases cinereum)* traveled between forested upland and marsh areas to feed, thereby acting as a pathway for transferring energy and nutrients between the marsh and the upland (Byers, pers. comm.). Preliminary observations of marshes by the Georgia Coastal Ecosystems Long-Term Ecological Research project also found evidence of a greater abundance of *Armases* crabs associated with forested uplands than in grassy uplands, with the lowest density of crabs occurring on upland areas adjacent to armored shoreline (McLenaghan and Gehman, pers. comm.).

Marsh migration space

There have been numerous studies done in the past decade that predict the effects of sea level rise. For example, model simulations of three coastal Georgia rivers (the Ogeechee, the Altamaha, and the Satilla) using the Intergovernmental Panel on Climate Change mean and maximum estimates of sea-level rise for the year 2100 suggest that salt marshes will decline in area by 20% and 45%, respectively (Craft et al. 2009). Although we did not find any studies specifically concerning the effectiveness of buffers as a soft adaptation method for these effects, there have been studies that evaluated salt marsh migration.

- Torio and Chmura (2013) developed a Coastal Squeeze Index (CSI), which measures the magnitude and location of the threat of coastal squeeze with rising sea levels. Using the CSI, the authors determined the portions of current and future marsh areas threatened by coastal squeeze and the factor(s) contributing to the threat for each of three salt marsh systems in Maine and New

Brunswick, Canada. Accounting for parameters such as slope, anthropogenic barriers, and incremental sea level rise, the CSI indicated that the most developed marsh system in the study had areas with suitable elevation that could accommodate inland migration if sea level rise does not exceed 5 feet, but at greater increases in sea level, suitable areas could substantially decrease. Use of this index could enable coastal communities to more effectively plan for marsh migration by indicating areas that will require future undeveloped space.

- A report by the European Commission of 60 case studies of coastal erosion management in the European Union found that coastal squeeze was one of the most frequently encountered causes of coastal erosion in Europe. Recognizing that sediment loss and lack of space to retreat were the key factors involved in maintaining a stable coastal system, the report suggested setting aside "strategic sediment reservoirs", defined as "supplies of sediment of appropriate characteristics that are available for replenishment of the coastal zone . . . " (Niesing 2005). Following designation, these areas would be left undeveloped in order to promote coastal resilience and conserve biodiversity by restoring the sediment balance and providing the space necessary to accommodate natural erosion and sediment processes (Niesing 2005).
- The need for migration space in response to storm surge was demonstrated in a study by March and Smith (2012).To address the potential impact of saltwater intrusion as a result of storm surge, the researchers calculated the areas affected by different sized storms in two peninsulas (Lamar and Live Oak) along the Gulf Coast of Texas. For a 3-m (10 ft) surge, they concluded that an additional 5 km^2 (3 miles) of forested and 1 km^2 (0.6 miles) of grassland habitat on Lamar Peninsula may experience adverse storm surge effects, whereas on Live Oak Peninsula the potentially impacted area extended to 12 km^2 (4.5 miles) of forested and 16 km^2 (10 miles) of grassland habitats.

Part Three: Effect of Upland Land Use on Coastal Systems

Salt marshes are intertidal habitats located between upland areas and estuarine water. Although marshes serve to filter pollutants and sediments before they reach the water, the studies described below demonstrate that upland land use can affect water quality in estuaries and their associated tidal creeks. By inference, this suggests that the presence of intertidal marshes alone is not always enough to protect estuarine water from land use impacts.

Sanger et al. (2008, 2011) conducted a study to evaluate the impacts of coastal development on tidal creek habitats. Samples of both intertidal (i.e. marsh) and subtidal areas of 19 tidal creek systems in the Southeast and five in the Gulf of Mexico were sampled during the summers of 2005, 2006 (Southeast), and 2008 (Gulf of Mexico), and analyzed for a suite of nutrients and phytoplankton indicators.

Creek watersheds draining uplands were classified into the following land use categories: forested (<10% impervious cover); suburban (≥10% but <35% impervious cover); and urban (≥35% impervious cover). Watersheds for creeks that only drained salt marshes were classified as marsh. Intertidal concentrations of $NO_2 + NO_3$and NH_4^+ increased significantly with increasing levels of impervious cover in the watersheds. Land use class had a significant effect on $NO_2 + NO_3$ levels, with concentrations for creeks in marsh and forested watershed classes being significantly lower than in developed watershed classes. The authors attributed these results to the combined increase of fertilizer use and stormwater runoff in more developed watersheds (Sanger et al. 2008, Sanger et al. 2011). In addition, all nutrient measures were significantly higher in intertidal compared to subtidal creeks, indicating that nutrients are trapped or processed in the intertidal marsh areas before they reach the tidal creeks. Concentrations of NH_4^+ in intertidal areas also increased significantly with increasing levels of impervious surface area. Although this study did not evaluate wetland buffers per se, areas with the least impervious surface have a de facto buffer.

A related study conducted by Van Dolah et al. (2008) further demonstrates the influence of land use on water quality. In this study, data from several studies conducted in South Carolina were analyzed to assess the relationships between land cover patterns in 29 estuarine watersheds using water and soil samples taken from tidal creeks and open water. Watersheds were divided into 3 land cover classes based on Landsat thematic mapping imagery: non-urban, suburban (30-75% development), and urban (>75% development). Tidal creeks were defined as any estuarine water body narrower than 100 meters. These analyses found that a composite measure of 24 inorganic and organic contaminants was significantly higher in tidal creeks associated with both suburban and urban categories as compared to non-urban areas. When these contaminants were analyzed separately, 13 PAHs (polycyclic aromatic hydrocarbons), pesticides, and metals were also significantly higher in creeks associated with both suburban and urban land covers. In open water samples, the level of composite contaminants was again significantly greater in samples associated with urban cover. Fecal coliform bacterial concentrations in both tidal creeks and open water were significantly higher in the urban as compared to the suburban land cover category. In contrast, measures of nutrient enrichment (e.g., nitrogen, phosphorus, and chlorophyll-a) were generally not significantly different in the various land cover classes in either creeks or open water samples. The authors concluded that the effects of urbanization of coastal uplands in South Carolina are "detectable in estuarine environmental quality at large spatial scales . . . with respect to sediment contaminants and fecal coliform bacterial concentrations, but generally not with measures of nutrient variables" (Van Dolah et al. 2008).

Land use can also affect the use of tidal marshes as habitat. Studds et al. (2012) looked at how land cover and annual changes in rainfall interact to shape waterbird community composition in 28 estuarine wetlands in Chesapeake Bay. In the drought year of 2002, waterbird community composition depended only on the direct effect of urban development in watersheds. In the wet year of 2003, waterbird community composition depended on both urban development and on indirect effects associated with nitrogen inputs to northern parts of the Bay, particularly in urban sub-estuaries. These findings suggest that increased runoff during high rainfall periods can lower wetland water quality enough to alter the composition of estuarine waterbird populations from mixed generalist-specialist communities to generalist-dominated communities. This effect appears to be intensified in sub-estuaries with large amounts of urban development.

Part Four – Wetland Buffer Application in Other States

Several states have instituted recommendations for wetland buffers in tidal areas. Below we summarize a few of these efforts.

Delaware

A study conducted for the Inland Bays area in Delaware provided two alternatives for setting wetland buffer width (Bason 2008). Buffers were to be measured landward from the mean high water line defined as "the point on the bank, tidal flat, beach or shore, up to which the presence or action of the water leaves a distinct mark, either by erosion, destruction of terrestrial vegetation (non-aquatic), physical markings or characteristics, and known vegetation lines, and may be further identified by tidal gauge data, or any other suitable means of delineating the mean height reached by a rising tide" (7 Del. C. §7403). The adequate protection alternative suggested buffers of 80 feet adjacent to tidal areas with steep uplands and 300 feet adjacent to tidal areas with gradual uplands. The optimum protection alternative suggested buffers of 150 feet adjacent to tidal areas with steep uplands and 500 feet adjacent to tidal areas with gradual uplands (Bason 2008). When promulgated, the Inland Bays Pollution Control Strategy established 100-foot buffers for all primary waters, which included tidal waters. However, these buffer requirements were declared void and unenforceable by the Delaware Supreme Court in 2011. Sussex County (including Inland Bays) currently retains a 50-foot buffer requirement for separating development from the mean high water line of tidal waters, tidal tributary streams, and tidal wetlands (§115-193).

Florida

St. John's County, Florida requires a 50-foot upland buffer landward of the state jurisdictional wetland line for all tidally-influenced water bodies. A 25-foot upland buffer with an additional 25-foot building setback from the buffer is required from all other contiguous wetland areas. An upland buffer is defined as a strip of undisturbed vegetated land along the edge of a wetland area (§4.01.06).

Maryland

Maryland's Critical Area Program includes all waters of and lands of the Chesapeake Bay and its tributaries, the Atlantic Coastal Bays and their tributaries, all state and private tidal wetlands, and all land and water areas within 1,000 feet of tidal waters and tidal wetlands. Under the Program, a Critical Area Buffer (CAB) (i.e., a naturally vegetated or planted area) must be established at least 100 feet directly adjacent to the State's tidal waters, tidal wetlands, and tributary streams. The CAB is measured from mean high water, from the landward edge of tidal wetlands, and from the edge of streams located within the Critical Area. Tidal wetlands include all wetlands, swamps, marshes, lands, open waters, and Submerged Aquatic Vegetation beds affected by the daily or periodic rise and fall of the tide within the Chesapeake Bay, the Atlantic Coastal Bays, and the Atlantic Ocean to a distance of three miles offshore. The edge of tidal wetlands is identified in the field either by a change in elevation or by a change in vegetation. When an abrupt and obvious change in elevation is not present, vegetation can be used to determine when a system is not regularly influenced by the tide. On property adjacent to a tidal marsh, the 100-foot CAB begins at the landward edge of the tidal extent of the marsh (MD-DNR 2012).

To ensure that development activity does not negatively affect water or wetland resources, the CAB may be expanded beyond 100 feet to include contiguous sensitive areas if there are steep slopes, non-tidal wetlands, or sensitive soils (hydric or highly erodible) adjacent to the CAB.[1] Expansion of the CAB when it is adjacent to, or crosses, a non-tidal wetland is to the limit of the non-tidal wetland. For areas of hydric soils that are not non-tidal wetlands, the CAB is expanded to the limit of the hydric soil or 300 feet, whichever is less (MD-DNR 2012).

Virginia

The Chesapeake Bay Preservation Act requires 100-foot buffers on tidal wetlands, non-tidal wetlands connected by surface flow and contiguous to tidal wetlands or water bodies with perennial flow, tidal shores, and other lands considered necessary to protect the quality of state waters. The 100-foot buffer is located adjacent to and landward of the waterbody (VA DCR 2009).

Washington

The Washington State Growth Management Act specifically requires local governments to adopt development regulations that include the best available science to protect the functions and values of critical areas, including wetlands (RCW 36.70A.172).The Washington State Department of Ecology has developed a rating system for the state's wetlands designed to differentiate between wetlands based on their sensitivity to disturbance, rarity, the functions they provide, and how replaceable they are. Category I wetlands are those that either 1) represent a unique or rare wetland type; 2) are more sensitive to disturbance than most wetlands; 3) are relatively undisturbed and contain ecological attributes that are impossible to replace within a human lifetime; or 4) provide a high level of ecological functions. Relatively undisturbed estuarine wetlands larger than one acre are Category I wetlands. Category II wetlands are considered to be difficult, but not impossible to replace and provide high levels of certain wetland functions. While they occur more commonly than Category I wetlands, Category II wetlands still need relatively high protection. Disturbed estuarine wetlands greater than one acre or any estuarine wetland smaller than one acre are classified as Category II wetlands (Hruby 2004).
A guidance document for local governments published by the Department of Ecology provides buffer width recommendations for each category of wetland (Granger et al. 2005). To provide local governments with some regulatory flexibility, three alternative scenarios based on land use impacts and wetland categories were developed. High impact land uses include commercial, urban, and high-intensity recreation (e.g., golf courses, sports fields, etc.), while moderate impact land uses include moderate-intensity open space (e.g., bike and jogging trails), utility corridors shared by several utilities and with access/maintenance road, and residential development of one unit/acre or less. Low impact land uses include forestry, unpaved paths/trails, and low intensity open space such as hiking, or bird-watching. Buffer widths in Alternative 1 are based solely on wetland category. In this case, a 300-foot buffer is recommended regardless of land use intensity. Alternative 2 considers land use impacts when calculating protective width, and Alternative 3 considers land use impacts and degree of functions or any special characteristics the wetland may have (Granger et al. 2005). Buffers widths for Alternatives 2 and 3 are given in Table 3.

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[1]Highly erodible soils are unstable and tend to wash away easily because of their composition and location in the landscape. Hydric soils tend to be under water, wet, or saturated for significant portions of the year and may or may not be considered non-tidal wetlands (MD-DNR 2012).

Table 3: Width of Buffers Needed to Protect Estuarine Wetlands under Alternatives 2 and 3
(Adapted from Granger et al. 2005)

Wetland Category	**Alternative 2** (category and land use impact)			**Alternative 3** (category, land use impact, and special characteristics)		
	High Impact	Moderate Impact	Low Impact	High Impact	Moderate Impact	Low Impact
Category I	300*	225	150	200	190	100
Category II	300	225	150	150	110	75

*Buffer width in feet

General Conclusions

Further research into the functions and efficacy of vegetated buffers adjacent to tidal marshes would be very useful to decision-makers and natural resource managers who are responsible for protecting coastal wetlands. As the coastal population grows, it will be accompanied by demand for additional development. However, the ability of intertidal marshes alone to protect estuarine water quality and habitat is limited. Wetland buffers can augment the capacity of salt marshes to carry out these important ecosystem functions. Wetland buffers can also serve to accommodate marsh migration in the face of sea level rise.

In the process of compiling this report, we were unable to find any studies that directly addressed the complicated hydrological and habitat issues specific to the coastal environment. Although data from studies of riparian buffers are relevant, the effectiveness of buffers in intertidal areas in general and in estuarine areas in particular is not well-understood. The Georgia Coastal Research Council will continue to identify scientific studies and other resources that are relevant to this issue.

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Appendix A. High Priority Animals Found in Georgia's South Coastal Plain

Table 1. High Priority Estuarine Animals Found in Georgia's South Coastal Plain (adapted from the GA Wildlife Action Plan 2005)

Scientific name	Common name	Classification	Habitat in Georgia	Status	
				State	Federal
Calidris canutus	Red Knot (SE Winter Population)	Bird	Beaches and sandbars	Rare	Proposed Threatened
Charadrius melodus	Piping Plover	Bird	Sandy beaches; mud and sand flats; isolated sand spits	Threatened	Threatened
Charadrius wilsonia	Wilson's Plover	Bird	Sandy beaches; sand and mud flats, dunes, and back dune swales	Threatened	
Egretta tricolor	Tricolored Heron	Bird	Coastal aquatic environments, salt and fresh, nests with other waders in low thick cover		
Elanoides forficatus	Swallow-tailed Kite	Bird	River swamps and upland adjacent habitats particularly with large, emergent pines and pine islands; marshes	Rare	
Haematopus palliatus	American Oystercatcher	Bird	Sandy beaches; tidal flats; salt marshes, oyster shell bars	Rare	
Haliaeetus leucocephalus	Bald Eagle	Bird	Edges of lakes & large rivers; seacoasts	Threatened	
Himantopus mexicanus	Black-necked Stilt	Bird	Shallow ponds; lagoons; isolated freshwater wetlands; dredge spoil sites; managed wetlands		Endangered
Ixobrychus exilis	Least Bittern	Bird	Freshwater and brackish marshes with tall, dense emergent vegetation. Nests close to open areas		
Laterallus jamaicensis	Black Rail	Bird	Freshwater marsh grassy margins; wet grassy meadows; brackish high marsh		
Limosa fedoa	Marbled Godwit (James Bay Population)	Bird	Breeds in marshes and flooded plains, in migration and winter also found on mudflats and beaches		
Mycteria americana	Wood Stork	Bird	Cypress/gum ponds; freshwater marshes; saltmarshes, river swamps; bays, isolated wetlands, ephemeral wetlands, coastal hammocks	Endangered	Threatened
Numenius phaeopus	Whimbrel	Bird	Saltmarsh openings, Mud flats, shell rakes, outer barrier sand spits		
Rallus elegans	King Rail	Bird	Freshwater marshes, often cattail bulrush, cutgrass, for breeding; also brackish marshes non-breeding		
Rynchops niger	Black Skimmer	Bird	Sandy beaches, isolated accretional sand spits, N and S tips of barrier islands	Rare	

Scientific name	Common name	Classification	Habitat in Georgia	Status	
				State	Federal
Sterna antillarum	Least Tern	Bird	Sandy beaches; sandbars, large flat gravel roof tops	Rare	Endangered
Sterna nilotica	Gull-billed Tern	Bird	Outer sand beaches and mud flats, Salt marshes; fields on barrier islands; Isolated sand spits	Threatened	
Acipenser brevirostrum	Shortnose Sturgeon	Fish	Estuaries; lower end of large rivers in deep pools with soft substrates	Endangered	Endangered
Lucania goodei	Bluefin Killifish	Fish	Heavily vegetated ponds and streams with little or no current; frequently associated with springs	Rare	
Trichechus manatus	West Indian Manatee	Mammal	Inshore ocean; estuaries, tidal rivers, warm and fresh water discharges	Endangered	Endangered
Tursiop struncatus	Bottlenose Dolphin	Mammal	Coastal estuarine and offshore waters of Georgia		
Caretta caretta	Loggerhead	Reptile	Open ocean; sounds; coastal rivers; beaches	Threatened	Threatened
Chelonia mydas	Green Sea Turtle	Reptile	Open ocean; sounds; coastal rivers; beaches	Threatened	Threatened
Dermochelys coriacea	Leatherback Sea Turtle	Reptile	Open ocean; sounds; coastal beaches	Endangered	Endangered
Lepidochelys kempii	Kemp's or Atlantic Ridley	Reptile	Open ocean; sounds; coastal rivers; beaches	Endangered	Endangered
Malaclemys terrapin	Diamondback Terrapin	Reptile	Entire coast, estuarine and marine edge. All saltmarsh, beaches	Unusual	

Estuaries defined:
Bay/Sound - subtidal (continuously submerged), open water, estuarine habitats, excluding river mouths
River mouth/Tidal river- lower reaches of rivers with both brackish water and tidal influence
Lagoon - open (unvegetated), shallow, estuarine waters isolated at low tide or separated from deeper waters by a natural barrier such as a spit or barrier island
Tidal flat/Shore - non-vegetated zone of wave or tidal action, intermittently exposed or inundated
Herbaceous wetland - vegetated areas characterized by emergent herbaceous aquatic plants, excluding mosses and lichens
Scrub-shrub wetland - vegetated areas dominated by woody plants less than 6 meters tall (e.g., some mangroves, marsh elder)
Forested wetland - areas vegetated by woody plants 6 meters tall or taller

Table 2: High Priority non-Estuarine Animals Found in the South Coastal Plain (adapted from the GA Wildlife Action Plan 2005)

Scientific name	Common name	Classification	Habitat in Georgia	Status	
				State	Federal
Necturus punctatus	Dwarf Waterdog	Amphibian	Sluggish streams with substrate of leaf litter or woody debris		
Notophthalmus perstriatus	Striped Newt	Amphibian	Pine flatwoods, sandhills; isolated wetlands	Threatened	Candidate
Pseudobranchus striatus	Dwarf Siren	Amphibian	Swamps; marshes; limesink ponds; cypress ponds		
Rana capito	Gopher Frog	Amphibian	Sandhills; dry pine flatwoods; breed in isolated wetlands	Rare	
Stereochilus marginatus	Many-lined Salamander	Amphibian	Sluggish, swampy streams and bayheads with substrate of leaf litter		
Aimophila aestivalis	Bachman's Sparrow	Bird	Open pine or oak woods; old fields; grassy forest regeneration	Rare	
Ammodramus henslowii	Henslow's Sparrow	Bird	Grassy areas, especially wet grasslands; wet pine savanna and flatwoods	Rare	
Ammodasmus savannarum	Grasshopper Sparrow	Bird	Grassland surrounded by open country (ag, grassland etc.)		
Colinus virginianus	Northern Bobwhite	Bird	Early successional mixed grass/forb habitat; longleaf pine savanna		
Falco sparverius paulus	Southeastern American Kestrel	Bird	Pine sandhills and savannas; open country with scattered trees for nesting; military base habitats; artificial/man-made nesting habitats include nest boxes, power poles, building columns	Rare	
Grus Canadensis pratensis	Florida Sandhill Crane	Bird	Freshwater prairies		
Lanius ludovicianus migrans	Loggerhead Shrike	Bird	Open woods; field edges; savannas		
Limnothlypis swainsonii	Swainson's Warbler	Bird	Dense undergrowth with heavy litter; canebrakes in swamps and river floodplains		
Passerina ciris	Painted Bunting	Bird	Shrub-scrub and open grassy habitats; open mature pine forest and maritime oak forest associated with freshwater wetlands		
Picoides borealis	Red-cockaded Woodpecker	Bird	Open pine woods; pine savannas	Endangered	Endangered
Tyto alba	Barn owl	Bird	Grassland savanna/neighborhoods with large cavity trees, generally needs open country		
Elassoma okatie	Bluebarred Pygmy Sunfish	Fish	Temporary ponds and stream backwaters with dense aquatic vegetation	Endangered	

Scientific name	Common name	Classification	Habitat in Georgia	Status	
				State	Federal
Enneacanthu schaetodon	Blackbanded Sunfish	Fish	Blackwater streams; bays; cypress/gum ponds		
Micropterus notius	Suwannee Bass	Fish	Flowing water over rocky shoals or large springs and spring runs	Rare	
Condylura cristata	Star-nosed Mole	Mammal	Moist meadows; woods; swamps		
Corynorhinus rafinesquii	Rafinesque's Big-eared Bat	Mammal	Pine forests; hardwood forests; caves; abandoned buildings; bridges; bottomland hardwood forests and cypress-gum swamps	Rare	
Eubalaena glacialis	North Atlantic Right Whale	Mammal	Inshore and offshore oceanic waters of Georgia	Endangered	Endangered
Geomys pinetis	Southeastern Pocket Gopher	Mammal	Sandy well-drained soils in open pine woodlands with grassy or herbaceous groundcover, fields, grassy roadsides	Threatened	
Lasiurus intermedius	Northern Yellow Bat	Mammal	Wooded areas near open water or fields		
Neofiber alleni	Round-tailed Muskrat	Mammal	Freshwater marshes; bogs	Threatened	
Sciurus niger shermani	Sherman's Fox Squirrel	Mammal	Pine forests; pine savannas		
Ursus americanus floridanus	Florida Black Bear	Mammal	Large undeveloped wooded tracts in areas that include multiple forest types		
Alasmidonta triangulata	Southern Elktoe	Mollusks	Large creeks and river mainstems in sandy mud and rock pools	Endangered	
Alasmidonta varicosa	Brook Floater	Mollusks	Small rivers and creeks in sand and gravel shoals		
Elliptio fraterna	Brother Spike	Mollusks	Sandy substrates of river channels with swift current		
Fusconaia masoni	Atlantic Pigtoe Mussel	Mollusks	Moderate to fast current in substrate of sand or gravel	Endangered	
Medionidu swalkeri	Suwannee Moccasinshell	Mollusks	Large creeks and medium-sized rivers with sand and gravel substrate		
Quincuncina kleiniana	Suwanee Pigtoe	Mollusks	Small to large rivers in the Suwannee Basin, in slow to moderate current, pools of flowing rivers, often in detritus. More common in Alapaha and Withalacoochee rivers and tributaries		
Toxola smapullus	Savannah Lilliput	Mollusks	Altamaha River; Savannah River	Threatened	
Clemmys guttata	Spotted Turtle	Reptile	Heavily vegetated swamps, marshes, bogs, and small ponds; nest and possibly hibernate in surrounding uplands	Unusual	
Crotalus adamanteus	Eastern Diamondback Rattlesnake	Reptile	Early successional habitats on barrier islands and mainland; pine flatwoods; sandhills		

Scientific name	Common name	Classification	Habitat in Georgia	Status	
				State	Federal
Drymarchon couperi	Eastern Indigo Snake	Reptile	Sandhills; pine flatwoods; dry hammocks; summer habitat includes floodplains and bottomlands	Threatened	Threatened
Eumeces anthracinus	Coal Skink	Reptile	Mesic forests; often near streams, springs or bogs		
Eumeces egregius	Mole Skink	Reptile	Coastal dunes; longleaf pine-turkey oak woods; dry hammocks		
Gopherus polyphemus	Gopher Tortoise	Reptile	Sandhills; dry hammocks; longleaf pine-turkey oak woods; old fields	Threatened	Candidate
Heterodon simus	Southern Hognose Snake	Reptile	Sandhills; fallow fields; longleaf pine-turkey oak		Under review
Macrochelys temminckii	Alligator Snapping Turtle	Reptile	Large streams and rivers; impoundments; river swamps	Threatened	
Ophisaurus mimicus	Mimic Glass Lizard	Reptile	Pine flatwoods; savannas; seepage bogs	Rare	
Pituophis melanoleucus mugitus	Florida Pine Snake	Reptile	Sandhills; scrub; old field		Under review
Rhineura floridana	Florida Worm Lizard	Reptile	Dry upland hammocks, sand pine and longleaf pine-turkey oak sandhills; old fields		
Tantilla relicta	Florida Crowned Snake	Reptile	Sandhills, scrub, and moist hammocks		

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Abstract: This document is primarily a review of best available science applicable to Island County, WA wetlands, as needed for categorizing wetlands for regulatory actions and determining widths for buffers that protect the functions of wetlands. Buffers are defined as a generally terrestrial area surrounding a wetland and measured a specified distance outward from the wetland/upland boundary. The distance (width) may depend on wetland type, size, intensity of adjacent land uses, and other factors. Buffers are intended to reduce impacts from adjacent land uses. Related terms are vegetated filter strip, wetland setback, and riparian strip. The number of technical papers and reports published on these topics is enormous, and none of the available reviews on these topics claims to have reviewed all of them. Similarly, we have not attempted to review all or even most such studies, but rather have emphasized information published since the review prepared by the Washington Department of Ecology (2005), up until April 2007. This document also provides some discussion of habitat functions of wetlands. [Abstract from Author]

Bason, Christopher (2008). *Recommendations for an Inland Bays Watershed Water Quality Buffer System*. The Delaware Center for the Inland Bays on behalf of the Scientific and Technical Advisory Committee of the Delaware Center for the Inland Bays, Dr. Sergio Huerta, Chair. Available at: http://www.inlandbays.org/wp-content/uploads/2011/01/Recommendations-for-an-Inland-Bays-Watershed-Buffer-System-Final.pdf.

Abstract: This document provides science-based recommendations for a water quality buffer system designed to protect and restore the quality of wetlands and waterbodies of the Inland Bays watershed located in coastal Sussex County, Delaware. The document focuses on the long-term nutrient removal and retention function of buffers with respect to the total maximum daily load (TMDL) reductions of nitrogen and phosphorus needed for the Inland Bays and their tributaries. Literature focused on Atlantic Coastal Plain buffers was reviewed to recommend buffer alternatives by waterbody type and by buffer system characteristics. The alternatives were then applied to eleven randomly selected developments to determine acreage of buffer zones in buildable areas. Further recommendations based on these results are then provided. [Abstract from Author]

Brennan, J.S., and H. Culverwell (2004). *Marine Riparian: An Assessment of Riparian Functions in Marine Ecosystems*. Washington Sea Grant Program, UW Board of Regents, Seattle, WA. Available at: http://albergstein.com/cao/CAO%20Committee%20Recommendation%20Files/Fish%20and%20Wildlife%20Habitat%20Conservation%20Areas/Marine/brennan%20et%20al%202005%20-%20marine%20riparian%20function.pdf.

Abstract: In this paper, we review riparian functions and associated benefits (i.e., ecological or social values) as they relate to the marine environment, using the most commonly reviewed freshwater riparian function topics as a template. The functions reviewed for this paper include water quality, soil stability, sediment control, wildlife habitat, microclimate, nutrient input, fish prey production, shade, and habitat structure with an emphasis on large woody debris (LWD). We also briefly review and discuss social values such as human health and safety, and aesthetics. In addition, we assess the relationship between current regulatory and management strategies and their effectiveness in protecting riparian and marine resources and the ecosystem as a whole. In addition to presenting the above-stated reviews and assessments, we provide a foundation to enhance discussions of shoreline management and improve resource protection through an increased understanding of nearshore and marine riparian ecosystems. [Abstract from Author]

Brittain, R., Schimmelmann, A., Parkhurst, D. and Craft, C. 2012. Habitat Use by Coastal Birds Inferred from Stable Carbon and Nitrogen Isotopes. *Estuaries and Coasts* 35:633-645. Available at: http://www.indiana.edu/~craftlab/publications/Brittain_et_al_2012.pdf

Abstract: Conservationists need to know the degree of habitat fidelity for species of conservation concern. Stable Isotope Analysis in R quantified the contribution of terrestrial vs. saltmarsh primary production sources to terrestrial passerine food webs from four habitats of Sapelo Island, Georgia (USA), saltmarsh, maritime scrub–shrub, maritime broadleaf (oak), and maritime narrowleaf (pine) forests, using δ13 C and δ15 N. Models suggested Northern Parula (*Parula americana*) in oak forests, White-eyed Vireos (*Vireo griseus*) in shrub, and Brown-headed Nuthatches (*Sittapusilla*) in pine forests derived most of their food from habitats they occupied (53–100%). Salt-marsh provided 47–94% of Painted Bunting (*Passerinaciris*) food sources, supporting previous findings by Springborn and Meyers (2005). Thus, Painted Bunting conservation in the Southeastern USA should focus on Springborn and Meyers' suggestion of maritime scrub–shrub habitat and forests with <75% canopy, >50% ground cover, and patches of shrubs that are within 700 m of saltmarsh. [Abstract from Author]

Center for Watershed Protection (2010). *Designing Aquatic Buffers for the Coastal Plain.* Available at: http://www.cwp.org/images/stories/Articles/cpwn_buffers.pdf.

Abstract: This article presents some recommendations for the design of aquatic buffers in the coastal plain that are based on the available research from the region so that coastal municipalities have greater support for implementing buffer programs that work for their communities.

City of Boulder (2007). *Wetland and Stream Buffers: A Review of the Science and Regulatory Approaches to Protection*. Developed by the City of Boulder Planning and Development Services and Biohabitats, Inc. Available at: https://www-static.bouldercolorado.gov/docs/wetland-stream-buffers-1-201308011516.pdf.

Abstract: This report reviews the current thinking about and approaches to buffer area protection across the country. The goal of the study is to provide background information that will guide the development of options for updating the city's wetlands protection program and ordinance. Section

II reviews the purpose and functions of buffers and the science-supported buffer widths needed to protect the ecological functions of streams and wetlands.

Craft, C.B., Clough, J., Ehman, J., Joye, S.B., Park, R., Pennings, S.C., Guo, H. and Machmuller, M. (2009). Forecasting the effects of accelerated sea level rise on tidal marsh ecosystem services. *Frontiers in Ecology and the Environment* 7(2):73-78. Available at: http://www.esajournals.org/doi/abs/10.1890/070219

Abstract: We used field and laboratory measurements, geographic information systems, and simulation modeling to investigate the potential effects of accelerated sea-level rise on tidal marsh area and delivery of ecosystem services along the Georgia coast. Model simulations using the Intergovernmental Panel on Climate Change (IPCC) mean and maximum estimates of sea-level rise for the year 2100 suggest that salt marshes will decline in area by 20% and 45%, respectively. The area of tidal freshwater marshes will increase by 2% under the IPCC mean scenario, but will decline by 39% under the maximum scenario. Delivery of ecosystem services associated with productivity (macrophyte biomass) and waste treatment (nitrogen accumulation in soil, potential denitrification) will also decline. Our findings suggest that tidal marshes at the lower and upper salinity ranges, and their attendant delivery of ecosystem services, will be most affected by accelerated sea level rise, unless geomorphic conditions (i.e., gradual increase in elevation) enable tidal freshwater marshes to migrate inland, or vertical accretion of salt marshes to increase, to compensate for accelerated sea-level rise. [Abstract from Author]

DeLuca, William, V., Colin E. Studds, Ryan S. King, and Peter P. Marra (2008). Coastal urbanization and the integrity of estuarine waterbird communities: Threshold responses and the importance of scale. *Biological Conservation* 141(11): 2669-2678. Available at: http://www.sciencedirect.com/science/article/pii/S0006320708002784

Abstract: Estuarine ecosystems are becoming increasingly altered by the concentration of human populations near the coastline; however a robust indicator of this change is lacking. We developed an index of waterbird community integrity (IWCI) and tested its sensitivity to anthropogenic activities within 28 watersheds and associated sub-estuaries of Chesapeake Bay, USA. The IWCI was used as a tool to gain insight into how human land use affects estuarine ecosystem integrity. Based on Akaike's information criteria (AIC), a single variable model including percent developed land in estuarine watersheds was thirteen (2002) and twenty-six (2003) times more likely than models including percent agriculture and forest cover to fit the IWCI data. Consequently, we examined how suburban, urban, and total development shaped IWCI scores at three spatial scales: (1) watershed; (2) inverse-distance-weighted (IDW) watershed (land cover near the coastline weighted proportionally greater than that farther away); (3) local (land cover within 500 m of the coastline). Suburban, urban, and total development were all significant predictors of IWCI scores. Relationships were stronger at the IDW and local scales than at the whole watershed scale. Nonparametric change point analysis revealed a >80% probability of a threshold in IWCI scores when as little as 3.7% (2002) and 3.5% (2003) of the IDW land cover within the watershed was urban. Our results indicate that, of the landscape stressors we examined, development near estuarine coastlines is the primary stressor to estuarine waterbird community integrity, and that estuarine ecosystem integrity may be impaired by even extremely low levels of coastal urbanization. [Abstract from Author]

DeLuca, William, V., Colin E. Studds, Larry L. Rockwood, and Peter P. Marra (2004). Influence of land use on the integrity of marsh bird communities of the Chesapeake Bay, U.S.A. *Wetlands* 2(4): 837-847. Available at: http://www.asc.psu.edu/public/pubs/articles/deluca%20et%20al.%202004.pdf

Abstract: The landscape within the Chesapeake Bay watershed has been and continues to be impacted by human modifications. Understanding if such anthropogenic disturbances influence organisms that are dependent upon estuarine wetlands remains unclear. We developed an index of marsh bird community integrity (IMBCI) to evaluate marsh bird communities and wetland condition. During the 2002 and 2003 summers, we detected 30 bird species at 219 point count locations distributed among 96 wetlands. IMBCI scores for each wetland were used to determine whether wetland habitat characteristics and urban/suburban development, agriculture, and forest at three different spatial scales (watershed, 1000-m buffer, and 500-m buffer) influenced marsh bird community integrity. We found no relationship between IMBCI scores and wetland habitat characteristics, implying that marsh bird community integrity is not related to any single plant community. Nonparametric change point analysis indicated that marsh bird community integrity was significantly reduced when the amount of urban/suburban development within 500 m and 1000 m of the marsh exceeded 14% and 25%, respectively. There was no effect of urban/suburban development on IMBCI scores at the watershed scale. The results of our study demonstrate that marsh bird community integrity shows a threshold response to urban/suburban development at local scales. IMBCI scores, combined with the identification of a land-use threshold, can be easy to interpret and may help communicate complex ecological data to natural resource managers and conservation planners. [Abstract from Author]

Drescher, Sadie Rain, Neely Leda Law, Deborah Susan Caraco, Karen Marie Cappiella , Julie Anne Schneider and David J. Hirschman (2011). Research and Policy Implications for Watershed Management in the Atlantic Coastal Plain. *Coastal Management* 39(3): 242-258. Available at: http://dx.doi.org/10.1080/08920753.2011.566123

Abstract: Coastal plain research and policy strive to protect unique coastal habitats and natural resources while managing for stressors such as seasonal population fluxes and coastal hazards. There is a need to translate scientific findings to impact policy for effective coastal management at a watershed scale that reaches local communities. The Center for Watershed Protection (CWP) uses an Eight Tools of Watershed Protection (Eight Tools) framework for watershed planning and assessments to systematically identify opportunities for better practices and improve natural resource protection. This article uses four of the Eight Tools, which were recently adapted for the coastal plain, to demonstrate research to policy options: (1) land use planning; (2) forested riparian buffers; (3) stormwater management; and (4) non-stormwater discharges—on-site wastewater discharge focus. It provides a synthesis of CWP's recent coastal plain research supplemented with additional coastal research to suggest ways where science may be more effectively integrated into policy and regulations that will protect and restore coastal resources at a watershed scale.

Summarizing and presenting the science to policymakers can increase the validity and likelihood for environmental regulations that will ultimately be implemented at the local level. [Abstract from Author]

Fisher, T.R., T.E. Jordan, K.W. Staver, A.B. Gustafson, A.I. Koskelo, R.J. Fox, A.J. Sutton, T. Kana, K.A. Beckert, J.P. Stone, G. McCarty, and M. Lang (2010). The Choptank Basin in Transition: Intensifying Agriculture, Slow Urbanization, and Estuarine Eutrophication. In: M.J. Kennish and H.W. Paerl (eds.). *Coastal Lagoons: Critical Habitats of Environmental Change*. CRC Press, Boca Raton, Florida; p. 137-168. Available at: http://www.chesapeakebay.net/channel_files/17855/fisher_et_alchapter88300_c007..pdf

Abstract: The Choptank basin and estuary are located on the Delmarva Peninsula in the Mid-Atlantic coastal plain. The regional hydrology is characterized by nearly uniform seasonal rainfall but large seasonal variations in temperature, evapotranspiration, groundwater levels, and stream discharge. Water quality in nontidal streams is largely determined by agricultural land use and animal feeding operations, and nitrogen (N) and phosphorus (P) concentrations have been increasing for decades. Inputs from nontidal streams, together with increasing human populations and wastewater discharges, have resulted in degraded estuarine water quality, including increases in chlorophyll-a in surface waters and declining oxygen in bottom waters. Attempts to reduce losses of N and P from nontidal streams in agricultural areas have met with limited success. One targeted watershed in the Choptank Basin showed stabilized concentrations of base flow N, along with small decreases in base flow P, a decade after extensive application of some best management practices (BMPs) in contrast to the nearby Greensboro watershed which was not targeted for BMPs and exhibited increases in base flow N and P. An attempt to improve water quality using increased stream buffers has yet to be successful, probably because new stream buffers represented only an 11% increase over existing ones. Based on our observations, we suggest policies to improve water quality in the Choptank basin and the Mid-Atlantic region in general. We recommend application of water quality standards at the watershed scale, reduced caps for wastewater discharges, lower fertilizer applications on agricultural areas, mandatory stream buffers and winter cover crops on farms, and banning of lawn fertilizers. Anthropogenically impacted systems, such as the Choptank and Delmarva coastal bays, require a more regulated approach at the watershed scale, with long-term monitoring to improve water quality. [Abstract from Author]

Georgia Department of Natural Resources (2005). *A Comprehensive Wildlife Conservation Strategy for Georgia*. Georgia Department of Natural Resources, Wildlife Protection Division. Available at: http://www.georgiawildlife.com/conservation/wildlife-action-plan

Abstract: To more proactively safeguard our state's natural heritage, the Wildlife Resources Division developed a comprehensive wildlife conservation strategy - more simply known as the State Wildlife Action Plan or SWAP. This management plan outlines the steps needed to conserve wildlife and habitats before they become rarer and more costly to protect. Work started in December 2002 and incorporated years of research and data accumulated by DNR staff and other natural resource organizations. Funding came through a State Wildlife Grant, with matching funds from Georgia's

Nongame Wildlife Conservation Fund. Creating a guide for the DNR and other conservation groups to follow proved a complex task, requiring input from several state and federal agencies, non-governmental organizations, land managers, various other stakeholders and the public. Approved by the US Fish and Wildlife Service in October 2005, Georgia's wildlife conservation strategy is now dubbed the State Wildlife Action Plan, or SWAP. [GA-DNR, WRD website description]

Granger, Teri, Tom Hruby, Andy McMillan, Douglas Peters, Jane Rubey, Dyanne Sheldon, Stephen Stanley, and Erik Stockdale (2005). *Wetlands in Washington State - Volume 2: Guidance for Protecting and Managing Wetlands*. Washington State Department of Ecology. Publication #05-06-008. Olympia, WA. Available at: http://www.ecy.wa.gov/programs/sea/wetlands/bas/vol2final/Cover%20and%20Table%20of%20Contents_Volume_2.pdf

Abstract: This document is the second part of a two-part document addressing wetlands in Washington and their protection and management. Volume 2 contains guidance primarily for local governments on protecting and managing wetlands and their functions. Although the primary audience is local governments, the information contained in this document should be useful to anyone who has an interest in the protection and management of wetlands in the state. The key themes or messages in Volume 2 are as follows:

- By relying on a site-by-site approach to managing wetlands, we are failing to effectively protect them;
- To effectively protect wetlands and their functions, we must understand and manage their interaction with the environmental factors that control wetland functions;
- To understand and manage these environmental factors and wetland functions, information generated through landscape analysis is needed;
- Landscape analysis should be one step in a four-step framework that should be used in developing a diversified program to protect and manage wetlands and their functions; the four-step framework should include analyzing the landscape, prescribing solutions, taking actions, and monitoring results and applying adaptive management; and
- Protection and management measures developed and implemented in steps two and three of the four-step framework (prescribing solutions and taking action) should incorporate a full range of components including:
    - Policies and plans such as landscape-based plans (such as Green Infrastructure), comprehensive plans, subarea plans, etc.
    - Regulations such as critical areas ordinances, clearing and grading ordinances, etc.
    - Non-regulatory activities such as incentives that encourage conservation, restoration, and preservation through voluntary efforts. [Abstract from Author]

Hruby, T. (2013). *Update on Wetland Buffers: The State of the Science, Final Report, October 2013*. Washington State Department of Ecology Publication #13-06-11. Available at: https://fortress.wa.gov/ecy/publications/publications/1306011.pdf

Abstract: Between 2003 and the winter of 2012. We focus on wetland buffers, since buffers are one of the most common elements of wetland regulations in Critical Area Ordinances (CAOs), and they are consistently the part of a CAO of most interest and concern to the public. Limited resources prevent us from expanding our review and update to other issues at this time. This update revisits the conclusions and key points concerning wetland buffers made in the 2005 synthesis. Each conclusion is reviewed with respect to any new information that was Buffers are vegetated areas adjacent to aquatic resources that can, through various physical, chemical, and/or biological processes, reduce impacts to these resources from adjacent land uses. Buffers also provide some of the terrestrial habitats necessary for wetland-dependent species that require both aquatic and terrestrial habitats.

Update on Wetland Buffers Final Report October 2013 published between 2003 and 2012, or information in earlier studies that we may have missed and that has come to our attention. If the conclusion is still valid, new references supporting it are noted. If the conclusion needs to be expanded or modified, then revised conclusions are presented based on the new information. In reviewing the recent information we also found that some of the studies address issues that were not commonly discussed in the past. New conclusions that can be made from this information are presented as updates of old conclusions in the appropriate sections. [Abstract from Author]

Hruby, T. (2004). *Washington State wetland rating system for western Washington – Revised*. Washington State Department of Ecology Publication # 04-06-025. Available at: https://fortress.wa.gov/ecy/publications/publications/0406025.pdf

Abstract: This rating system is designed to differentiate between wetlands based on their sensitivity to disturbance, rarity, the functions they provide, and whether we can replace them or not. The emphasis is on identifying those wetlands: where our ability to replace them is low, that are sensitive to adjacent disturbance, that are rare in the landscape, that perform many functions well, that are important in maintaining biodiversity.

The following description summarizes the rationale for including different wetland types in each category. As a general principle, it is important to note that wetlands of all categories have valuable functions in the landscape, and all are worthy of inclusion in programs for wetland protection. Tools are needed to provide information on the functions and values of wetlands in a time - and cost - effective way. One way to accomplish this is to categorize wetlands by their important attributes or characteristics based on the collective judgment of regional experts. Such methods are relatively rapid but still provide some scientific rigor. The Washington State Wetland Rating System categorizes wetlands based on specific attributes such as rarity, sensitivity to disturbance, and functions. This rating system was designed to differentiate between wetlands based on their sensitivity to disturbance, their significance, their rarity, our ability to replace them, and the functions they provide. The rating system, however, does not replace a full assessment of wetland functions that may be necessary to plan and monitor a project of compensatory mitigation. The rating categories are intended to be used as the basis for developing standards for protecting and managing the wetlands to reduce further loss of their value as a resource. Some decisions that can be made based on the rating include the width of buffers needed to protect the wetland from adjacent development; the ratios needed to compensate for impacts to the wetland, and permitted uses in the wetland. [Abstract from Author]

March, R.G. and Smith, E.H. (2012). Modeling potential coastal vegetation response to sea level rise and storm surge on estuarine peninsulas. *Journal of Coastal Research* 28(5): 993–1007. Available at: http://jcronline.org/doi/pdf/10.2112/JCOASTRES-D-10-00177.1

Abstract: Upland vegetation changes in response to sea level rise and storm surge were evaluated on two peninsulas adjacent to the Copano Bay–Aransas Bay system and within a semiarid coastal environment in south-central Texas. Potential natural land cover models were created in a geographical information system (GIS) using soil data attributes and elevation data to compare land cover shifts under various sea level rise and storm surge scenarios. Ecological sites used as mapping units were related to land cover classes by generating a classification crosswalk. Crosswalks were expanded in the GIS to define how each land cover type would change with each meter of estuarine inundation using digital elevation models. Potential natural land cover maps show that grassland and/or evergreen are concentrated in the center of both peninsulas with grassland lining the perimeter. Mainland connections of Lamar and Live Oak peninsulas are primarily salty prairie and grassland, respectively. On Lamar Peninsula, a 1-m sea level rise results in a conversion of salty prairie (- 99%) to estuarine emergent (+ 97%). A total rise of 3 m reduces grassland by 99% and evergreen forest by 71%. A 1-m sea level rise on Live Oak Peninsula eliminates over half of the salty prairie, which becomes estuarine emergent class. These values indicate the vegetation that will at least be temporarily impacted by storm surge. Higher elevations and steeper slopes on Live Oak Peninsula result in lower inundation values for upland habitats as compared with Lamar Peninsula. Sea level rise and storm surge events will continue to be a major influence on vegetative composition in estuarine environments and should be considered in future land use and conservation planning. [Abstract from Author]

Maryland Coastal Zone Management Program, Department of Natural Resources (2012). *The Green Book for the Buffer*. Prepared by Adkins Arboretum and the Critical Area Commission for the Chesapeake and Atlantic Coastal Bays. Available at: http://www.dnr.state.md.us/criticalarea/pdfs/GreenBook_Buffer_sm.pdf

Abstract: Maryland's Critical Area Program includes specific regulations for the "Critical Area Buffer" that address protection of existing buffer vegetation, as well as requirements to plant additional buffer vegetation when development activity takes place on a property that includes shoreline, wetland frontage, or a stream. This book was developed to help landowners gain a better understanding of the buffer requirements and how to comply with the regulations. It includes some of the science and technical details about the many important functions of vegetated buffers, information about how to measure the buffer on private property, and a description of the different types of Buffer Management Plans and when they are used. The second part of the book includes Garden Plans that can be used to design and plant in a buffer. The plans are organized so that if there is a specific planting area requirement, a plan can easily be selected that will provide the correct square footage credit. Buffer Management Plan Notes are included in the following chapter to make it easy to submit a complete Buffer Management Plan to the local planning office. There is also information about maintaining and enhancing an existing forested buffer. [Abstract from Author]

Mayer, P.M., S.K. Reynolds, M.D. McCutchen, and T.J. Canfield (2007). Meta-Analysis of Nitrogen Removal in Riparian Buffers. *Journal of Environmental Quality* 36: 1172–1180. Available at: https://www.agronomy.org/publications/jeq/pdfs/36/4/1172.

Abstract: Riparian buffers, the vegetated region adjacent to streams and wetlands, are thought to be effective at intercepting and reducing nitrogen loads entering water bodies. Riparian buffer width is thought to be positively related to nitrogen removal effectiveness by influencing nitrogen retention or removal. We surveyed the scientific literature containing data on riparian buffers and nitrogen concentration in streams and groundwater to identify trends between nitrogen removal effectiveness and buffer width, hydrological flow path, and vegetative cover. Nitrogen removal effectiveness varied widely. Wide buffers (0.50 m) more consistently removed significant portions of nitrogen entering a riparian zone than narrow buffers (0–25 m). Buffers of various vegetation types were equally effective at removing nitrogen but buffers composed of herbaceous and forest/herbaceous vegetation were more effective when wider. Subsurface removal of nitrogen was efficient, but did not appear to be related to buffer width, while surface removal of nitrogen was partly related to buffer width. The mass of nitrate nitrogen removed per unit length of buffer did not differ by buffer width, flow path, or buffer vegetation type. Our meta-analysis suggests that buffer width is an important consideration in managing nitrogen in watersheds. However, the inconsistent effects of buffer width and vegetation on nitrogen removal suggest that soil type, subsurface hydrology (e.g., soil saturation, groundwater flow paths), and subsurface biogeochemistry (organic carbon supply, nitrate inputs) also are important factors governing nitrogen removal in buffers. [Abstract from Author]

McElfish, James M. Jr., Rebecca L. Kihslinger, and Sandra S. Nichols (2008). *Planner's Guide to Wetland Buffers for Local Governments*. Environmental Law Institute, Washington D.C. Available at: http://www.eli.org/sites/default/files/eli-pubs/d18_01.pdf

Abstract: While many publications assist local governing boards with land use planning and zoning, this publication compiles the scientific literature on wetland buffers (the lands adjacent to wetland areas) and identifies the techniques used and legislative choices made by local governments across the United States to protect these lands. This guide for planners is based on detailed examination of approximately 50 enacted wetland buffer ordinances and nine model ordinances, and upon several hundred scientific studies and analyses of buffer performance. This guide identifies both the state-of-the-art and the range of current practice in the protection of wetland buffers by local governments. Local governments considering enacting or amending a wetland buffer ordinance will find here what they need to know to manage land use and development in these important areas. [Abstract from Author]

McMillan, Andrew (2000). *The Science of Wetland Buffers and Its Implication for the Management of Wetlands*. Thesis for Master of Environmental Studies, Evergreen State College, Olympia, Washington. Available at: http://archives.evergreen.edu/masterstheses/Accession86-10MES/McMillan_AMESThesis2000.pdf

Abstract: The protection of upland buffers around wetlands is a source of controversy for wetland regulators. Despite considerable scientific evidence that buffers are necessary to maintain wetland functions, the protection of buffers is frequently challenged as being an unnecessary and overly burdensome requirement of private property owners. Most local governments in Washington require the protection of buffers around wetlands although the required widths vary greatly. In 1995, the Growth Management Act was amended to require that local governments must include the "best available science" when adopting regulations to protect wetlands and other critical areas. Guidance adopted in spring, 2000 by the state Department of Community, Trade and Economic Development defines key characteristics of good scientific information and identifies and defines sources of valid scientific information. With this information, local governments are directed to either rely upon documents provided by state agencies or conduct their own independent review of the scientific literature to determine the "best available science." Where local governments deviate from the best available science in adopting local policies and regulations, they must specify why they deviated and what the possible environmental consequences might be.

The scientific literature on wetland buffers is substantial, and unequivocal in establishing that protection of buffers is critical to maintaining a wetland's functions and values. Numerous studies conducted across the United States and elsewhere in the world document the ways that buffers protect wetlands from the adverse impacts of adjacent development. The principal buffer functions that protect wetlands are: removal of sediments, nutrients and toxic substances in surface and shallow, subsurface runoff; reduction of noise, light and human and pet intrusion into wetlands; and the provision of adjacent riparian and upland habitat critical to numerous wildlife species that utilize wetlands. The scientific literature also indicates that the buffer characteristics and widths necessary to maintain wetland functions and values are dependent on site-specific conditions. The primary factors that should dictate buffer character and width are: 1) the quality, sensitivity and functions of the wetland; 2) the nature of adjacent land uses and their potential to impact the wetland; and 3) the character of the existing buffer area, including soils, slope and vegetation. While site-specific factors should be evaluated to determine effective buffer widths, generally widths of 15 to 30 meters are the minimum necessary to protect wetland water quality and widths of 30 to 100 meters are necessary to protect wetland wildlife habitat.

According to the Washington State Growth Management Act, wetland buffer protection and management programs must incorporate the best available science. However, local regulatory programs also need to be predictable for landowners and efficient for local staff to implement. Historically, most local buffer regulations have addressed the need for efficiency and predictability by adopting fixed buffer widths. However, given the need for site-specific consideration of the three factors outlined above, reliance on standard buffer widths may not be adequate to protect wetland functions in many cases and may require more than is necessary in other situations. By establishing

standard buffer widths based on the type of wetland and the type of adjacent land use and including specific provisions for making site-specific adjustments, local governments can address the need for predictability and efficiency while incorporating the best available science. [Abstract from Author]

Niesing, Hugo (2005). EUROSION: Coastal erosion measures, knowledge and results acquired through 60 studies. In: *Proceedings 'Dunes and Estuaries 2005' - International Conference on Nature Restoration Practices in European Coastal Habitats*, Herrier J.-L., J. Mees, A. Salman, J. Seys, H. Van Nieuwenhuyse and I. Dobbelaere (Eds). Koksijde, Belgium, 19-23 September 2005. Available at: http://scholar.google.com/scholar?cluster=7842595469871016566&hl=en&as_sdt=1,11&as_ylo=2005&as_yhi=2014

Abstract: Approximately twenty percent of the European Union's coast is currently eroding despite the development of a wide range of measures to protect shorelines from eroding and flooding. The prospect of further sea level rise due to climate change and the heritage of mismanagement in the past – such as inappropriate infrastructure – imply that coastal erosion will be a growing concern in the future. This is why DG Environment of the European Commission tendered the EUROSION project, which was realized by a consortium led by the National Institute for Coastal and Marine Management of the Dutch Ministry of Transport, Public Works and Water Management.

A state of the art report was compiled, based on a Europe wide review of successful and unsuccessful strategies, measures and experiments to prevent or manage erosion for different types of coast. This paper presents the main lessons learned from the practical level of coastal erosion management. It aims to provide an overview to coastal managers at the European, national and regional and municipal levels with a state-of-the-art of coastal erosion management solutions in Europe, based on the review of 60 case studies. The case studies along the European coast have been selected on the following criteria: coastal erosion, land use and geographical distribution. The cases, scattered around Europe, are meant to illustrate the different situations on the assessment levels; coastal classification, exiting policy, technical measures and socio-economic backgrounds. This paper focuses on the practical lessons learned and their possible utilization in coastal erosion management. To a lesser extent the relationship between the perspective provided by the European database and the EUROSION policy recommendations is discussed. [Abstract from Author]

Novotney, Michael. 2009. *Coastal Stormwater Supplement to the Georgia Stormwater Management Manual*. Center for Watershed Protection. Available at: http://www.gaepd.org/Documents/CoastalStormwaterSupplement.html

Abstract: The purpose of the Coastal Stormwater Supplement (CSS) is to protect Georgia's existing water quality standards, particularly those of the state's coastal waters. It also provides for the implementation of the federally established "management measures" related to new development, watershed protection and site development in the Coastal Nonpoint Source Management Area and Area of Special Interest. To provide for the implementation of these "management measures, it provides comprehensive guidance on an integrated, green infrastructure-based approach to natural resource protection, stormwater management and site design that can be used by Georgia's coastal communities to better protect coastal Georgia's unique and vital natural resources from the negative impacts of land development and nonpoint source pollution.

Although communities may choose to use the information presented in this CSS to regulate new development and redevelopment activities, the document itself has no independent regulatory authority. The integrated approach to natural resource protection, stormwater management and site design detailed in this CSS can only become required through:

(a) Codes and ordinances established by local governments; or
(b) Rules and regulations established by other local, state and federal agencies (i.e. the Rules associated with the upland development component of new Coastal Marshlands Protection Act permits). [Abstract from Author]

Polyakov, V., A. Fares, A., and M.H. Ryder (2005). Precision riparian buffers for the control of nonpoint source pollutant loading into surface water: A review. *Environmental Reviews* 13:129-144. Available at: http://www.co.benton.or.us/cd/riparian/documents/precision_riparian_buffers.pdf

Abstract: Numerous studies have shown the effectiveness of riparian buffers in reducing sediment, pathogen, and nutrient loads into surface and groundwater in agricultural catchments. Reported retention rates of sediment, N, and P were as high as 97%, 85%,and 84%, respectively. Often, however, riparian buffers fail to perform their protective functions due to low adaptability of their designs to local settings. This is caused by our inadequate understanding of the conditions under which riparian buffers perform the best at field scale. Therefore, a precision oriented approach based on thorough analysis of spatially variable characteristics of landscape has to be undertaken in riparian buffer construction. Such an approach has a potential to improve the protective qualities and the economic viability of the riparian buffers. This paper gives an overview of the current level of research on riparian buffers and discusses the importance of spatial variability of local conditions on their performance. It presents the approaches for precision buffer design and its practical implementation and highlights the directions for future development of precision conservation. [Abstract from Author]

Sanger, D., A. Blair, G. DiDonato, T. Washburn, S. Jones, R. Chapman, D. Bergquist, G. Riekerk, E. Wirth, J. Stewart, D. White, L. Vandiver, S. White, D. Whitall (2008). Support for Integrated Ecosystem Assessments of NOAA's National Estuarine Research Reserves System (NERRS), Volume I: *The Impacts of Coastal Development on the Ecology and Human Well-being of Tidal Creek Ecosystems of the US Southeast*. NOAA. Available at: http://hml.noaa.gov/pdf/nos-nccos-82.pdf

Abstract: A study was conducted, in association with the Sapelo Island and North Carolina National Estuarine Research Reserves (NERRs), to evaluate the impacts of coastal development on sentinel habitats (e.g., tidal creek ecosystems), including potential impacts to human health and well-being. Nineteen tidal creek systems, located along the southeastern United States coast from southern North Carolina to southern Georgia, were sampled for water and sediment quality, pathogens, and abundance and responses of biological resources. Study results indicate that the integrity and productivity of headwater tidal creeks were impaired by land use changes and associated non-point source pollution, suggesting these habitats are valuable early warning sentinels of ensuing ecological impacts and potential public health threats. Shellfish bed closures and the flooding vulnerability of headwater regions become a concern when impervious cover values exceed 10-30%. This information can be used to forecast the impacts of changing land use patterns on tidal creek environmental quality as well as associated human health and well-being. [Abstract from Author]

Sanger, D., D. Bergquist, A. Blair, G. Riekerk, E. Wirth, L. Webster, J. Felber, T. Washburn, G. DiDonato, A.F. Holland (2011). *Gulf of Mexico Tidal Creeks Serve as Sentinel Habitats for Assessing the Impact of Coastal Development on Ecosystem Health*. NOAA Technical Memorandum NOS NCCOS 136. 64 pp. Available at: http://noaa.ntis.gov/view.php?pid=NOAA:ocn774386510

Abstract: A study was conducted, in association with the Sapelo Island and North Carolina National Estuarine Research Reserves (NERRs), to evaluate the impacts of coastal development on sentinel habitats (e.g., tidal creek ecosystems), including potential impacts to human health and well-being. Five Gulf of Mexico systems from Alabama and Mississippi were sampled for water and sediment quality, pathogens, and abundance and responses of biological resources. Results indicate that the tidal creek classification system developed for the southeastern US could be applied to the Gulf of Mexico tidal creeks. However, pollutants appeared to translate further downstream in the Gulf of Mexico streams compared to those of the southeastern states. These differences are likely the result of the morphological and oceanographic differences between the two regions. Tidal creeks appear to serve as sentinel habitats to provide an early warning of the ensuing harm to the larger ecosystem in both the Southeastern and Gulf of Mexico US tidal creeks. [Abstract from Author]

Shellenbarger, Jones, A., C. Bosch, and E. Strange (2009). Vulnerable species: the effects of sea-level rise on coastal habitats. In: *Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region*. [J.G. Titus (coordinating lead author), K.E. Anderson, D.R. Cahoon, D.B. Gesch, S.K. Gill, B.T. Gutierrez, E.R. Thieler, and S.J. Williams (lead authors)]. U.S. Environmental Protection Agency, Washington DC, pp. 73-84. Available at: http://papers.risingsea.net/coastal-sensitivity-to-sea-level-rise-5-vulnerable-species.html

Abstract: This chapter presents simplifications of habitat interactions in order to identify primary potential effects of both increased rates of sea-level rise and likely shore protections on vulnerable species. Under natural conditions, habitats are continually shifting; the focus of this chapter is the effect that shoreline management will have on the ability for those shifts to occur (e.g., for marshes or barrier islands to migrate, for marsh to convert to tidal flat or vice versa) and any interruption to the natural shift. This chapter also describes the primary coastal habitats and species that are vulnerable to the interactive effects of sea-level rise and shore protection activities, and highlights those species that are of particular concern.

Shepard, Christine C., Caitlin M. Crain, and Michael W. Beck (2011). The Protective Role of Coastal Marshes: A Systematic Review and Meta-analysis. *PLoS ONE* 11/23. Available at: http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0027374

Abstract: Salt marshes lie between many human communities and the coast and have been presumed to protect these communities from coastal hazards by providing important ecosystem services. However, previous characterizations of these ecosystem services have typically been based on a small number of historical studies, and the consistency and extent to which marshes provide these services has not been investigated. Here, we review the current evidence for the specific processes of wave attenuation, shoreline stabilization and floodwater attenuation to determine if and under what conditions salt marshes offer these coastal protection services. We found that combined across all studies (n = 7), salt marsh vegetation had a significant positive effect on wave attenuation as measured by reductions in wave height per unit distance across marsh vegetation. Salt marsh vegetation also had a significant positive effect on shoreline stabilization as measured by accretion, lateral erosion reduction, and marsh surface elevation change (n = 30). Salt marsh characteristics that were positively correlated to both wave attenuation and shoreline stabilization were vegetation density, biomass production, and marsh size. Although we could not find studies quantitatively evaluating floodwater attenuation within salt marshes, there are several studies noting the negative effects of wetland alteration on water quantity regulation within coastal areas. Our results show that salt marshes have value for coastal hazard mitigation and climate change adaptation. Because we do not yet fully understand the magnitude of this value, we propose that decision makers employ natural systems to maximize the benefits and ecosystem services provided by salt marshes and exercise caution when making decisions that erode these services. [Abstract from Author]

Simpson, Thomas and Sarah Weammert (2009). *Developing Best Management Practice Definitions and Effectiveness Estimates for Nitrogen, Phosphorus and Sediment in the Chesapeake Bay Watershed Final Report.* University of Maryland Mid-Atlantic Water Program. Available at: http://archive.chesapeakebay.net/pubs/BMP_ASSESSMENT_REPORT.pdf

Abstract: The Mid-Atlantic Water Program (MAWP) housed at the University of Maryland (UMD) led a project commissioned and funded by the EPA/CBPO to develop the definitions and effectiveness estimates of select BMPs that states were implementing or proposing to implement as part of the Tributary Strategies. The objective was to scientifically-rigorous approach for development of definitions and effectiveness estimates by reflecting the average operational condition representative of the entire Chesapeake Bay Watershed. BMPs were evaluated and their effectiveness estimates revised to better reflect current research and knowledge, providing more realistic, science-based estimates of expected pollution reduction levels. This report provides definitions for each BMP, and when applicable, subcategories of definitions based on level of management, BMP design, hydrogeomorphic location or the land use to which the practice is applied. Effectiveness estimates are provided for total nitrogen, total phosphorus and total suspended sediment. [Abstract from Author]

Studds, Colin E., William V. DeLuca, Matthew E. Baker, Ryan S. King, and Peter P. Marra (2012). Land cover and rainfall interact to shape waterbird community composition. *PLoS ONE* 7(4): e35969. Available at:

http://www.plosone.org/article/fetchObject.action?uri=info%3Adoi%2F10.1371%2Fjournal.pone.0035969&representation=PDF

Abstract: Human land cover can degrade estuaries directly through habitat loss and fragmentation or indirectly through nutrient inputs that reduce water quality. Strong precipitation events are occurring more frequently, causing greater hydrological connectivity between watersheds and estuaries. Nutrient enrichment and dissolved oxygen depletion that occur following these events are known to limit populations of benthic macroinvertebrates and commercially harvested species, but the consequences for top consumers such as birds remain largely unknown. We used non-metric multidimensional scaling (MDS) and structural equation modeling (SEM) to understand how land cover and annual variation in rainfall interact to shape waterbird community composition in Chesapeake Bay, USA. The MDS ordination indicated that urban sub-estuaries shifted from a mixed generalist-specialist community in 2002, a year of severe drought, to generalist-dominated community in 2003, of year of high rainfall. The SEM revealed that this change was concurrent with a sixfold increase in nitrate-N concentration in sub-estuaries. In the drought year of 2002, waterbird community composition depended only on the direct effect of urban development in watersheds. In the wet year of 2003, community composition depended both on this direct effect and on indirect effects associated with high nitrate-N inputs to northern parts of the Bay, particularly in urban sub-estuaries. Our findings suggest that increased runoff during periods of high rainfall can depress water quality enough to alter the composition of estuarine waterbird communities, and that this effect is compounded in sub-estuaries dominated by urban development. Estuarine restoration programs often chart progress by monitoring stressors and indicators, but rarely assess multivariate relationships among them. Estuarine management planning could be improved by tracking the structure of relationships among land cover, water quality, and waterbirds. Unraveling these complex relationships may help managers identify and mitigate ecological thresholds that occur with increasing human land cover. [Abstract from Author]

Torio, D.D. and Chmura, G.L. (2013). Assessing coastal squeeze of tidal wetlands. *Journal of Coastal Research* 29(5): 1049–1061. Available at: http://www.jcronline.org/doi/abs/10.2112/JCOASTRES-D-12-00162.1

Abstract: As sea level rise accelerates and land development intensifies along coastlines, tidal wetlands will become increasingly threatened by coastal squeeze. Barriers that protect inland areas from rising sea level prevent or reduce tidal flows, and impermeable surfaces prevent wetland migration to the adjacent uplands. As vegetation succumbs to submergence by rising sea levels on the seaward edge of a wetland, those wetlands prevented from inland migration will decrease in area, if not disappear completely. Tools to identify locations where coastal squeeze is likely to occur are needed for coastal management. We have developed a "Coastal Squeeze Index" that can be used to assess the potential of coastal squeeze along the borders of a single wetland and to rank the threats faced by multiple wetlands. The index is based on surrounding topography and impervious surfaces derived from light detection and ranging and advanced space-borne thermal emission and reflection radiometry imagery, respectively, and uses a fuzzy logic approach. We assume that coastal squeeze varies continuously over the coastal landscape and tested several fuzzy logic

functions before assigning a continuous weight, from 0 to 1, corresponding to the influence of slope and impervious surfaces on coastal squeeze. We then combined the ranked variables to produce a map of coastal squeeze as a continuous index. Using this index, we compare the present and future threat of coastal squeeze to marshes in Wells and Portland, Maine, in the United States and Kouchibouguac National Park in New Brunswick, Canada.

Van Dolah, Robert F., George H.M. Riekerk, Derk C. Bergquist, Jordan Felber, David E. Chestnut, and A. Fredrick Holland (2008). Estuarine habitat quality reflects urbanization at large spatial scales in South Carolina's coastal zone. *Science of the Total Environment* 390(1): 142-154. Available at: http://www.sciencedirect.com/science/article/pii/S0048969707010492

Abstract: Land cover patterns were evaluated in 29 estuarine watersheds of South Carolina to determine relationships between urban/suburban development and estuarine habitat quality. Principal components analysis and Pearson product moment correlation analyses were used to examine the relationships between ten land cover categories and selected measures of nutrient or bacterial enrichment in the water column and contaminant enrichment in sediments. These analyses indicated strong relationships between land cover categories representing upland development and a composite measure of 24 inorganic and organic contaminants using the Effect Range Median-Quotient (ERM-Q). Similar relationships also were observed for the summed concentrations of polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), pesticides, and metals. Data obtained from tidal creeks generally showed stronger correlations between urban/suburban land use and pesticides and metals compared to data obtained from larger open water habitats. Correlations between PAH concentrations and the urban/suburban land cover categories were similar between creek and open water habitats. PCB concentrations generally showed very little relationship to any of the land cover categories. Measures of nutrient enrichment, which included total Kjeldahl nitrogen (TKN), nitrate–nitrite, phosphorus, chlorophyll-a, and total organic carbon, were generally not significantly correlated with any land cover categories, whereas fecal coliform bacteria were significantly and positively correlated with the urban/suburban land cover categories and negatively correlated with the non-urban land cover categories. Fecal coliform correlations were stronger using data from the open water sites than from the tidal creek sites. Both ERM-Q and fecal coliform concentrations were much greater and more pervasive in watersheds with relatively high (> 50%) urban/suburban cover compared to watersheds with low (< 30%) urban/suburban cover. These analyses support the hypotheses that estuarine habitat quality reflects upland development patterns at large spatial scales, and that upland urbanization can result in increased risk of biological degradation and reduced safe human use of South Carolina's coastal resources.

Vidon, P. G. F., and A. R. Hill (2004). Landscape controls on nitrate removal in stream riparian zones. *Water Resour. Res*. 40: W03201. Available at: http://onlinelibrary.wiley.com/doi/10.1029/2003WR002473/pdf

Abstract: We examined how landscape hydrogeologic characteristics influence groundwater nitrate removal by eight stream riparian sites on glacial till and outwash landscapes in southern Ontario,

Canada. During high water table periods in 2000–2002, mean NO_3-Ninput concentrations from adjacent cropland to the riparian sites ranged from 0.15 to 44.7 mg L^{-1}. Seven of the 8 sites had a mean nitrate removal efficiency of >90%. This removal occurred within the first 15 m of the riparian zone at three sites with loamy sand and sandy loam soils overlying a shallow confining layer at 1 to 2 m. However, at four of five sites with more conductive sand and cobble sediments the width required for 90% nitrate removal varied from >25 m to a maximum of 176 m at a site with a confining layer at 6 m. Sites linked to an extensive thick (>6 m) upland aquifer with a slope gradient of >15% at the riparian perimeter had high nitrate inputs throughout the year and were large nitrate sinks. Sites with gentle topography (<4–5%) and <2 m of permeable sediments were minor nitrate sinks because of small nitrate inputs that were limited to the late autumn-spring period. A conceptual model linking landscape hydrogeologic characteristics to riparian zone nitrate removal capacity is developed to understand and predict the effectiveness of riparian buffers at the landscape scale. [Abstract from Author]

Virginia Department of Conservation and Recreation (2009). *Resource Protection Area: Onsite Buffer Area Delineation*. (DCR-CBLAB-013) (06/09). Available at: http://www.deq.virginia.gov/Portals/0/DEQ/Water/Guidance/ChesBayPreservAct/RPA-OnsiteBufferAreaDelineation.pdf

Abstract: This document provides guidance on requirements of the Chesapeake Bay Preservation Act with regard to the onsite delineation of the buffer component of the RPA. The guidance has been developed to establish the procedure for physically measuring the buffer area component of the Resource Protection Area on a development site. The Bay Act Regulations establish the Resource Protection Area (RPA) as the "shoreward" component of the Chesapeake Bay Preservation Area. RPA's are composed of tidal wetlands, non-tidal wetlands connected by surface flow and contiguous to tidal wetlands or water bodies with perennial flow, tidal shores, such other lands considered necessary to protect the quality of state waters and a 100-foot buffer adjacent to and landward of these features. [Abstract from Author]

Zhang, X., X. Liu, M. Zhang, and R.A. Dahlgren (2010). A review of vegetated buffers and a meta-analysis of their mitigation efficacy in reducing nonpoint source pollution. *Journal of Environmental Quality* 39:76-84. Available at: http://eva.universidad.edu.uy/file.php/1426/PAPERS/Colloquia_1/Zhang_Team2.pdf

Abstract: Vegetated buffers are a well-studied and widely used agricultural management practice for reducing nonpoint-source pollution. A wealth of literature provides experimental data on their mitigation efficacy. This paper aggregated many of these results and performed a meta-analysis to quantify the relationships between pollutant removal efficacy and buffer width, buffer slope, soil type, and vegetation type. Theoretical models for removal efficacy (Y) vs. buffer width (w) were derived and tested against data from the surveyed literature using statistical analyses. A model of the form $Y = K \times (1-e^{bwYK})$, $(0 < K \leq 100K)$ successfully captured the relationship between buffer width and pollutant removal, where *K* reflects the maximum removal efficacy of the buffer and *b* reflects its probability to remove any single particle of pollutant in a unit distance. Buffer width alone

explains 37, 60, 44, and 35% of the total variance in removal efficacy for sediment, pesticides, N, and P, respectively. Buffer slope was linearly associated with sediment removal efficacy either positively (when slope ≤ 10%) or negatively (when slope > 10%). Buffers composed of trees have higher N and P removal efficacy than buffers composed of grasses or mixtures of grasses and trees. Soil drainage type did not show a significant effect on pollutant removal efficacy. Based on our analysis, a 30-m buffer under favorable slope conditions (≈ 10%) removes more than 85% of all the studied pollutants. These models predicting optimal buffer width/slope can be instrumental in the design, implementation, and modeling of vegetated buffers for treating agricultural runoff. [Abstract from Author]