Exhibit A

UNIVERSITY OF GEORGIA

Odum School of Ecology

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To whom it may concern: Comments on "A Literature Review: The Chemical, Physical and Biological Significance of Geographically Isolated Wetlands and Non-Perennial Streams in the Southeast"

Overall evaluation and context:

The U.S. Environmental Protection Agency and the U.S. Army Corp of Engineers have proposed to rescind the 2015 Clean Water Rule. As a result, many of the nation's freshwater ecosystems are at risk of being removed from protection. These systems include headwater streams that can be ephemeral or intermittent in nature (non-perennial streams), and any wetlands that do not have a surface connection with or abut other jurisdictional waters. This literature review describes the rich variety of wetlands that do not have direct hydrologic surface connection (i.e., geographically isolated wetlands (GIW)) and ephemeral and intermittent streams in the Southeast U.S. The literature review focuses on the ecosystem services provided by these systems and uses a rigorous framework for their description, which includes supporting, regulating, provisioning and cultural ecosystem services. The ecosystem services described are irreplaceable and contribute to human health and well-being, now and in the future. The literature review also describes case studies of human modification of these systems and the benefits in ecosystem services gained with restoration of degraded systems and services lost with degradation. These case studies are useful to illustrate what is at risk in removing protection from these freshwater systems.

Assessment of the Ecosystem Services provided by GIW and Intermittent and Ephemeral streams:

Ecosystem services derive from the structural components of ecosystems and the emergent properties of those systems in terms of their functions. Ecosystem structures are the building blocks of systems, such as the animals (large and small) that live in the systems to do the 'work', the food resources they depend on, and aspects of pollution concentrations, substrate, and habitat that comprise natural and human-modified systems[1,2]. Ecosystem functions include the rates of carbon and nutrient cycling, fish production, pollution removal, primary production, and decomposition. Ecosystem services are defined by aspects of ecosystem structures and functions that are valued by humans. In many cases, the terms to describe ecosystem services are the same ones used by scientists for ecosystem structures and functions. In other cases, the terms for ecosystem services are focused on integrative functions of systems that people can perceive or see value in. Thus, natural functioning ecosystems provide biodiversity, fish production, drinking water purification, water quantity, aesthetic pleasure, etc. – all of which are either ecosystem structures and functions (e.g., fish production), human perception of those (e.g., drinking water purification = pollutant removal and nutrient cycling), or new perceptions based on the human-nature relationship (e.g, aesthetics and recreation, flood mitigation).

Geographically isolated wetlands provide a diversity of ecosystem services that include the rich variety of plants and animals that live in these systems, and in many cases are found only in these systems. Animals include not only small invertebrates, but also reptiles and amphibians, and the terrestrial animals such as birds that depend on these systems. These systems are critical for the retention of cycling of carbon, nitrogen, and phosphorus. Upland systems retain essential water, nutrient, and energy sources available for the production of freshwater animals and keep the unwanted transport of these materials from going too quickly downstream (in the case of excess water or nutrients). These systems play critical roles in flood mitigation and water purification. These systems also provide cultural and economic benefit to humans through enabling opportunities for fishing, hunting, tourism, and reducing negative economic impact to downstream systems.

Non-perennial streams also deliver a multitude of ecosystem services to humans. Southeastern rivers are known as the 'treasure chest' of species of fish and mussels found nowhere else on earth. Conservation of these systems, particularly non-perennial streams, is paramount to the conservation of many imperiled fish species. Headwater and non-perennial streams are the 'branches' of river networks. The retention and processing of energy and nutrients in the smallest branches of river systems affects all downstream functions and conditions. The literature review provides a comprehensive view of the function of non-perennial streams relative to larger rivers that are the 'trunks' of river systems. Large river 'trunks' can only function if the functions and services of small branches are conserved.

What is gained when GIW and Intermittent and Ephemeral streams are conserved or restored?:

Geographically isolated wetlands that have been conserved for decades provide unique and valuable services. These include those associated with Ellenton Bay, SC and Green Swamp, NC, and include support of the growth and survival of many different kinds of plant, bird, mammal, reptile and amphibian species. These include turtles, migratory waterfowl, bear, and orchids. Without suitable habitat, these organisms would not thrive or persist. The literature review outlines ecosystem services that have been gained through restoration of damaged GIW and non-perennial streams. These include increases in flood control and protection of downstream water quality and significant amenities associated with recreation.

This literature review provides a comprehensive view of the ecosystem services that geographically isolated wetlands and non-perennial streams provide to citizens of the U.S. It provides the scientific basis for our understanding of how those services are derived by exploring the underlying ecosystem structures and functions that work together to provide these services. These services are critical now for the health and vitality of the people and economies of the U.S. and will be needed for future generations of Americans. Removing protection from these systems compromises these services. The literature review is well-researched and supported by credible and many peer-reviewed sources. It provides a good overview of the chemical, physical and biological significance of geographically isolated wetlands and non-perennial streams in the Southeast, which is consistent with my own research, teaching, and experience.

Sincerely,

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President-Elect, Society for Freshwater Science

References: [1]Palmer and Febria. 2012. The heartbeat of ecosystems. *Science* 336, 1393; [2]Kominoski and Rosemond. 2012. Conservation from the bottom up: forecasting effects of global change on dynamics of organic matter and management needs for river networks. *Freshwater Science* 31, 51-68.

A Literature Review: The Chemical, Physical and Biological Significance of Geographically Isolated Wetlands and Non-Perennial Streams in the Southeast

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Contents

1 Introduction

The Clean Water Act protects all "waters of the United States" from unpermitted discharges of pollutants. In 2015, the Environmental Protection Agency and the Army Corps of Engineers promulgated the Clean Water Rule. The Clean Water Rule was challenged immediately by states and industry in federal courts across the country. Currently, the Trump administration is attempting to repeal and replace the Clean Water Rule with another rule. The proposed replacement rule would not extend Clean Water Act protections to many types of wetlands that are currently jurisdictional, including geographically isolated wetlands, ephemeral streams, and possibly intermittent streams.

The purpose of this literature review is to identify and comment on peer-reviewed studies and federal reports that discuss the importance of GIWs, intermittent streams, and ephemeral streams. These studies are organized by ecosystem services defined in Section 3. The literature review is limited to studies conducted in Alabama, Georgia, North Carolina, South Carolina, Tennessee, and Virginia, as well as states that have similar geography to these states. Waters that are particularly important or well-studied have been developed into case studies.

2 Definition of Waters

2.1 Geographically Isolated Wetlands

The Scalia test excludes protection under the Clean Water Act for many currently jurisdictional wetland types, including so-called *geographically isolated wetlands* (GIWs). Named for their lack of apparent surface water outlets, GIWs can be both non-floodplain and riparian/floodplain wetlands (U.S. EPA, 2015) and are defined broadly as wetlands that are completely surrounded by uplands (Tiner, 2003). The distinction between wetlands and uplands is based on three criteria: vegetation, soils, and hydrology (Cowardin et al., 1979).

GIWs are considered isolated because they display unmeasurable or limited surface water connections to other surface waters (Golden et al., 2014). However, this does not imply functional isolation given that GIWs exhibit hydrological connections to other waters (Leibowitz, 2003; Tiner, 2003; U.S. EPA, 2015). Additionally, the strength of GIWs hydrological connection continuously varies (Leibowitz et al., 2018). For example, GIWs can spill over into adjacent surface waterbodies during periods of high precipitation (Winter and LaBaugh, 2003). The connections between GIWs and surface water can occur in a variety of ways including overland flow, groundwater flow, perched groundwater discharge, or horizontal near-surface flow (Golden et al., 2014; U.S. EPA, 2015; Leibowitz, 2003). The impact to groundwater flow can be wide spread, GIWs have been hydrologically connected over long distances (∼18 miles; Ameli and Creed, 2017). In regions dominated by GIWs, like the Carolina bays of the upper coastal plain of South Carolina, the combined effect of GIWs play a significant role in regulating flows to downgradient waters (Rains et al., 2016, see Section 5.3). These hydrological connections can also impact downstream biogeochemical conditions (i.e. nitrogen, phosphorus, and carbon; see Sections 5.2.2 and 5.2.3).

This suggests GIWs are better viewed as occurring along a constantly changing hydrological connectivity continuum instead of geographically isolated waters (Leibowitz and Nadeau, 2003; Euliss et al., 2004).

GIWs are common, comprising 15.6% of the freshwater wetland area in the contiguous U.S. (Lane and D'Amico, 2016). In other studies, scientists have found that of 276 vegetative-based wetland systems in the U.S., 29% are considered to be geographically isolated (Comer et al., 2005). In the southeastern states of interest, GIWs range from 4.1% to 12.2% of the total freshwater wetland habitat area by state for a total of 1.7 million acres [1] (Table 1).

Table 1: Geographically isolated wetlands in the southeast. The frequency and area of geographically isolated wetlands in the southeast U.S. Values calculated by Lane and D'Amico, 2016.

State	Count of GIWs	Total GIW Area (acres)[a]	GIW % of Total Freshwater Wetland Area
AL	87,653	161,073	4.1
GA	163,334	651,411	12.2
NC	83,581	362,064	8.7
SC	103,991	398,005	10.7
TN	130,951	92,662	6.2
VA	64,906	116,975	8.7

[a] A conversion factor of 2.47 acres per hectare, rounded to nearest whole number, was used.

2.2 Wetlands found in the southeastern U.S.[2]

While most GIWs occur in depressions, some naturally isolated wetlands occur on slopes or on broad flats (U.S. EPA, 2002; Tiner, 2003). The GIWs of the southeastern U.S. fall into one of these three categories (depressions, slopes, or flats).

2.2.1 Depressional wetlands

Depressional wetland systems are located in topographic depressions where surface water can accumulate (U.S. EPA, 2002). A majority of GIWs belong to the depressional wetlands category (Brinson, 1993; Leibowitz and Nadeau, 2003). The specific types of depressional GIWs found in the southeastern U.S. are described below.

Carolina bay wetlands

A Carolina bay is an elliptical depression that occurs throughout the southeastern Coastal Plain from New Jersey to northern Florida, but is most abundant in southeastern North Carolina and mid-coastal South Carolina (Sharitz, 2003). They have a unique geomorphic structure and hydrology is dominated by precipitation inputs and evapotranspiration losses (Sharitz, 2003). Water levels fluctuate seasonally and among years, depending on rainfall and groundwater water levels. Thus, while some bays may have surface waters at all times, other bays may appear dry most of the time (Sharitz, 2003).

In addition to precipitation, bays can also obtain water from artesian wells, shallow groundwater and runoff during periods of high rainfall (Wells and Boyce, 1953; Lide et al., 1995; Sharitz, 2003). There is uncertainty regarding the extent to which Carolina bays are connected to groundwater, but it is generally understood that some bays seem to be influenced

[1] converted from reported 721,222 hectares

[2] Please note that not all wetlands that fall in the categories below are GIWs. Some are located adjacent to other covered waters.

by subsurface lateral flows (Lide et al., 1995). Typically, intact Carolina bays have no natural drainages and overland surface flows are minimal. However, a few Carolina bays have small creeks flowing into them and a few form the headwaters of perennial streams. For example, Lake Waccamaw, the largest Carolina Bay, drains into the Waccamaw River in North Carolina. Additionally, some Carolina bays have natural stream drainages, which lead to other bays at lower elevations (Sharitz, 2003). More commonly, Carolina bays are connected to other waters through man-made ditches designed to either drain uplands into the bay or drain the bay itself (Bennett and Nelson, 1991). In fact, Bennett and Nelson, 1991 found ditches in about 65% of the 2,651 bays in South Carolina.

Carolina bays range in size from less than 1 *ha* to over 3,600 *ha* (Sharitz, 2003). Generally, they are distinguished by a southeastern sand rim. It is estimated that approximately 10,000-20,000 Carolina bays currently exist. Carolina bays occur in areas of sandy surficial sediments across elevations ranging from several meters above sea level to more than 200m above sea level. Soils range from highly organic to mineral, and some larger bays in eastern North Carolina have peat layers up to 4.5m thick (Ingram and Otte, 1981). Temperatures fluctuate with the seasons, ranging from lows near freezing to highs of 31-33°C during the summer, creating a highly variable and unique habitat (Sharitz and Gibbons, 1982). There are 11 main types of Carolina bays based on vegetation associations: lakes, small depression ponds, vernal pools, pond cypress ponds, non-alluvial swamps, pond cypress savannas, depression meadows, low and high pocosins, small depression pocosins, pond pine woodlands, and bay forests (Sharitz, 2003).

Sinkhole wetlands

Sinkhole wetlands are typical of karst landscapes where the collapse of land surface creates distinct basins (Tiner, 2003). All six southeastern states of interest have karstlands, which are characterized by sinkholes, caves, and springs. Some of these wetlands receive groundwater discharge from underlying limestone deposits, while others occur in basins formed by dissolution of underlying limestone (Tiner, 2003). An underground network of fissures moves water rapidly through the system, and surface water entering the system can impact groundwater quality on a rapid time scale (Tiner, 2003).

Upland swamps

Upland swamps generally occur from Maryland to South Carolina (Fleming and Patterson, 2004). They are primarily found in small, shallow basins in upland settings where water pools due to limited soil drainage (Fleming and Patterson, 2004). Most upland swamps are found over mafic (a mineral group rich in magnesium and iron) bedrock (NatureServe, 2017). Shallow, seasonal flooding is induced by perched water tables during the winter and spring months (NatureServe, 2017). Hydroperiods are irregular and unpredictable (NatureServe, 2017).

Canopy cover in upland swamps ranges from open to complete cover (Fleming and Patterson, 2004). Upland swamps in northern Virginia typically have pin oak, swamp white oak, and red maple canopies, while those found in the Southern Piedmont usually have willow oak, sweetgum, and overcup oak canopies (Fleming and Patterson, 2004). In these wetlands, the central depression with standing water is surrounded by a ring of shrubs, and an exterior ring of trees (NatureServe, 2017).

2.2.2 Slope wetlands

Slope wetlands occur on slopes where groundwater discharges reach the surface of a slope. Typically these wetlands do not have the capacity for surface water storage (U.S. EPA, 2002). Geographically isolated slope wetlands found in the southeastern U.S. include hillside seeps, Southern Appalachian seepage wetlands, and fens.

Hillside seeps

Hillside seeps are small patch ecosystems found on moist to wet slopes in sandy terrain. These wetlands are most common from Texas to southwestern Georgia (Harper et al.,1998). Hillside seeps represent natural groundwater discharge points. They may be dominated by shrubs or herbs (including pitcher plants), with scattered trees such as pond, slash, or longleaf pine (McMillan et al., 2002). Most seeps in the state of Georgia are fire-suppressed. Fire exclusion in hillside seeps can allow woody species to invade (Harper et al.,1998).

The soils of hillside seeps are saturated by discharge of groundwater between an overlaying permeable sandy layer and relatively impermeable lower layer (Harper et al.,1998). Soils are generally acidic and nutrient poor (Harper et al.,1998). They are hydrologically unique in that they are nearly constantly saturated but never inundated (Bridges and Orzell, 1989).

Southern Appalachian seepage wetland

This distinctive wetland is found where groundwater discharges on gentle slopes in the Southern Appalachians (NatureServe, 2017b). They tend to be small and can be found over wide elevational range, but generally lacking from flat valley bottoms (NatureServe, 2017b). At higher elevations, these wetlands are typically associated with headwater streams (U.S. EPA, 2008). Vegetation varies from low to high elevation ranging from forb-dominated to moss- or sedge-dominated, respectively (NatureServe, 2017b).

Fens

Fens are distinguished by a strong connection to groundwater and often occur where groundwater becomes surface water (Bedford and Godwin, 2003). Southeastern fens are groundwater-fed wetlands richer in nutrients and less acidic than bogs, typically with a slow internal drainage through seepage on a gradual slope (Richardson and Gibbons, 1993). Fens are generally found in the southern Appalachian region of the southeastern U.S.

Fens develop where a relatively constant supply of groundwater to the plant rooting zone maintains saturated conditions and water chemistry reflects the mineral content of surrounding soils and geological materials (Bedford and Godwin, 2003). The degree to which groundwater dominates fen water budgets is a continuum, but in all cases the influence of groundwater exceeds that of precipitation and surface water (Bedford and Godwin, 2003). These wetlands rarely flood creating a unique environment that supports highly diverse vegetation and many uncommon fauna, including many federally listed endangered species (Bedford and Godwin, 2003). Fens tend to be isolated from other surface waters, but can feed headwaters (Bedford and Godwin, 2003). When connected to surface waters the flow is predominately unidirectional out of the fen (Bedford and Godwin, 2003). Botanists distinguish fens from bogs by their vegetation, especially the presence of indicator species (Bedford and Godwin, 2003).

2.2.3 Flats wetlands

Flats wetlands are found in areas of low topographic relief, such as large floodplain terraces, with precipitation as the main source of water (U.S. EPA, 2002). Geographically isolated flats wetlands in the southeastern U.S. include pocosins and highland bogs.

Pocosins

Pocosin is an Algonquin Indian word meaning “swamp on a hill” (Richardson, 2003). Pocosins are classified as palustrine wetland ecosystems since they are nontidal wetlands and trees, shrubs, persistent emergent, and emergent mosses or lichens cover 30% of more of their area (Richardson, 2003). Pocosins are generally restricted to the southeastern coastal plain, occurring in broad, shallow basins, drainage basin heads, or on interfluves which are narrow plateau-like landforms between two valleys (Tiner, 2003). They occur from Virginia to northern Florida, but 70% of pocosins are in North Carolina and they comprise more than 50% of North Carolina’s freshwater wetlands (Tiner, 2003). Pocosin vegetation consists of evergreen trees and broad-leaved evergreen shrubs (Tiner, 2003) .

Pocosins are distinguished by long wet and dry periods, ephemeral surface water, periodic burning and sandy humus, muck or peat soils (Richardson, 2003). Most pocosins are seasonally connected to drainageways leading to estuaries or contiguous with other wetlands that drain into perennial rivers, streams, or estuaries (Tiner, 2003). However, there are some isolated pocosins including small depressional pocosins and those located in the Sandhills of the Carolinas or seasonally saturated interfluves (Weakley and Schafale, 1991; Tiner, 2003). One of the major functions of pocosins is to temporarily hold water that would otherwise run off the land more quickly into adjacent estuaries (Tiner et al., 2002; Tiner, 2003).

Highland bogs

Bogs are defined by their nutrient-poor, acidic and saturated soils, and are usually found in low-lying areas filled by precipitation (Brinson, 1993). Mosses and shrubs flourish while mature trees are rare. They are distinguished by the presence of Sphagnum species or peat moss (Brinson, 1993). Found in the southern Appalachian region of the southeastern U.S., bogs are saturated with water for most of the year.

Bog wetlands in Tennessee are associated with flat sites in the Southern Blue Ridge and Cumberland Mountains (TN Wildlife Action Plan Team, 2015). These sites occur at elevations below 1,220 m in poorly drained bottomlands on soils which are often saturated (TN Wildlife Action Plan Team, 2015). Vegetation is a mixture of partially open vegetative zones, with herbaceous-dominated areas as well as shrub thickets and forested zones (TN Wildlife Action Plan Team, 2015).

2.3 Streams

A stream is defined as a visible, natural channel that contains a relatively small volume of flowing water, where the subsurface water flows in the same direction as the surface water. The water in a stream can spread out beyond its channel and flow laterally as well. The lateral flows connect streams to floodplains and riparian areas (U.S. EPA, 2015; Naiman and Bilby, 1998). A channel is a natural or constructed passageway or linear depression that conveys water and materials from higher to lower elevations, and is defined by continuous bed and bank structures or a permeable, uninterrupted bottom and lateral boundaries (U.S. EPA, 2015).

Under pre-2015 regulatory definitions of the Clean Water Act, tributaries of all defined waters of the U.S. are within Army Corps of Engineers jurisdiction (U.S. EPA, 2015). This standard includes "relatively permanent" streams, and those which are not relatively permanent but possess a "significant nexus" to traditional navigable waters (Grumbles and Woodley, 2008).

2.3.1 Intermittent and Ephemeral Streams

Different flow duration classes include perennial, intermittent, and ephemeral streams. The classes can be distinguished by the duration and magnitude of baseflow (U.S. EPA, 2015). Baseflow sustains streamflow between hydrologic events and originates from groundwater discharge or seepage.

Perennial streams have baseflow year round and streambed elevation is below surrounding groundwater elevation, that is, the groundwater table is higher than the bottom of the channel (U.S. EPA, 2015). In a representative southeastern U.S. watershed, the Chattooga River basin, perennial streams comprise approximately 19% of total headwater stream length (Hansen, 2001). Intermittent streams have seasonal baseflow and may or may not maintain a groundwater connection. Continuous flow occurs only at wetter times of the year, while at other times portions of an intermittent stream can be dry. In these systems, flow is derived from seasonal precipitation, ground-water or surface water sources and typically surface flow has a low residence time (U.S. EPA, 2015). Unlike intermittent streams, ephemeral streams lack baseflow and are above the water table at all times. These systems flow briefly (hours to days) during and immediately following hydrologic events such as precipitation or snowmelt leading to stormflow (Brooks, 2009; U.S. EPA, 2015). In practice, these two stream types are often combined for the purposes of research and reporting and termed "ephemeral streams."

These definitions are consistent in U.S. regulatory agency reports and the peer-reviewed, scientific literature.

When considering the legal protection of intermittent and ephemeral streams compared to those that are perennial, it is important to recognize that the flow duration class of a stream may change through time, and is subject to human impacts. For example, the Upper Kansas River Basin lost 21% of its stream length from 1950 to 1980 as the presumed result of extensive groundwater pumping and climate change (Perkin et al., 2017). Furthermore, losses of streams or changes in the flow duration class of streams are consistently underestimated because drainage networks are mapped at a coarse scale that overlooks a large proportion of small streams (Meyer and Wallace, 2001). For example, the USGS's best maps estimate the Upper Little Tennessee River drainage density at 1.23 $km\ km^{-2}$, however newer modeling techniques estimate the drainage density at 3.88 $km\ km^{-2}$ (Benstead and Leigh, 2012). This three fold difference in drainage density is most likely due to the inclusion of small streams; some of which are intermittent and ephemeral (Benstead and Leigh, 2012).

Traditional map-based approaches are potentially producing under-estimates of intermittent and ephemeral streams ecosystem services, especially biogeochemical regulating service since reach length is essential to calculating the service (Benstead and Leigh, 2012). This underscores the notion that legal protection of streams based solely on flow duration class risks haphazard and inconsistent overall stream protection.

2.3.2 Headwaters

Headwater streams are defined by agencies and peer-reviewed literature as low order streams (0-3) which are visible at the 1:100,000 map or image scale (Freeman et al., 2007; Nadeau and Rains, 2007; Meyer et al., 2007). Headwater streams comprise 50-70% of total stream length in the U.S. and can encompass all categories of streams (Nadeau and Rains, 2007). Approximately 50% of headwaters are considered intermittent or ephemeral (Nadeau and Rains, 2007). Headwaters are likely the most studied type of intermittent or ephemeral waters in the Southeast, therefore this review will draw heavily from this literature on headwaters and their restoration. Where possible, this review will distinguish between research conducted explicitly on ephemeral or intermittent headwaters and non-headwaters.

3 Definition of Ecosystem Services

The concept of an ecosystem service first emerged in the 1970s as a way to demonstrate human dependence on the environment (Gómez-Baggethun et al., 2010). In one of the first iterations, ecosystem services were defined as the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life (Daily, 1997). The ecosystem services concept uses a utilitarian framing of ecosystem functions that are beneficial to human well-being in order to promote conservation (Braat and de Groot, 2012) and the concept transcends boundaries, reaching the non-profit, private, and public sectors (Gómez-Baggethun et al., 2010). An analysis completed in 1997 estimated that the global value of ecosystem services was approximately \$33 trillion USD annually in 1995 USD values (about \$46 trillion USD based on values in 2007; Costanza et al., 1997). As of 2017, Costanza et al., 1997, the paper reporting this first global ecosystem service valuation analysis, has been cited over 18,000 times. An updated estimate values global ecosystem services at between \$125-145 trillion USD annually (based on 2007 values), much of which is not captured in the GDP (Costanza et al., 2014).

The Millennium Ecosystem Assessment (MEA) was a four-year study with input from 1,300 scientists. Its release in 2005 put ecosystem services on the policy agenda (Gómez-Baggethun et al., 2010; Costanza et al., 2014). The MEA divided ecosystem services into four different categories: *supporting services*, *provisioning services*, *regulating services*, and *cultural services*. Supporting services refer to those services that are necessary to produce other ecosystem services, like nutrient cycling and soil formation (MEA, 2005). Provisioning services represent products that are directly obtained from ecosystems, like food and freshwater (MEA, 2005). Regulating services are benefits obtained from the regulation of ecosystem processes, like water purification (MEA, 2005). Lastly, cultural services are nonmaterial benefits from ecosystems, like recreation, ecotourism, and education opportunities (MEA, 2005). Changes in any of these service types affect human well-being, both directly and indirectly, by impacting health, security, and more (MEA, 2005). The assessment further found that 60% of global ecosystem services are being degraded or used unsustainably, including freshwater and fisheries services (MEA, 2005).

4 Methods

Articles for this literature review were collected from the Web of Science citation database and Google Scholar search engine. Specific search terms are listed in the subsections below. This approach is a widely accepted method for identifying literature to be included in a review. The returned citations were then filtered for geographical appropriateness.

4.1 Wetlands

The literature synthesized for the wetlands portion of this review was found using the search terms "geographically isolated wetlands," "geographically isolated wetlands ecosystem services," and "isolated wetlands ecosystem services." Additionally, the Wetlands 2003 Special Issue on geographically isolated wetlands was used to identify important researchers in the field and is cited throughout this study (Nadeau and Leibowitz, 2003). Citations of this special issue were also tracked to find more recent relevant research on GIWs.

4.2 Streams

The search terms "ephemeral streams," "intermittent streams," "headwater streams," and "south-east US intermittent streams" were used to collect citations for this review. The 2007 Headwaters Hydrology featured collection of the Journal of American Water Resources Association was also important for identifying research on intermittent and ephemeral streams.

4.3 Spillover effects

In this review of the literature, special attention has been paid to spillover effects. Spillover effects refer to functions that occur in one location (e.g., within a geograpically isolated wetland) but have consequences that extend beyond that specific location. Many of the ecosystem services described in Section 5 and Section 7 can be thought of as spillover effects, and these effects are largely attributable to the connectivity of water across landscapes. Water found within geographically isolated wetlands, ephemeral streams, or intermittent streams, as well as the energy, material, and organisms associated with it, is unequivocally connected to larger downstream waters via groundwater and surface flows (U.S. EPA, 2015). Therefore, impacts to water within these temporary waterbodies can have profound effects on downstream wetlands, rivers, and lakes. These spillover effects can be found within each category of ecosystem service defined in Section 3. Thus, while examples of spillover effects are not always labeled as such in the followings sections, we have endeavored to highlight these spillover effects in our review of the ecosystem services of temporary waterways.

5 Ecosystem Services of Wetlands including Geographically Isolated Wetlands (GIWs)

5.1 Overview

The ecosystem services provided by GIWs directly and indirectly benefits humans (Costanza et al., 1997; MEA, 2005). The designation of "geographically isolated wetland" implies the wetland is separated from the landscape, and is misleading. Wetlands provide many ecosystem services such as providing habitat for species; retaining nutrients, sediments and pollutants; storage of floodwaters; recharging groundwater that eventually feed river baseflows; regulating the freshwater flow into estuaries; and providing recreational areas and supporting tourism. In all of these cases, GIWs differ from non-geographically isolated wetlands only in the amount of an ecosystem service provided. However, GIWs also provide unique services such as providing habitat for endemic and threatened species (Section 5.2.1); and the cultural significance of pre-historic and historic settlements found near Coralina bays (Section 5.5.2).

The amount of services provided per area differs by wetland characteristics including hydroperiod (duration filled with water), duration of surface water connectivity, size, shape and location. Wetland characteristics' impact on supporting services can be used as an example. Wetlands lacking surface water connection are often more efficient (ie. yield more human benefits per area) at retaining nutrients than similar wetlands with surface water connection to traditional navigable waters. For example, GIWs are often able to sequester more carbon when compared to wetlands with a surface water connection (see Section 5.2.3). Within GIWs, smaller wetlands are more efficient at retaining phosphorus, while larger wetlands are more efficient at retaining nitrogen (Marton et al., 2015). Many of the bioremediation supporting services provided are a function of the GIWs' perimeter to area ratio, rather than total volume or area, and are cheaper than constructing waste water treatment plants (see Section 5.2.2).

The landscape surrounding a GIW also impacts the ecosystem services provided. The small effects of individual wetlands accumulate over space and time to impact downstream waters (see Section 5.3). For example, downstream nutrient concentrations are both a function of biogeochemical processes within a GIW and the connections between waters that allow transport of nutrients (Fritz et al., 2018; Leibowitz et al., 2018; Goodrich et al., 2018; Lane et al., 2018).

A variety of wetlands, including those lacking surface water connections, need to be preserved to maintain the current level of services provided given the impact of wetland characteristics on the magnitude of ecosystem services.

The case studies for the geographically isolated wetlands section will focus on the ecosystem services provided by first reviewing preserved or intact GIWs (see Section 6.1). The second section focuses the ecosystem services gained through the more recent restoration of previously drained GIWs (see Section 6.2). These case studies are designed to highlight the timescale that ecosystem services are provided during the restoration process. Some services, like flood control, return almost immediately, while other services, like sequesting carbon in above ground biomass, have a longer lag time. Based on these case studies highlighting the resumption of ecosystem services gained from restoration we can inferr the adverse consequences of draining, and landuse conversion. In other words we assume that filling previously drained geographically isolated wetlands, and draining geographically isolated wetlands have an equal but opposite effect on any ecosystem service.

5.2 Supporting services

5.2.1 Biodiversity

Geographically isolated wetlands provide greater habitat diversity on the landscape compared to non-isolated wetlands due to the inherent variability of GIWs. GIWs can be large or small, have wet and dry years, and long and short hydroperiods (Sharitz, 2003). Decision-makers tend to assume that larger wetlands are more important, but in fact smaller wetlands can be more valuable for maintaining biodiversity as populations depend on a landscape covered by a variety of wetlands. Further, the source and sink dynamic of isolated wetlands is crucial to the regional survival of species (Semlitsch and Bodie, 1998).

GIWs contribute to the larger landscape, providing a network of energy and chemical interactions for organisms that depend on the presence of surface water during some part of the year (Gibbons, 2003). Many species are highly dependent on GIWs for all of their life requirements including wetland plants and breeding amphibians (Kirkman et al., 1999). The habitat diversity of GIWs can support a range of habitat specialists that can lead to high species richness within and between wetlands (Leibowitz, 2003). GIWs increase biodiversity at multiple scales by contributing an aquatic feature in a terrestrial matrix (Calhoun et al., 2017). These aquatic features act as "stepping stones" within the matrix and provide a source of food and resting habitat for migrating species (Calhoun et al., 2017). For instance, the bullfrog spends winter months in deep-water habitats but migrates to ephemeral wetlands for both reproduction and feeding (Mushet et al., 2015). Mammals and birds use vegetation and wildlife (e.g., algae, invertebrates, amphibian eggs, etc.) in GIWs to supplement their diet (Calhoun et al., 2017). GIWs can also serve as important habitats for specific lifestages of animals: wetlands that act as nurseries for birds or fish may influence adult populations at other locations or times (Hoehn et al., 2003).

Isolation contributes to regional biodiversity by supporting connected populations or metapopulations of upland species (Leibowitz, 2003). Metapopulation dynamics consist of local extinctions of populations within certain habitat patches and subsequent recolonization from neighboring patches through dispersal (Leibowitz, 2003). Proposed changes to Clean Water Act jurisdiction could substantially increase the distance between isolated wetlands. As distance increases between wetlands, the potential for migration and recolonization decreases reducing the chances of a healthy population rescuing a neighboring declining population (Semlitsch and Bodie, 1998). Wetland mitigation often proposes to replace multiple, small wetlands with one big wetland but research on the topic specifically demonstrates that one 20 ha wetland does not equal 20 1-ha wetlands in terms of function (Semlitsch and Bodie, 1998).

GIWs are important because they provide habitat for a variety of species, ranging from mammals to plants to amphibians. Pocosins serve as refuges for mammals such as black bears, white-tailed deer, bobcats, marsh rabbits, and gray squirrels (NCASI, 2008). In one study conducted in 1985, scientists either trapped or observed 40 different mammal species in pocosins and Carolina bays (Clark et al., 1985; NCASI, 2008). *Lindera melissifolia*, a federally endangered shrub, is endemic to isolated wetlands of the southeast (Beckley and Gramling, 2013). Unfortunately, habitat availability is declining steeply for the species due to wetland conversion to other land uses (Beckley and Gramling, 2013).

Amphibians and reptiles

GIWs provide valuable habitat for a multitude of amphibian and reptile species. Particularly, the southeastern U.S. is a global hotspot of amphibian biodiversity, many of these species are endemic and inhabit ephemeral wetlands (Duellman, 1999). The southeastern U.S. is also a hotspot for freshwater turtle diversity and richness (Mittermeier et al., 2015). Many of these species are as dependent on the terrestrial habitat surrounding GIWs for some aspect of their life cycle as they are on the wetlands themselves (Gibbons, 2003). Thus, the integrity of the associated uplands with geographically isolated wetlands is important from a biodiversity standpoint (Gibbons, 2003). Research shows that the survival of amphibian eggs, larvae and breeding adults is more likely if a wetland is isolated (Gibbons, 2003). More than 1,500 adult amphibians were observed in a 0.2 *ha* Alabama sinkhole wetland, including 527 mole salamanders, 127 eastern tiger salamanders, 269 gopher frogs, 241 southern leopard frogs, and 191 ornate chorus frogs (Tiner, 2003).

Within the southeastern Coastal Plain, GIWs provide breeding or primary habitat for 36 different amphibian species (Liner et al., 2008). A study by Liner et al., 2008 found that GIWs in Georgia had a mean species richness of 12.7 $\pm$ 0.5 species. The maximum species richness measured, 25 species, is similar to the most diverse wetlands in the southeast and across the U.S. (Liner et al., 2008). GIWs can also support extremely dense amphibian populations. For example, Ellenton Bay, a GIW in Atkin, South Carolina, has an estimated 38,612 individuals per hectare (Gibbons et al., 2006). The same study also estimated 159 $kg\ ha^{-1}\ year^{-1}$ of amphibian biomass was transferred from the wetland to surrounding uplands showing that GIWs can substantially contribute to overall productivity of the surrounding terrestrial systems (Gibbons et al., 2006). The position of GIWs among upland habitat is critical to supporting such high reptile and amphibian populations. Many species of amphibians in the southeastern Coastal Plain exhibit life histories that require both terrestrial and aquatic habitat. Adult salamanders and anurans migrate to GIWs for mating and egg deposition but return to upland habitats for the remainder of the year (Russell et al., 2002). The eggs hatch as aquatic larvae that develop in wetlands until metamorphosis (Russell et al., 2002). Survival rates of pond-breeding amphibian eggs and tadpoles in GIWs are higher than wetlands with surface water connections (Werner et al., 2009). The higher survival rate is a function of the GIWs lack of surface water connections, which prevent colonization of predatory fish species (Werner et al., 2009). After metamorphosis, juveniles head to adjacent terrestrial habitats where they stay until reproductive maturity. Associated uplands provide nesting habitat for freshwater turtles and snakes. Turtles also use terrestrial sites for hibernation or periods of dormancy (Russell et al., 2002; Gibbons, 2003). Many species live in underground caves associated with southeastern karst wetlands, like Georgia blind salamanders, cave shrimp, cave isopods, and cave amphipods (Tiner, 2003). Looking forward, several amphibian species associated with GIWs are ranked as most vulnerable to changes in climate through 2100 (Barrett et al., 2014). These species include the federally listed threatened frosted flatwoods salamander (Endangered and Threatened Wildlife and Plants; Final Rule To List the Flatwoods Salamander as a Threatened Species, 64 Red. Reg. 15,691, [15,691] (April 1, 1999)), currently petitioned for federal listing gopher frogs (Endangered and Threatened Wildlife and Plants; 90-Day Findings on 31 Petitions, 80 Fed. Reg. 37,568, [37,569] (July 1, 2015)), state-listed striped newt, and the eastern tiger salamander which is of special concern in Georgia (GA DNR, 2015).

Carolina Bays

The shifting hydroperiods of Carolina bays create a variable environment, allowing for a diverse collection of plants and animals (Burbage, 2004). The large variation in plant communities among bays themselves and the presence of rare, endangered, and endemic species in Carolina bays contribute greatly to the biodiversity of the southeastern U.S. (Semlitsch and Bodie, 1998; Burbage, 2004; Leibowitz, 2003; Altman-Goff, 2016). In fact, Carolina bays exhibit levels of endemism that rival many global biodiversity hotspots (Altman-Goff, 2016). Bennett and Nelson, 1991 identified 23 different species within Carolina bays in South Carolina that are considered rare, threatened, or endangered. Thousands of amphibians were counted in a 1-*ha* Carolina bay at the Savannah River site in 1979 (Tiner, 2003). Over a two-year period, researchers collected over 72,000 amphibians from the same bay, including 9 species of salamanders and 16 species of frogs (Tiner, 2003). Kirkman and Sharitz, 1994 reported 56-105 species per bay from a sample of four Carolina bays at the Savannah River Site in Atkin, South Carolina. A study in 2000 found 27 species of frogs, toads, salamanders in the 0.5 *ha* Rainbow Bay in South Carolina, which represents one of the highest species diversities for amphibians in the region (Semlitsch and Bodie, 1998). This study recorded breeding activity of 41,776 females and production of 216,251 metamorphosing juveniles. Juvenile recruitment is generally higher in wetlands that seasonally dry out (Semlitsch and Bodie, 1998). Species richness in Carolina bays on the coastal plain of South Carolina ranged from 14 to 56 species per bay (Altman-Goff, 2016).

The Carolina bay seed bank, with an estimated 72,600 seedlings m^{-2}, is larger than reported for most other freshwater wetlands (Kirkman and Sharitz, 1994). The isolated nature of Carolina bays excludes aquatic predators that require permanent water, creating a sanctuary for prey species (Burbage, 2004; Richardson and Gibbons, 1993). A study comparing an undisturbed Carolina bay, a partially drained Carolina bay and a man-made pit found that fewer individuals metamorphosed at the pit compared to the undisturbed bay, with the lowest number at the partially drained bay (Pechmann et al., 1989).

Carolina bays have been recognized for extraordinary zooplankton diversity (Mahoney et al., 1990). In 1987, 23 Carolina bays on the upper coastal plain in South Carolina were sampled for zooplankton. These wetlands demonstrated remarkably rich zooplankton communities, including 44 species of cladocerans and seven species of calanoid copepods (Mahoney et al., 1990). Cladoceran richness was related to both bay size and hydroperiod. A comparison between zooplankton species richness in undisturbed and disturbed bays showed no differences, suggesting either that zooplankton communities are resistant to disturbance or that the bays had adequate time for recovery (Mahoney et al., 1990).

Research shows that bat activity is higher over undrained Carolina bays (Menzel et al., 2005). Furthermore, there is significantly more bat activity after bay restoration compared to prior, suggesting that Carolina bay restoration can have an immediate positive impact on bat activity (Menzel et al., 2005). Carolina bays are also important to bird species; bird species richness is greater in pine forests with Carolina bays than those without during winter months (Czapka and Kilgo, 2011). In 2012, NatureServe gave a global conservation rank of G1 (critically imperiled) or G2 (imperiled) to 27 different community associations found within Carolina bays, indicating the extent to which Carolina bays provide habitat for vulnerable organisms (Altman-Goff, 2016).

Pocosins

Like Carolina bays, pocosins also contribute to regional biodiversity in the southeastern U.S. At least 24 mammal, 48 reptile and amphibian, and 145 bird species occur in typical pocosin habitats (Zeveloff, 1983). Pocosins provide wildlife habitat for many animals including rare species like the Hessel's hairstreak butterfly, the federally endangered pine barrens tree frog, and the specialized swallowtail (Tiner, 2003; Richardson, 2003). The North Carolina state-endangered eastern diamondback rattlesnake and American alligator are found in pocosins (Richardson, 2003). Pocosins provide refuges for big game species like black bears and white-tailed deer. The federally endangered red-cockaded woodpecker inhabits mature pond pines in pocosins as well (Richardson, 2003). Pocosins are also important wintering places for migratory birds because of their location along migratory corridors and the availability of open, unfrozen water (Zeveloff, 1983). Pocosins can provide the large areas needed for breeding populations of neotropical migrant birds (Zeveloff, 1983).

In general, the loss of GIW habitats impacts a wide array of fauna, both permanent residents and passersby, and most prominently, turtles, amphibians, birds, and small mammals, many of which are threatened or endangered (Cohen et al., 2016). Southeastern GIWs are highly threatened habitats, receiving little legal protection and high levels of development pressure (Tiner, 2003). There is a need for realistic wetland conservation and restoration strategies in order to maintain southeastern biodiversity into the future (Liner et al., 2008).

5.2.2 Bioremediation and phytoremediation

Wetlands are commonly referred to as "nature's kidneys" because they provide a similar function by absorbing waste products from the environment. The physical and chemical properties of wetlands provide many positive attributes for remediating contaminants (Williams, 2002). High primary production and anaerobic soils allow for the retention of metals, nutrients, and pesticides in organic matter (Cohen et al., 2016). Phytoremediation, or the use of living plants to treat contaminants in soil and water, can be an effective, low-cost option for areas of moderate contamination (Weis and Weis, 2004). Wetland plant tissue uptakes elements that then become immobilized within the tissue (Weis and Weis, 2004). The large rhizosphere of wetland plant species provides an enriched culture zone for microbes involved in degradation, and redox conditions in the soil further enhance degradation pathways (Williams, 2002). Further, GIWs tend to have higher perimeter-to-area ratios than non-GIWs because GIWs tend to be smaller than non-GIWs (Cohen et al., 2016). This higher ratio leads to increases in reactivity, or the processes that can lead to remediation of contaminants (Cohen et al., 2016).

In general, elemental uptake by wetland plants varies among species, and is related to rooting depth and plant life form (Collins et al., 2010). Typha, Phragmites, Eichhornia, Azolla, Lemna, and other aquatic macrophytes are some of the most effective wetland plants for heavy metal removal (Rai, 2008). Research shows that seed germination for many wetland species occurring in Carolina bays is not responsive to contaminant exposure.

In some areas, wastewater treatment systems use depressional wetlands to treat water (Ewel, 1997). In particular, cypress wetlands have demonstrated a potential for treating secondary wastewater, however, disposal of raw sewage can decrease tree productivity (Lemlich and Ewel, 1984). The Carolina Bay Natural Land Treatment Program in Horry County, South Carolina uses four natural Carolina bays to treat tertiary wastewater (U.S. EPA, 1993). The use of wetlands significantly lowers the cost of wastewater treatment, and because of the project, these four bays will be protected and represent one of the largest public holdings of Carolina bays in South Carolina. The only side effect found was an increase in plant productivity due to the influx of nutrients (U.S. EPA, 1993).

The Savannah River Site (SRS) in Aiken, South Carolina, is active in promoting both phytoremediation and bioremediation as low cost, natural remediation strategies (Schwitzguébel et al., 2002). One study at SRS showed that four common species of southeastern wetlands (*Myriophyllum aquaticum*, *Nymphaea odorata*, *Juncus effuses*, *Pontederia cordata*) can accumulate phosphorus and metals in their biomass for at least two growing seasons, demonstrating their potential to remove these elements from coal runoff waters (Collins et al., 2010). Another SRS wetlands study on uptake of chlorinated ethenes showed that bald cypress, tupelo, and loblolly pine contained the highest concentrations of trichloroethene (TCE), with lesser amounts in nearby oak and sweet gum (Vroblesky et al., 1999).

GIWs can be used as cost-effective means to immobilize uranium. Research in SRS shows that uranium may be strongly bound to wetland sediments under both reducing and oxidizing conditions (Li et al., 2014). These findings indicate that uranium is much less likely to be released as a result of seasonal changes in the oxidation state of the wetlands, indicating sustained uranium retention under a range of environmental conditions (Li et al., 2014). Vegetated wetlands can help remediate acidic, metal-contaminated water, but on occasion there can be undesirable side effects like lower pH and greater iron and manganese concentrations in effluent (Collins et al., 2005).

5.2.3 Biogeochemical cycles

GIWs are integral to biogeochemical processing on the landscape and thus to maintaining the integrity of U.S. waters (Marton et al., 2015). GIWs can act as hotspots for sediment deposition, nutrient retention and transformation, organic matter cycling and storage, and metal and pesticide immobilization (Mitsch and Gosselink, 2000; Walbridge and Lockaby, 1994; Cohen et al., 2016). GIWs typically have large, complex perimeters relative to their overall size, which means that a substantial portion of most GIWs are subjected to wet-dry cycles that enable high rates of biogeochemical processing (Marton et al., 2015). As a result, GIWs greatly influence the delivery of reactive nitrogen, phosphorus and other pollutants to downstream navigable waters, an important spillover effect (Marton et al., 2015). Long residence times due to seasonal or slow connections facilitate kinetically-limited reactions, like phosphorus sorption, and increase GIW sink functions (Cohen et al., 2016). No direct surface connection is required for GIWs to have a biogeochemical effect on downstream waters, and in fact hydrologic connection can reduce nutrient retention (Marton et al., 2015). Both GIWs' intermittent connectivity and high potential for biogeochemical processing lead to a significant reduction in nutrient delivery downstream (Marton et al., 2015; Freeman et al., 2007; Alexander et al., 2007).

Spatial and temporal processes drive variability in the biogeochemical processes of isolated wetlands (Marton et al., 2015). Smaller wetlands are more effective at phosphorus retention, while larger wetlands are more effective at nitrogen retention due to an increase in water retention time. The shape of a wetland's perimeter can influence biogeochemical processes as well, as rates of water loss from GIWs vary with the length of shoreline per unit area, causing variation in wetland water levels (Marton et al., 2015). The frequency of wetting and drying is greater in concave profile wetlands. This is important because wetting and drying increases leaching and desorption of phosphorus from sediment organic matter, and can also increase denitrification and export of nitrate (Marton et al., 2015).

The position of a GIW in the watershed also influences biogeochemistry. Upper reach GIWs are better at removing sediment (Marton et al., 2015). Midreach GIWs are better at retaining phosphorus, while lower reach wetlands are better at removing nitrogen (Marton et al., 2015). GIWs with steep slopes and shallow soils are likely to receive more nutrients from runoff and thus have higher water quality improvement potential. Lastly, the number of GIWs can increase the potential to remove nutrients. When 2-7% of a watershed is wetland cover, there are noticeable improvements in water quality (Marton et al., 2015).

Sediment accumulation can be similar or even greater in GIWs compared to other wetlands. Craft and Chiang, 2002 measured sediment accumulation rates of 951 $g\ sediment\ m^{-2}yr^{-1}$ in depressional wetlands and 1,289 $g\ sediment\ m^{-2}yr^{-1}$ in floodplain wetlands in southwestern Georgia (Marton et al., 2015). In areas where plant production exceeds decomposition, GIWs can become filled with peat (Whigham and Jordan, 2003). The intensity of nearby agricultural land use is a main determinant of biogeochemical processes through increased sediment and excessive drainage that can accelerate organic matter decomposition (Craft et al., 2017). Draining or filling in a wetland creates drier environments like uplands, which can decrease the processing ability of wetlands and impair carbon, nitrogen and phosphorus accumulation (Cabezas et al., 2014; Lane and Autrey, 2017). Altering hydrology in this way can bypass wetland processing and send nutrient-loaded waters to ditches and other waterways with negative downstream impacts (Lane and Autrey, 2017).

Carbon

Carbon sequestration is an important process due to its role in regulating global climate change (MEA, 2005). Depressional wetlands are capable of sequestering enormous amounts of carbon, significantly impacting landscape carbon dynamics when wetlands are abundant (Lane and Autrey, 2017). Carbon enters wetlands through plants, leaf litter, and in the form of suspended organic sediment from runoff (Gala and Young, 2015). It is retained due to wet, anaerobic conditions that slow decomposition rates (Gala and Young, 2015). This potential is threatened, however, by changes in land use. For example, converting a wetland to agriculture can reduce the soil carbon pool or carbon sequestration by 20-40% (Neely, 2008).

Lane et al., 2012 mapped nearly 1.2 million ha of GIWs in southeastern states, estimating that this quantity of wetlands has the potential to sequester 0.25–3.8 teragrams (Tg; equivalent to one billion kg) of organic carbon (C) annually. The Dougherty Plain in southeastern Georgia has approximately 43,000 ha of mapped GIWs representing cumulative carbon storage rates of 0.023 Tg per year (Marton et al., 2015). Coastal plain wetlands have average accumulation rates of 43.4 $\pm$ 39.0 $g\ C\ m^{-2}yr^{-1}$ (Lane and Autrey, 2017). Watt and Golladay, 1999 found that litterfall productivity—the quantity of leaves produced annually—in GIWs in South Georgia was among the highest reported for wetland systems, but that these systems efficiently processed and accumulated the organic material from these leaves. Dissolved organic carbon (DOC) concentrations, another measurement of carbon sequestration in these wetlands ranged from 10 to 40 $mg\ C\ L^{-1}$ and were comparable to those measured in other wetland types such as cypress swamps and bogs (Opsahl, 2005).

Pocosins are noted for sequestering carbon in organic soils and accreting peat, providing protection from sea level rise (Steven and Lowrance, 2011). The restoration of pocosins has the potential to store enormous amounts of carbon in soil and biomass (Neely, 2008). A study in Ohio showed that GIWs had higher organic content ($146 \pm 4.2\ g\ C\ kg^{-1}$) than riverine ones ($50.1 \pm 6.9\ g\ C\ kg^{-1}$; Bernal and Mitsch, 2012). Soil carbon was 98-99% organic in isolated depressional wetland communities and 85-98% organic in riverine wetlands (Bernal and Mitsch, 2012). Further, the depressional wetlands sequestered more carbon annually ($317 \pm 93\ g\ C\ m^{-2}yr^{-1}$) than riverine wetlands ($140 \pm 16\ g\ C\ m^{-2}yr^{-1}$; Bernal and Mitsch, 2012). These differences in carbon sequestration abilities highlight the importance of recognizing wetland type when determining the role of wetlands in the global carbon budget.

Nitrogen

GIWs contribute to nitrogen removal and limit the exposure of downstream systems to nitrogen (N). Wetlands with a high supply of nitrogen and phosphorus may have elevated denitrification rates which suggests an important role for GIWs in agricultural and urban landscapes (Lane et al., 2012; Marton et al., 2015). Denitrification services provide improved water quality and downstream system integrity (Lane et al., 2012). Small wetlands, like many GIWs, play a disproportionately large role in landscape-level nutrient processing. A study by Cheng and Basu, 2017 showed that 50% of nitrogen removal globally occurred in wetlands smaller than 0.1 acres.

Southeastern GIWs can denitrify from 0.0095–0.063 Tg of nitrogen per year (Marton et al., 2015). Nitrogen retention capacity of pocosins ranges from 22 to 89% percent of total nonpoint source inputs (Walbridge and Lockaby, 1994), indicating that areas adjacent and downstream to these wetlands can benefit immensely. Within pocosins, biological processes like plant uptake (15 to 51.8 $kg\ N\ ha^{-1}yr^{-1}$) and microorganism absorption (16.2 to 87.0 $kg\ N\ ha^{-1}yr^{-1}$) are important aspects of nitrogen services of wetlands (Walbridge and Lockaby, 1994). Studies show that drained wetlands have greater concentrations of nitrite (NO_2) and nitrate (NO_3) in surface runoff compared to restored and reference Carolina bays (Miller et al., 2017). The Dougherty Plain in Georgia has approximately 43,000 ha of mapped GIWs representing cumulative nitrogen storage rates of 0.0020 Tg per year (Marton et al., 2015).

A study in southwest Georgia found that GIWs store a disproportionate amount of nitrogen compared to upland soils (Craft and Chiang, 2002). The studied depressional wetlands were islands of nitrogen in the nitrogen-poor southeastern coastal plain landscape. Researchers found 2 $mg\ cm^{-3}$ organic nitrogen in the wetlands, and observed higher C:N ratios in uplands compared to wetlands indicating the nitrogen limitation of plant growth in upland areas (Craft and Chiang, 2002). It is likely that the saturation of soil in the wetland areas favors the sequestration of organic forms of nitrogen (Craft and Chiang, 2002). Waterlogged soils favor a higher proportion of nitrogen to phosphorus ratio, creating a gradient from nitrogen limited upland soils to phosphorus limited wetland soils (Craft and Chiang, 2002). GIW soils saturated with water also encourage the sequestration nitrogen and phosphorus in an organic or non-biologically available form (Craft and Chiang, 2002). There are limits to GIWs nutrient sequestering abilities, and occur when in agricultural landscape. Carolina bays adjacent to fields where poultry litter was used as fertilizer had N_2O emissions of 1.8 $mg\ m^{-2}day^{-1}$ (Miller et al., 2017).

Phosphorus

The limited surface water connections to GIWs provides a service to downstream waters by retaining phosphorus (P; Lane and D'Amico, 2010). GIWs store a higher quantity of total phosphorus compared to the uplands that surround them, most which is in soil rather than plant biomass or litter (Lane and Autrey, 2017; Dunne et al., 2007). Phosphorus fluxes from wetland soils to the water column depend on various factors, including physical and chemical characteristics of the soil and changes in soil redox conditions (Bhadha et al., 2011). These factors determine whether wetland soils act as a sink or source of phosphorus to the system. Biological processes like phosphorus uptake by plants (0.2 to 3.8 $kg\ P\ ha^{-1}yr^{-1}$) and microorganism absorption (6.6 to 40.0 $kg\ P\ ha^{-1}yr^{-1}$) are important parts of the phosphorus cycling services provided by pocosins on the southeastern Coastal Plain (Walbridge and Lockaby, 1994). Southeastern GIWs store between 0.00012–0.059 Tg of phosphorus (Marton et al., 2015).

The Dougherty Plain in Georgia has approximately 43,000 ha of mapped GIWs representing phosphorus storage rates of $3.4\times10-5$ Tg P per year (Marton et al., 2015). Annual phosphorus accumulation rates for the Atlantic Coastal Plain are approximately 0.01 ± 0.01 $g\ P\ m^{-2}yr^{-1}$ (Lane and Autrey, 2017). Generally, wetlands along lower order streams have lower rates of phosphorus deposition in sediment (1.6 to 3.0 $kg\ P\ ha^{-1}yr^{-1}$) compared to wetlands along higher order streams (13.6 to 36.0 $kg\ P\ ha^{-1}yr^{-1}$; Walbridge and Lockaby, 1994). A study in southwest Georgia found an increase of phosphorus in GIWs soils compared to adjacent upland areas (Craft and Chiang, 2002).

5.3 Regulating services

5.3.1 Water and material storage

Water storage is crucial for flood control. Nearly 2 billion people live in high flood risk areas, a risk that will increase if wetlands are lost or degraded (MEA, 2005). GIWs support numerous watershed functions, including hydrologic regulation, because of their variability in hydrologic connection and disconnection (Rains et al., 2016). GIWs are important for reducing peak floodwater flows, contributing to groundwater recharge and providing stream base flow (Calhoun et al., 2017). A watershed composed of at least 30% wetlands can reduce flood water levels by 60-80% (NRCS, 2006), and rainfall retention by wetlands can reduce flooding at separate geographical locations (Brinson, 1991). GIWs provide "spill and fill" and "spill and merge" functions on the landscape (Calhoun et al., 2017). "Spill and fill" refers to intermittent surface water connections (Leibowitz et al., 2016). "Spill and merge" occurs when wetland ponds merge or when two adjoining wetlands overlap (Leibowitz et al., 2016).

Carolina bays are sinks for runoff and groundwater discharge, especially during the spring and summer when the depressions are more empty which is an important spillover effect within the southeastern Coastal Plain, especially after large storm events in the late summer months (Sun et al., 2006). In regions dominated by GIWs, like the Carolina bays of the upper coastal plain of South Carolina, the regulatory ecosystem service on downgradient waters is produced by the combined effect of all GIWs rather than single GIW (Rains et al., 2016). This implies that many Carolina bays need to be maintained in order to preserve the ecosystem function (Rains et al., 2016). Within the lower Neuse River Basin, North Carolina as the average distance of GIWs, mostly Carolina bays, in a subbasin to a stream increases so does GIWs streamflow contributions (Golden et al., 2016). This seemingly counter intuitive pattern is strongest in winter months, when Carolina bays can significantly contribute to streamflow (Golden et al., 2016). This seasonal pattern could be explained by more distant GIWs impacting streamflow over longer time periods (i.e. seasons or annually) compared to GIWs closer to the stream (Golden et al., 2016).

Pocosins, regardless of "isolation" status, play a similar role attenuating peak rates of surface runoff during storms given their abundant retention storage (Daniel, 1981). Pocosins are comprised of porous, organic soils with a high capacity for stormwater retention (Daniel, 1981). The importance of this service is apparent when pocosins are connected to estuaries that require time to assimilate freshwater runoff in order to avoid sudden, detrimental changes in salinity (Tiner, 2003). For example, substantial decreases in estuarine salinity levels as a result of heavy rains and compromised pocosins are factors suspected in reduced harvests of North Carolina brown shrimp, the state's most valuable shrimp species (Street and McClees, 1981). When a pocosin is ditched or drained, it loses its buffering capacity, and consequently contributes more and oftentimes enriched water to streamflow (Tiner, 2003).

There are direct economic benefits related to the water storage services of GIWs. Stormwater management costs directly affect local economies in terms of flood damage and degradation of drinking water (Lane and D'Amico, 2010). U.S. FEMA estimated annual property damage from all types of flooding averages $2 billion USD a year (as cited by Lane and D'Amico, 2010). Constructing artificial retention basins can ameliorate flooding events but are significantly costlier than maintaining natural wetlands. For example, the Natural Resources Council estimates costs from $100-3000 per acre for wetland construction for water storage, and estimated that stormwater and sediment control adds $1500-9000 to the cost of new homes in North Carolina (NRC, 2009; Lane and D'Amico, 2010). Overall, maintaining wetlands on the landscape can limit flooding impacts and cut down on costs related to flooding.

GIWs buffer aquifer dynamics. GIWs provide water storage in the landscape that reduces water table changes in response to rainfall (McLaughlin and Cohen, 2013). Regular sink-source reversals buffer aquifer dynamics by limiting aquifer variation, in turn stabilizing the regional drainage network (McLaughlin and Cohen, 2013). Evapotranspiration varies seasonally in GIWs, causing water table fluctuations that release water slowly in saturated conditions and provide rainwater storage after dry periods (Steven and Lowrance, 2011). Adjacent to coastal areas, these controlled releases are important for regulating salinity in estuarine habitats (Steven and Lowrance, 2011).

5.3.2 Water purification and filtering

The degradation of water quality can increase the prevalence of disease and limit access to water for drinking and other human uses (MEA, 2005). Numerous studies demonstrate the importance of freshwater wetlands for maintaining water quality by remediating nonpoint runoff (Craft and Richardson, 1997; Knox et al., 2008; Atkinson et al., 2011). When groundwater flows are consistent, GIWs can serve as stable sources of potable water (Hoehn et al., 2003). Further, episodic reversals in the direction of groundwater exchange increase biogeochemical reaction rates and improve water quality (McLaughlin et al., 2014).

All wetlands assimilate nutrients from runoff through uptake in plant biomass and subsequent deposition in sediments, or through microbial denitrification in wetland soils (Atkinson et al., 2011). Generally, GIWs like fens, swamps and forested wetlands have high microbial biomass (Gala and Young, 2015). Aerobic and anaerobic microbes attack nutrients and chemically transform them into harmless substances (Gala and Young, 2015). The effectiveness of this process varies across wetland types and is influenced by a wetland's degree of connectivity with the surrounding landscape (Craft and Casey, 2000; Marton et al., 2015). The ability of a GIW to provide water quality services depends on factors such as water residence time, the proportion of the watershed composed of wetlands, and the types of interaction between wetlands and the surrounding landscape (Marton et al., 2015). Even in the absence of a surface water connection, a GIW can still provide functions to improve the water quality of navigable waters (Marton et al., 2015). GIWs process pollutants at rates similar to or higher than those of wetlands with apparent hydrologic connectivity (Whigham and Jordan, 2003; Marton et al., 2015). Deghi and Ewel, 1984 found that GIWs that received wastewater inputs removed more than 90% of incoming nutrients.

The water quality of GIWs can be very sensitive to adjacent land use (Yu et al., 2015). Episodic flows generated in agricultural fields often flow through GIWs before entering perennial waters, especially in the agriculturally dominated landscapes of the southeast (Deemy et al., 2015). One study conducted at Ichauway in southwest Georgia found evidence of greater planktonic cell numbers in GIWs influenced by agriculture (Knox et al., 2008). These higher numbers are likely crucial to the assimilation and cycling of nutrients (Knox et al., 2008). Another study at Ichauway found evidence of improvement of water quality as water moved between and through GIWs in Georgia's Dougherty Plain (Deemy et al., 2015). Improvement across biological, chemical, and physical water quality parameters demonstrates a crucial spillover effect of GIWs for the water quality of more permanent waterbodies in the region (Deemy et al., 2015). Thus, particularly in highly disturbed agricultural landscapes, isolated wetlands can provide valuable water quality services for the landscape as a whole (Atkinson et al., 2011).

Pocosins are a significant source of freshwater in the southeastern coastal plain where they cover large geographic areas (Richardson, 2003); consequently, the conversion of pocosins to agricultural fields or plantation forests is predicted to decrease downstream water quality via increased nutrient export (Walbridge and Richardson, 1991). The water quality of Carolina bays and pocosins depend on the degree of connection between the wetland and the underlying substrate (Whigham and Jordan, 2003). Generally, water quality in "short" pocosins, which are marked by shrubby vegetation and a thick peat layer, is similar to water quality in ombrotrophic, "cloud-fed" bogs (Whigham and Jordan, 2003). By contrast, "tall" pocosins, characterized by taller vegetation and little-to-no peat, have water quality similar to ground water (Whigham and Jordan, 2003). Data shows that water quality is seasonally variable in southeastern GIWs (Whigham and Jordan, 2003).

5.3.3 Erosion and flood control

The erosion control services of GIWs are attributed to the storage of runoff during rainstorms (Gala and Young, 2015). Wetland vegetation impedes the downstream momentum of floodwaters by slowing the water's momentum and allowing it to be stored in the underlying soils. Roots ensure that soils stay in place and stabilize wetland edges (Gala and Young, 2015). By lowering the frequency of high water table conditions, GIWs reduce downstream vulnerability to overland flows and associated hazards like stream bank erosion (McLaughlin et al., 2014). Thus, wetlands protect downstream landowners from both flood and erosion damage to crops and infrastructure (Gala and Young, 2015). Furthermore, by storing floodwater, wetlands enable evapotranspiration (Gala and Young, 2015).

5.3.4 Groundwater recharge

Groundwater is a vital source of water for domestic use (Gala and Young, 2015); in 2010 an estimated 130 million people, or one-third of the population, in the U.S. rely on groundwater for drinking water (DeSimone et al., 2014). The Northern Atlantic Coastal Plain aquifer system which spans coastal Virginia and North Carolina is particularly vulnerable to manmade contaminants like nitrate, pesticides, and volatile organic compounds (DeSimone et al., 2014). While the Upper Floridan Aquifer is naturally protected from manmade contaminates, supply wells in South Carolina, Georgia, and Alabama can increase the aquifer's vulnerability to contaminates by pulling shallow groundwater into the deep aquifer (DeSimone et al., 2014). Each day 80 billion gallons of water is pumped from aquifers in the U.S. (DeSimone et al., 2014). As the population continues to increase, groundwater will become an increasingly more important resouce (DeSimone et al., 2014). This is especially the case in areas with limited surface water supplies (DeSimone et al., 2014).

Groundwater recharge is defined as a change in water table height caused by water percolating through the vadose zone to the zone of saturation (Williams et al., 2014). GIWs impact groundwater dynamics through subsurface exchanges with surrounding uplands (McLaughlin et al., 2014). Pyzoha et al., 2008 found that a Carolina bay was hydraulically connected to surrounding uplands during wet periods and during the onset and end of droughts. The volume of this exchange is controlled by wetland perimeter, not area; thus, the magnitude of groundwater recharge that occurs within several, small wetlands will be greater than that of a single, large wetland of comparable size (McLaughlin et al., 2014).

Groundwater recharge rates are spatially and temporally dynamic, but generally, wetlands recharge groundwater at rates ranging from 0.03 $cm\ day^{-1}$ to 1.1 $cm\ day^{-1}$ (Gala and Young, 2015). Research shows higher groundwater exchange occurs in areas with coarse, upland soil, like those in the Atlantic Coastal Plain, compared to finer soils (McLaughlin et al., 2014). Coes et al., 2007 found summer recharge rates of 0.054 $cm\ day^{-1}$[3] and winter rates of 0.036 $cm\ day^{-1}$ [4] in a North Carolina pocosin. Williams et al., 2014 found GIW recharge rates of 3.29 $cm\ day^{-1}$, and did not find a significant difference between recharge rates of GIWs compared to riverine wetlands in South Carolina. The groundwater recharge rate from GIWs can be increased if regional groundwater pumping lowers hydraulic heads through

[3]converted from reported 20 $cm\ yr^{-1}$
[4]converted from reported 13 $cm\ yr^{-1}$

water removal (Rains et al., 2016).

5.4 Provisioning services

Among the provisioning services of GIWs, the most important is likely the direct provisioning of water for myriad human uses, including drinking water, which has been described in detail in Section 5.3.1 and Section 5.3.2. Wetlands also provide livelihoods for over a billion people globally via fishing, tourism, transport, and other activities. Specifically, GIWs support domestic animal farming by providing foraging resources during periods of drought (Gala and Young, 2015). GIWs also have documented impacts on fisheries, and can influence habitat quality in geographically-separate nursery areas for fish and shellfish (Brinson, 1991). Pocosin wetlands regulate drainage in a way that protects estuarine wetlands from sudden changes in salinity, which can diminish shrimp recruitment (see Section 5.3.1; Swallow, 1994). Each acre of pocosin wetland converted to other uses can cost the shrimp industry up to $3.73 USD per year in nearby estuaries (Swallow, 1994). The substantial economic impact of GIWs generated through their recreational use is highlighted in Cultural services (Section 5.5.1).

5.5 Cultural services

5.5.1 Human recreation

Wetlands provide many recreational opportunities, including hunting, fishing, boating, birdwatching, and wildlife photography (Gala and Young, 2015). Between 35–45 million people take part in recreational fishing in the United States, spending a total of $24–37 billion USD each year on their hobby (MEA, 2005), and this opportunity is supported by the presence of wetlands. Birdwatching, a recreational activity that generated nearly $107 billion USD in total industry output in 2011 (Carver, 2013), is also reliant on the presence of intact wetland habitat for many bird species. When found in densely populated areas, wetland habitat provides important open space amenities (Hoehn et al., 2003). Wetlands can be important cultural heritage sites for indigenous groups and provide diverse educational opportunities (Gala and Young, 2015). An Iowa study showed that willingness to pay for wetland visits per year was more than two and half times the willingness to pay derived from resident's actual visits and travel costs ($264.65 USD versus $99.61 USD; Boyer and Polasky, 2004).

Across the southeastern U.S., wetlands provide many opportunities for recreation. Table 2 shows 2011 wildlife-related expenditures in the Southeast, including activities like fishing and hunting, which total over $16 million USD (U.S. DOI, 2011). Most southeastern states have a statewide comprehensive outdoor recreation plan (SCORP), with sections highlighting the importance of wetlands to recreation (Tummons and Marshall, 2009; SC ADC, 2013; VA DCR, 2013; SC DPRT, 2014; NC DENR, 2015; Parks, 2016). Georgia's SCORP makes note of anticipated population growth, particularly for areas adjacent to wetlands, and mentions a need to prioritize landscape-level wetland areas for development of wetland mitigation banks or other wetland restoration activities (Parks, 2016). The Virginia SCORP explicitly states that wetlands are among the most important natural resources in Virginia's landscape (VA DCR, 2013). The Tennessee SCORP highlights the state's Wetland Acquisition Fund administered by the Tennessee Wildlife Resources Agency

(Tummons and Marshall, 2009). South Carolina's SCORP identified species of greatest conservation concern that rely on isolated ponds and wetlands, including 19 amphibians, 4 freshwater fishes, and 7 varieties of crayfish (SC DPRT, 2014).

Table 2: Wildlife related expenditures and number of people fishing or hunting in 2011 for Alabama, Georgia, North Carolina, South Carolina, Tennessee, and Virginia (U.S. DOI, 2011)

State	Total wildlife related expenditures[a]	Fishing and hunting expenditures[a]	Sportspersons (in thousands)
AL	2,665,172	1,930,968	1,732
GA	4,556,286	2,753,862	3,058
NC	3,294,423	2,364,762	3,497
SC	2,019,749	1,552,496	1,729
TN	2,868,103	1,925,532	2,584
VA	3,542,179	2,583,572	3,269

[a]Reported in thousands of dollars, USD

North Carolina is home to six different wildlife refuges that contain GIWs (Alligator River, Pocosin Lakes, Cedar Island, Mattamuskeet, Roanoke River, Swanquarter). Pocosin Lakes National Wildlife Refuge contains 100,000 acres of wetlands, forests and swamps (Edgell, 2016) and is known for providing black bear tours; birdwatching and wildlife photography are also popular at the refuge (Edgell, 2016). Pocosin Lakes receives 34,000 visitors annually, and about 1,500 anglers use the refuge for recreational fishing (U.S. FWS, 2010). The North Carolina State Park System offers wetland features like Dismal Swamp, Goose Creek, Hammock Beach, Lake Waccamaw, Merchants Mill Pond, and Pettigrew State Park (NC DENR, 2015).

Within the state of Alabama, both residents and nonresidents spent $2.2 billion on wildlife recreation in 2006, including almost $700 million in fishing related expenses. More than 1 million Alabama residents participated in wildlife watching; 600,000 fished and 310,000 hunted (U.S. DOI, 2006). Over the last decade, Alabama has experienced an increased use of wetlands associated with the river system for trail development, environmental education, and interpretive sites (SC ADC, 2013). Approximately 40 wetland sites across the state offer birding opportunities and scenic appreciation (SC ADC, 2013). Alabama's SCORP includes strategies for the use of wetland areas for purposes like education, mitigation, and ongoing wetland trend studies (SC ADC, 2013).

5.5.2 Cultural significance

Some Carolina bays are sites of archaeological research which reveal pre-historic and historic settlement patterns. These wetlands have dense and diverse artifact assemblages (Brooks et al., 2010). For example, Oak Bay in South Carolina, a GIW, has evidence of a Sewee shell ring that was used to make a dam over 4000 years ago (Middaugh, 2013).

5.6 Ecosystem service tradeoffs

Understanding the value of any wetland involves prioritizing among the many services it provides (McLaughlin and Cohen, 2013). The augmentation of some functions (like carbon sequestration) may be at the expense of others (like habitat), demonstrating a trade-off between ecosystem services (McLaughlin and Cohen, 2013). For instance, high water levels lower CO_2 emissions and increase bird habitat, whereas low water levels improve grazing, reduce floods and reduce methane emissions (Maltby and Acreman, 2011).

Considering tradeoffs between ecosystem services is important for ecosystem managers. Management decisions on wetlands often involve tradeoffs between services, like flood releases from reservoirs causing changes in water levels (Maltby and Acreman, 2011). Tradeoffs are not recognized with current wetland regulation and mitigation, which shows preference for habitat integrity and underestimates the value of "working wetlands" (McLaughlin and Cohen, 2013). This is particularly relevant when considering wetlands in disturbed areas, like those found in urban or agricultural settings. Often, these wetlands have reduced habitat functions, but other services like water storage and water quality improvements may be present and perhaps more important due to the greater need to ameliorate the disturbances of a human-dominated landscape (McLaughlin and Cohen, 2013).

6 GIWs Case Studies

6.1 Preserved GIWs

The following case studies highlight the ecosystem services provided by GIWs that have been intact since the late 1970's or earlier. These systems have been allowed to flourish, and are maintained for research or conservation purposes. Given the 40 plus years of recovery, the biodiversity of plants and animals in these case studies are quite impressive.

6.1.1 Ellenton Bay, South Carolina

Ellenton Bay is a semi-permanent, open-water herbaceous Carolina bay located within the Department of Energy (DOE) Ellenton Bay set-aside (Davis and Janecek, 1997). The DOE's Set-Aside Program is a system of reserve areas on DOE facilities that provide reference sites for human impacts on the environment (Davis and Janecek, 1997). Ellenton Bay was originally set aside in the 1960's, after being selected for study by University of Georgia scientists, and gained recognition for being the site of Eugene Odum's prominent research on old-field succession and energy flow (Davis and Janecek, 1997). The set-aside itself is about 580 acres, and is one of few set asides that allows for manipulative studies (Davis and Janecek, 1997).

Ellenton Bay is an acidic, softwater system dominated by aquatic and marsh vegetation. The Carolina bay itself is 27 acres and remains inundated throughout most of the year, drying to small pools only during exceptionally dry summers (Gibbons and Coker, 1977). Dominant plants include water lilies, switch cane, sedges, willow and Panicum grass. The bay is ringed by blackberries and pine trees (Davis and Janecek, 1997). The bay has a maximum water depth of 2 meters and mosquito fish are seasonally abundant (Gibbons, 1970; Davis and Janecek, 1997). A road embankment divides the bay into two main sections (Davis and Janecek, 1997). Gibbons et al., 2006 detected the presence of 24 species in the bay. These included sensitive species like the eastern tiger salamander, the Carolina gopher frog, the American alligator, the southern hognose snake, the Carolina swamp snake, and the bobcat. Ellenton Bay is one of the most biodiverse wetland habitats in the nation (Davis and Janecek, 1997; Gibbons et al., 2006).

Ellenton Bay is a site of ongoing research on the life histories of various reptile and amphibian species

(Davis and Janecek, 1997). In 1997, 250 publications and reports had been published based on research from the Ellenton Bay Set Aside (Davis and Janecek, 1997).

The site has infrastructure in place for research, including an amphibian call recording device and box installations for studying wood ducks (Davis and Janecek, 1997). Prominent research themes include the use of radioactive tracers to study energy flow and food webs, life histories of freshwater turtles, ecology and reproductive biology of wood ducks, the relationship between structure and function in old-field communities, the effects of gamma radiation on the reproduction and survival of small mammals, life histories of salamanders, amphibian disease dynamics, reptile metapopulations, and more (Davis and Janecek, 1997).

Research on freshwater turtles in Ellenton Bay has shown the importance of long term studies to reveal ecological phenomena in animal populations (Congdon and Gibbons, 1983). Further study on freshwater turtles has shown that critical life cycle stages, including nesting and hibernation, occur beyond wetland boundaries. Freshwater turtles require a 275-m upland buffer zone to protect all of their nesting and hibernation sites (Burke and Gibbons, 1995), demonstrating the equal importance of wetlands and adjacent uplands habitat to the survival of turtles. Work in Ellenton Bay on reptile metapopulations has also shown the necessity of studies of sufficient duration to allow for meaningful results, as demonstrated by a 26-year long mark-recapture study on slider turtles (Burke et al., 1995).

A 2014 study examined the value of reptile and amphibian species found in Ellenton Bay. Researchers determined the values of the different species using commercial values listed in peer reviewed literature, pet trade companies, and biological supply companies (DeGregorio et al., 2014). They estimated that the 392,605 individuals, representing 17 species, captured at Ellenton Bay over the span of a year were worth \$3,605,848 (DeGregorio et al., 2014). This estimate is likely low because it does not include the aesthetic value of the species, but it does highlight the importance of the Bay's biodiversity. According to the researchers, the value of Ellenton Bay (\$360,085 ha^{-1}) exceeds that of agriculture (\$24,000 ha^{-1}) by two orders of magnitude (DeGregorio et al., 2014).

6.1.2 Green Swamp, North Carolina

The Green Swamp Preserve is located in the southeastern corner of the North Carolina Coastal Plain and covers an area of 6,700 *ha*. Much of the preserve was owned and managed by the Federal Paper Board until the company donated it to The Nature Conservancy in 1977. The Preserve is mostly shrub-dominated pocosin scattered amongst savanna (Palmquist et al., 2014). Periodic droughts occur in the region and can result in the temporary loss or dormancy of species that depend on moist soils (Palmquist et al., 2014). Soils are generally poorly drained, and the water table is within 25 cm of the soil surface for several months of the year (Palmquist et al., 2014).

Green Swamp Preserve is noted for its incredible biodiversity. It is home to a black bear population (Drewry et al., 2013) and many rare animals including the American alligator, the fox squirrel, Henslow's sparrow, Bachman's sparrow, and Hessel's hairstreak butterfly (TNC, 2017). The preserve is also habitat for the venus flytrap, a vulnerable species on the conservation list, and the endangered red-cockaded woodpecker (TNC, 2017). Despite their worldwide renown, venus flytraps are in fact found only in few areas in North Carolina and South Carolina.

Beyond its animal diversity, Green Swamp is also renowned for its high diversity of herbaceous species with more than 30 species m^{-2}, including endemic species like the rough-leaf loosestrife (Walker and Peet, 1984). This level of diversity surpasses all other North American plant communities. In a study looking at over 20,000 plots in temperate North American forests, species richness never exceeded 17 species m^{-2}, and in studies of tall-grass prairie, richness averaged 18 m^{-2} and never exceeded 28 m^{-2} (Peet et al., 1983; Walker and Peet, 1984). Frequent fires are critical to maintaining this diversity (Bucher and High, 2002), with highest richness in sites with high fire frequency near the middle of the moisture gradient (Walker and Peet, 1984).

Green Swamp also contains threatened longleaf pine savannas and many rare orchid species, including the Spiranthes orchid. Since becoming a preserve in 1977, it has been a site for research on prescribed burns (Reardon et al., 2007; Palmquist et al., 2014) and on species richness (Rome, 1988), demonstrating the importance of the pocosin wetlands.

6.2 Recent restoration of GIWs

The restoration of GIWs can lead to the provision of previously lost or impaired ecosystem services. Reestablishing wetland hydrology is often cited as the most important component to wetland restoration success (Bruland et al., 2003) and can be easily achieved by plugging drainage ditches (Barton et al., 2008). Regional interest in restoration of longleaf pine habitats in the southeast could provide an opportunity to promote GIWs restoration as well, since these wetlands compose a significant part of the longleaf pine ecosystem (Kirkman et al., 1999). Determining the suitability of a wetland for restoration generally involves an assessment of disturbance level, location, and accessibility (Barton et al., 2008).

6.2.1 Barra Farms Regional Wetland Mitigation Bank, North Carolina

Barra Farms Regional Wetland Mitigation Bank is a Carolina bay complex in North Carolina. The complex was cleared and ditched beginning in the 1960's (Bruland et al., 2003). The establishment of drainage ditches changes hydrologic dynamics by lowering the water table, which leads to rapid drainage and continuous surface water flow (Bruland et al., 2003). These artificial conditions lead to soil erosion and the loss of organic matter. Furthermore, the use of this area for agriculture exacerbated changes, causing the compaction of wetland soils, changes in pH, and increases in decomposition (Bruland et al., 2003).

In order to reverse some of these negative impacts, 250 *ha* at the southern end of the site were restored to wetland in 1997-1998 (Bruland et al., 2003). The restoration consisted of filling ditches and planting native seedlings (Bruland et al., 2003). The filling of ditches almost immediately restored wetland hydrology despite years of artificial drainage (Bruland et al., 2003), leading to the return of flood control services (Bruland and Richardson, 2006). Beyond these benefits, the restoration actions also provided water quality services. The outflow from the restored wetland had less phosphorus and nitrogen when compared to outflow from agricultural sites (Bruland et al., 2003). This reduction has impacts downstream, and research shows that the water quality of nearby Harrison Creek and Cape Fear River has improved in response to the restoration actions (Flanagan and Richardson, 2010).

6.2.2 Pocosin Lakes National Wildlife Refuge, North Carolina

The U.S. Fish and Wildlife Service aims to increase climate change resilience by restoring the hydrology of carbon-rich wetlands like those found at the 59,305 acre [5] Pocosin Lakes National Wildlife Refuge (NWR) based on science showing that rewetting peatland can sequester greenhouse gases (Ward and Settelmeyer, 2014). Prior to being a wildlife refuge, this span of pocosins in North Carolina was drained for agricultural and peat mining operations, leading to releases of carbon to the atmosphere and nearby water sources (U.S. FWS, 2010). The drainage of organic soils like those found in pocosins promotes aerobic decomposition, CO_2 emissions can eventually lead to land subsidence (U.S. FWS, 2010). Further, it can cause an increase in severity and frequency of peat fires due to the significant changes in moisture regime (Poulter et al., 2006). A 1985 pocosin fire in the area led to the estimated release of 1 to 3.8 teragrams Carbon (1 Tg is equivalent to one billion kg) (Poulter et al., 2006).

When this area became a national wildlife refuge in 1990, managers aimed to implement restoration efforts in order to decrease fire frequency and sequester carbon. Restoration efforts were two-fold: restore hydrology and reforest native vegetation (U.S. FWS, 2010). A hydrology restoration plan was created in 1994 that involved the installation of water control structures to raise the water table (Ward and Settelmeyer, 2014). Over 14 miles of roads were raised to encourage the return of natural sheetflow. This led to the rewetting of 9,500 acres of pocosin (U.S. FWS, 2010). Reforestation was also a key part of the project at Pocosin Lakes. About 100,000 trees of Atlantic white-cedar, pond pine, and bald cypress were planted in April 1995 (U.S. FWS, 2010).

Estimates have been made for the carbon sequestration benefits of the restoration project. These estimates are based on amount of carbon retained in peat soils, the amount retained that would otherwise be lost, and the amount sequestered in aboveground biomass (Ward and Settelmeyer, 2014). The rewetting benefits at Pocosin Lakes are estimated to be 1080 metric tons of CO_2 equivalents per acre over 100 years. Ultimately this will result in over 21 million tons of CO_2 equivalents for the total 20,000 acres of restoration efforts (U.S. FWS, 2010; Ward and Settelmeyer, 2014). Furthermore, studies show that restoration did not increase N_2O emissions, which have the potential to counteract carbon sequestration (Kluber et al., 2014).

Pocosin restoration also improves water quality. When pocosins are drained, soils become oxidized, mobilizing mercury and other nutrients that can become contaminants delivered downstream (U.S. FWS, 2010). The restoration project will improve aquatic habitat and provide connections for migratory fish like herring, shad, and striped bass (U.S. FWS, 2010). Improvements in water quality will also benefit fish reproduction. Improvements in terrestrial habitat due to reforestation will help support Pocosin Lake's black bear population and the endangered red wolf that was re-introduced to the area in 1987 (Tredick et al., 2007; Kindall and Manen, 2007; Karlin et al., 2016).

Pocosin restoration will reduce wildfire impacts by decreasing the frequency and intensity of fires (U.S. FWS, 2010). The restoration project will help improve resiliency to climate change. Restoration allows for biomass and soil accumulation, and this increase in soil provides a mechanism to combat sea level rise (U.S. FWS, 2010). Local livelihoods will also benefit. The economic development of this area in North Carolina depends on sustainable conservation of natural resources,

[5] converted from reported 24,000 hectares

many people come to the area for ecotourism, hunting, and fishing (U.S. FWS, 2010).

6.2.3 Juniper Bay, North Carolina

The Juniper Bay Mitigation Site is a Carolina bay located in Robeson County, North Carolina encompassing 728.5 acres (Environmental Services, Inc., 2009). Juniper Bay was cleared and ditched in 1966 and used for agricultural production until being purchased by the North Carolina Department of Transportation in January 2000 (Environmental Services, Inc., 2009). Historical information from maps and photos helped to identify problem areas for restoration of the Carolina bay for mitigation purposes (Ewing et al., 2005). The restoration of Juniper Bay is being used to provide compensatory wetland mitigation credits in the Lumber River Basin with a goal to restore hydrologic function and revegetate the site with wetland species (Ewing et al., 2005; Environmental Services, Inc., 2009).

In order to restore hydrology, efforts were made to plug and backfill the ditch network to increase water storage capacity and retention (Environmental Services, Inc., 2009). Reforestation goals were to establish two Carolina bay community types: the peatland Atlantic White Cedar Forest and the Pond Pine Bay Forest (Environmental Services, Inc., 2009). The project set five-year goals for each aspect of the project. Successful hydrology restoration required the soil to be saturated within 12 inches of the surface for at least 12.5% of the growing season during non-drought years (Environmental Services, Inc., 2009). During the 2006 monitoring period, 86% of the monitoring gauges met this criterion (Environmental Services, Inc., 2009). The vegetation restoration required 320 surviving stems per acre; in 2006, 11/20 plots met this criterion (Environmental Services, Inc., 2009).

The establishment of this vegetation appears to have reduced soil temperature and the rate of carbon mineralization (Taggart et al., 2011). Furthermore, previous wetland restoration projects in agricultural areas have experienced phosphorus release to nearby surface waters, but the Juniper Bay restoration project did not result in this phosphorus export (Vepraskas et al., 2016). These results seem to suggest that Carolina bays are ideal sites for future wetland restoration projects due to minimal negative impacts on nearby surface water (Vepraskas et al., 2016).

7 Ecosystem Services of Intermittent and Ephemeral Streams

7.1 Overview

Although they function temporarily as waterways, intermittent and ephemeral streams serve as permanent ecosystems that moderate biogeochemical cycles, support diverse biota, and protect valuable water resources. Intermittent and ephemeral streams provide critical ecosystem services locally and downstream both when they are flowing and when they are not. In many cases, the unique cycling of wet and dry periods produce benefits that cannot be met by streams with continuous flow. Wet periods can transport nutrients and organisms downstream which stabilize downstream aquatic communities, while dry periods allow for the accumulation of nutrients (see Sections 7.2.1 and 7.2.3). Many of the ecosystem services presented below maybe underestimates given the tendency of map-based estimates of drainage networks tend to overlook small streams (see Section 2.3.1; Benstead and Leigh, 2012).

The southern Appalachians, spanning the southeastern states of this review, are among the oldest mountainous ecosystems on Earth since they escaped glaciation (Bernhardt and Palmer, 2011. This allowed the southern Appalachians to become the biodiversity hotspot it is today (Bernhardt and Palmer, 2011. Today, the intermittent and ephemeral streams of the southern Appalachians are buried during mountain top mining, destroying many of the ecosystem services provided by intermittent and ephemeral streams, or dry channels (for examples see Sections 7.2.1, 7.2.2, and 7.4). Mountain top mining in the region is common; the footprint is an estimated 2,278 square miles [6] in 74-county 32,046 square mile [7] area of Central Appalachia spanning West Virginia, Kentucky, Tennessee, and Virginia (Pericak et al., 2018).

In regions undergoing development, intermittent and ephemeral streams are often piped (Elmore and Kaushal, 2008). In these cases, the stream looses energy inputs from the sun, and the water-sediment boundary. Sunlight is required for most primary production which is essential for many supporting, regulating, and cultural ecosystem services (see Sections 7.2, 7.3, and 7.5; respectively). The water-sediment boundary is just as crucial for providing ecosystem services. This boundary is where many of the reactions associated in biogeochemical cycles of supporting services (see Section 7.2.3). These reactions should not be overlooked given the potentially disproportionate by area contribution made to the watershed's services provided. For example, within a watershed, 23% of sequestered carbon can be found in the headwaters despite the headwaters comprising less than 1% of the watershed by area (Wohl et al., 2012).

The case studies for the intermittent and ephemeral streams section will focus on the impact of stream burial given it is such a threat to the ecosystem services provided by intermittent and ephemeral streams (see Section 8). The first section will focus on the impact of unrestored or impaired buried streams on ecosystem services (see section 8.1). The second section focuses the ecosystem services gained through the restoration or daylighting of previously buried streams (see Section 8.2). Based on these case studies highlighting the resumption of ecosystem services gained from restoration we can inferred the adverse consequences of backfilling, burying, or piping drainages. In other words we assume that restoring impacted waters, and impacting waters have an equal but opposite effect on any ecosystem service.

7.2 Supporting services

7.2.1 Biodiversity

The southeastern United States is a hotspot for endemic or highly localized species of plants and animals, containing some of the most species-rich amphibian, reptilian, and freshwater fish communities in North America (Jenkins et al., 2015). Freshwater biodiversity in this region is the highest in the nation. Alabama alone supports 38% of native freshwater fish species and 60% of native mussel species (Lydeard and Mayden, 1995).

In general, biodiversity of commonly studied taxonomic groups (i.e., insects, fish, algae, and plants) is higher in perennial than in intermittent or ephemeral streams (Soria et al., 2017). However, the species found in intermittent and ephemeral streams are often specialized for those systems and dependent upon the unique hydrologic flow patterns found in these systems (Delucchi and Peckarsky, 1989; Williams, 1996; Wood et al., 2005). The biodiversity of intermittent and

[6] converted from reported 5,900 km^2
[7] converted from reported 83,000 km^2

ephemeral streams has significant, positive impacts on downstream and terrestrial ecosystem services through the upstream and downstream movement of aquatic species (Meyer et al., 2007). As climate change progresses and urban centers grow, intermittent and ephemeral streams may become more prevalent due to increased drying events (Soria et al., 2017).

Invertebrates

Ephemeral and intermittent streams are habitat for a diverse macroinvertebrate community, including mollusks, snails, and insects (Grubbs, 2011). Small streams can support a wider range of aquatic insects (Meyer et al., 2007), harboring distinct communities of certain functional groups (Grubbs, 2011). Indeed, much of the diversity in aquatic insects of the Southeast can be found in small streams (Morse et al., 1993). Additionally, select macroinvertebrate species are only found in ephemeral streams (Feminella, 1996), including some crayfish (Yarra and Magoulick, 2017). As the larval habitat for emergent insects (Wohl, 2017), ephemeral streams play an important role in linking aquatic and terrestrial ecosystems. Dry river beds also provide unique ecosystems for insects and other arthropods (Steward et al., 2012; Datry et al., 2014).

Vertebrates

Headwater streams in the Southeast support the most biodiverse and imperiled freshwater fish communities in North America (Jenkins et al., 2015), including both game and nongame species. Often, species in ephemeral and intermittent headwaters are a subset of the species found downstream. For example, brook trout (*Salvelinus fontinalis*) are found in both perennial and intermittent Appalachian streams (Courtwright and May, 2013; Hudy et al., 2008). In other cases, the species assemblages of ephemeral headwaters are unique when compared to downstream assemblages (Paller, 1994; Paller et al., 2016). These unique assemblages boost regional fish diversity and are typically comprised of small-bodied, insectivorous fishes. Alternatively, some fish use headwater streams specifically for spawning (Meyer et al., 2007). Several species of Southeast darters use seepage streams and ephemeral streams for reproduction, including the trispot darter (*Etheostoma trisella*) that spawns in tiny creeks flowing out of ephemeral ponds (Ryon, 1986). Beyond fish, headwater streams support an array of amphibians like salamanders (Meyer and Wallace, 2001).

Plants

Southeastern intermittent streams can provide habitat for a wide variety of plants including macroalgae, bryophytes, and angiosperms (Everitt and Burkholder, 1991). In North Carolina, headwater streams support a diverse algal community, dominated by diatoms with low abundance of cyanobacterial and chlorophytic groups (Greenwood and Rosemond, 2005). Riparian zones of ephemeral streams in Georgia serve as habitat for 120 flora species ranging from hardwood trees to loblolly pines (Jolley, 2008). Appalachian streams in multiple states also harbor an array of non-vascular plants like bryophytes and mosses (Glime, 1968).

7.2.2 Bioremediation and phytoremediation

Intermittent and ephemeral streams are important locations for the remediation of waste and toxins by biota. Flowing periods enable the processing and retention of contaminants such as pesticides, which have been shown to be sequestered in temporary waterways through the sorption of pesticides to bed sediments and deeper soils (Dages et al., 2015). During dry phases, precipitation and runoff passes through soil and bed material, providing further opportunities for filtration and purification before entering groundwater and downstream waterways (Datry et al., 2017). Additionally, riparian vegetation can augment the filtration services that take place within intermittent and ephemeral streams (Gilliam, 1994). However, intermittent and ephemeral streams do not possess a limitless capacity to sequester and remediate toxins; therefore, it is important that these waterbodies are protected from needless contamination, which can result in degradation of downstream waterbodies. Ephemeral streams often experience the strongest influx of pollutants from mountaintop mines and other environmental disturbances (Bernhardt and Palmer, 2011), and these impacts propagate downstream to perennial waters (Meyer et al., 2007). For example, mine waste deposited in headwaters has led to metal contamination within the sediment, floodplains, and organisms more than 250 miles downstream (Hornberger et al., 2009).

7.2.3 Biogeochemical cycles

Downstream waterways are intrinsically linked to the biogeochemical processes that occur in upper stream reaches (Vannote et al., 1980). From decomposition to carbon storage and nitrogen transformation, ephemeral and intermittent streams lay the biogeochemical foundation upon which the entire aquatic ecosystem is built. Thus, maintaining the health of these streams is critical for protecting and preserving water resources.

Carbon

Ephemeral streams transform and store carbon before transporting remaining compounds downstream, and therefore play an important role regulating both downstream biological activity (Fritz et al., 2018) and global climate change (MEA, 2005). Headwater reaches contribute significantly to downstream processing of organic matter, breaking down leaf litter and other organic matter. Approximately 50% of the organic matter entering forested headwater streams is leaf litter (Benfield, 1997), and yet less than 2% of the exported organic matter is in this form (Fritz et al., 2018), as microbes and invertebrates decompose leaves, assimilating carbon into their tissue and exporting dissolved carbon downstream. In one North Carolina stream, invertebrates in ephemeral streams processed up to 74% of particulate organic matter (Romito et al., 2010). In ephemeral streams, provisioning of carbon to downstream waters is unique in that leaves and organic matter accumulate during dry periods (Fritz et al., 2010) and are then released downstream in pulses during storm events (Datry et al., 2014). These pulses are an important source of carbon for downstream animals (Bunn et al., 2006). Ephemeral streams also play a role in carbon sequestration, a process in which carbon is stored in sediment or taken up by organisms rather than being released into the atmosphere where it contributes to climate change. In one study, headwater streams and their valleys were estimated to store an out-sized percentage of the organic carbon within their watersheds—up to 23%—despite comprising less than 1% of watershed area; much of this carbon will remain sequestered for hundreds of years in the form of floodplain sediment and coarse wood (Wohl et al., 2012). In the southeast, ephemeral streams store greater stocks of carbon in the form of coarse benthic organic carbon than perennial waterways (Fritz et al., 2010).

Nitrogen

Biological activity in ephemeral streams plays an important role in regulating the downstream transport of nutrients such as nitrogen, one of the main ingredients in fertilizers. The processing of nitrogen within small streams is important because it decreases the loading of nitrogen to larger downstream waters, an important spillover effect (Meyer et al., 2007). Excess nitrogen exported downstream can cause impairments such as increased harmful algal growth, decreased light penetration, and reduced dissolved oxygen levels, collectively known as eutrophication. Approximately 40% of the nitrogen in small to medium navigable waters originates in small streams, including ones that are ephemeral (Alexander et al., 2007). Therefore, any impact that diminishes nitrogen processing within small streams—such as stream burial—is expected to increase the amount of nitrogen that is transported to downstream, navigable waters (Mulholland et al., 2008).

Small streams process nitrogen in several ways. For example, biological activity in headwater streams can rapidly transform inorganic nitrogen inputs (like the nitrate and ammonia found in fertilizer) to dissolved organic forms (Johnson et al., 2013), some of which are less likely to promote harmful algal growth downstream compared to nitrate or ammonia (Lewis et al., 2011). Ephemeral streams can also promote the microbial conversion of nitrate into harmless nitrogen gas, a process known as denitrification; nitrogen loads in downstream waters have been reduced by up to 8% as a result of denitrification in headwater streams (Alexander et al., 2007). Denitrification primarily occurs when channel sediments are wet (Welter and Fisher, 2016), so impacts like stream piping that reduce the residence time of water in streams will lead to lower denitrification rates there. Finally, nitrogen in ephemeral streams can be taken up and retained in the biomass of plants and animals living there; riparian trees, for example, can remove substantial amounts of nitrate from water and retain it in their roots (O'Neill and Gordon, 1994). The loss of intact riparian plant communities in ephemeral streams would therefore be expected to cause increased exports of nitrogen and other nutrients to downstream waters.

Phosphorus

Uptake of phosphorus in intermittent and ephemeral streams can reduce the export of this potent nutrient to downstream waters, where it frequently causes harmful eutrophication, the most common impairment of surface waters in the U.S. (Carpenter et al., 1998). In forested headwater streams, phosphorus concentrations in the water are reduced through the binding of phosphorus to stream sediment (Meyer and Likens, 1979). The replacement of small headwater streams with pipes, as frequently occurs in urban settings (Elmore and Kaushal, 2008), has been predicted to greatly reduce phosphorus uptake: in a North Carolina headwater catchment, a modeling exercise indicated that the rate of phosphorus export would increase by 179% if pipes were to replace headwater streams (Meyer and Wallace, 2001). In the field, evidence of reduced phosphorus uptake with stream piping has been observed: an urban headwater stream in New Hampshire showed no uptake of phosphorus in the piped sections, whereas phosphorus uptake was detected in an unpiped reach at a relatively high rate (Hope et al., 2014). Piped streams receive no light, a necessity if plants and algae are to grow and take up nutrients like phosphorus (Hope et al., 2014). However, even unpiped urban headwaters do not appear to provide the same phosphourus uptake services as intact, forested headwaters: the speed at which phosphorus was taken up in degraded, urban headwater streams in Georgia was reduced compared to streams in forested catchments (Meyer et al., 2005), indicating that increased phosphorus loads will be exported to downstream waters when streams are impaired. This may be related to the retention of leaves and wood in forested headwater streams, which act as important substrates and food sources for stream food webs (Wallace et al., 1997). The presence of this detritus drives the uptake and retention of phosphorus by microbes as they decompose the organic matter (Meyer et al., 2005). In degraded urban streams, a lack of leaf and wood inputs leads to reduced phosphorus demand by microbes, further contributing to the export of excess phosphorus to downstream waters (Aldridge et al., 2009).

While the uptake of phosphorus within headwaters can play an important role in reducing downstream nutrient pollution, some river and coastal systems rely on periodic phosphorus inputs from ephemeral streams during periods of flowing water. For example, the ephemeral Santa Clara River in California provides nutrients such as phosphorus to coastal waters during the winter, a season in which nutrient concentrations from ocean upwelling are lowest (Warrick et al., 2005). This represents another example of the importance of predictable pulses of water and nutrients from ephemeral and intermittent streams to downstream waterbodies that rely on these inputs.

7.3 Regulating services

7.3.1 Water and material storage and transport

Intermittent and ephemeral streams serve as important links connecting water and materials between upper catchments and downstream waterbodies. An estimated 55% of the annual water volume in large rivers originates in first-order streams, the majority of which only flow intermittently (Alexander et al., 2007; Acuña et al., 2014). Within intermittent and ephemeral streams, water may be transferred downstream in the form of surface water during periods of hydrologic connectivity. However, water may also be delivered downstream via infiltration into groundwater and eventual reemergence in springs or lower reaches, where it can be an important source of baseflow, energy, and nutrients (Fisher and Grimm, 1985). The substantial contribution of small streams to the overall water volume in a watershed is a function of the high percentage of total stream length that headwater streams comprise (Nadeau and Rains, 2007), and also the higher elevation of most headwater streams within catchments. This feature of small streams leads to greater accumulation of precipitation and more isolated rain events compared to downstream reaches.

In addition to water transport, intermittent and ephemeral streams accumulate debris and nutrients during dry phases, producing highly concentrated pulses of organic matter once rewetting occurs (Datry et al., 2014). In the Southeast, many headwater, intermittent, and ephemeral streams occur in steep mountainous landscapes which are prone to bank slope failure and erosion during precipitation events (Gomi et al., 2002). These erosive processes create sediment, nutrients, and organic matter that are important for channel formation and food web processes downstream (Gomi et al., 2002). Impairment of intermittent and ephemeral streams can reduce overall hydrological connectivity in watersheds, disrupting the flow of crucial water and material from intermittent and ephemeral streams to downstream waterbodies that rely on these inputs (Gomi et al., 2002).

7.3.2 Water purification and filtering

Small streams, regardless of flow permanence, improve water quality downstream through the on-site filtration, sequestration, storage and accumulation of toxins by microorganisms, algae, plants, and animals (Datry et al., 2017). When intermittent and ephemeral streams are piped, buried, or otherwise degraded, the intrinsic capacity of these stream reaches to purify and filter water is compromised, which can lead to declines in downstream water quality. The magnitude of these filtration processes is so substantial that having intact headwater streams is more predictive of downstream water quality than downstream factors such as local land use or riparian cover (Dodds and Oakes, 2008; Alexander et al., 2007).

Furthermore, intermittent and ephemeral streams perform a large proportion of this ecosystem service due to the high prevalence of these flows in headwater streams. One study estimated that 69% percent of small streams below 60° latitude (i.e. south of Juneau, Alaska) flow only intermittently (Acuña et al., 2014). In much of the Southeast, the relative proportion of intermittent and ephemeral streams may exceed these estimates; in the Chattooga watershed in Georgia, North Carolina, and South Carolina, for example, 72% of the stream miles within a watershed were classified as intermittent or ephemeral streams (Hansen, 2001). The ubiquity of intermittent and ephemeral streams and the necessity of the functions that they perform underscore the crucial role that intermittent and ephemeral streams play in maintaining water quality, particularly for large waterbodies upon which humans rely.

7.3.3 Erosion and flood control

Intermittent and ephemeral streams play a crucial role in erosion and flood mitigation. By enabling the infiltration of water into dry sediments and groundwater supplies, intermittent and ephemeral channels buffer against large stormflows (Datry et al., 2017). Compared to reaches that are paved over or otherwise compacted, intact headwater streams and intermittent and ephemeral streams can reduce storm flows by 200-500% (Freeman et al., 2007). The infiltration and slowing of storm pulses reduce the likelihood of flows overtopping riverbanks, which often damage human infrastructure and agriculture. By reducing the volume and velocity of water following precipitation, infiltration within intermittent and ephemeral streams reduces the erosive capacity of storm flows, preventing the transport of excess sediment into downstream portions of watersheds. Excess sediment is considered the foremost pollutant of streams and rivers (Cooper, 1993), and is detrimental to municipal and industrial water supplies, dam longevity, and the health of aquatic organisms (Wenger, 1999).

Riparian vegetation associated with intact intermittent and ephemeral streams also helps mitigate floods and erosion. First, the presence of riparian vegetation decreases stormflow volumes via evapotranspiration. Areas maintained in forests promote enhanced evaporation of water from soil and leaf surfaces compared to land converted to other uses (Calder et al., 1995). Second, intact riparian vegetation associated with functioning intermittent and ephemeral streams slows the momentum of water moving across the land surface. This not only helps moderate potentially catastrophic pulses of water downstream, it enables sediment to settle out of water and remain on land, and limits stream bank erosion and collapse (Wenger, 1999).

7.3.4 Groundwater recharge

Intermittent and ephemeral streams replenish aquifers that are crucial sources of human water (Boulton, 2014). In many basins, the infiltration of water from intermittent and ephemeral streams constitutes a primary source of groundwater recharge (Pool, 2005; Amiaz et al., 2011). Ephemeral streams, by definition, always flow above the groundwater table. Therefore, during periods of flow, some surface water, solutes and organic matter are transferred to underground aquifers (McDonough et al., 2011). The role of intermittent and ephemeral streams can be especially important in porous, karstic systems, which are topographies characterized by the presence of sinkholes and caves (Katz et al., 1998). Karst topography predominates in parts of the Southeast, most notably in the areas of southern Alabama, Georgia and South Carolina that comprise the Floridan aquifer system (Katz et al., 1998; DeSimone et al., 2014). Among the most important aquifer systems nationwide, the Upper Floridan aquifer is the primary source of water for more than 10 million people and has supported water withdrawals of nearly 2 billion gallons per day for irrigation purposes in recent years (Marella and Berndt, 2005). With demand for water resources projected to expand rapidly in the coming decades as a result of agricultural, human population growth, and climate change (Carter et al., 2014), intermittent and ephemeral streams will become increasingly important in replenishing aquifers and thus human water sources.

7.4 Provisioning services

Riparian zones supported by intermittent and ephemeral streams serve as an important source of plant materials for livestock as well as habitat for economically valuable wildlife. Riparian zones around intermittent and ephemeral streams generally support more substantial vegetation than areas not adjacent to streams, particularly in drier regions. This vegetation can provide forage for livestock, as well as timber products (Steward et al., 2012). These riparian zones also represent important habitat for wildlife, including valuable game species such as deer (Compton et al., 1988). As hunting is a large driver of economic activity in the southern U.S., responsible for over $10 billion in expenditures in 2011 (Poudel et al., 2016), conservation of important wildlife habitats, such as intermittent and ephemeral streams, provides important benefits in terms of sustaining this valuable industry.

The importance of intermittent and ephemeral streams has also been demonstrated for many fish, including commercially and recreationally valuable salmon and trout species (Wigington et al., 2006). Brook trout, an important and iconic sportfish in mountainous portions of the South, often utilize isolated pools within intermittent streams for critical summer habitat (Hudy et al., 2008; Courtwright and May, 2013). Furthermore, brook trout that occupy isolated intermittent streams in summer rely heavily on surrounding riparian areas for food; in one study, terrestrial invertebrates comprised 54% of brook trout diet despite representing only 7% of potential food resources (Courtwright and May, 2013). Therefore, alterations to riparian habitat that disrupt the input of terrestrial invertebrates to intermittent streams can have negative impacts on brook trout. Trout fishing has direct economic benefits for the Southeast, with an estimated economic value of $130.3 million in Georgia in 2012 (Dorison, 2012), and approximately $174 million in economic output generated annually in North Carolina (NC WRC, 2013). A considerable percentage of the streams that comprise the historic range of trout in Virginia and North Carolina are intermittent or ephemeral (37% and 7%, respectively; Trout Unlimited, 2014).

7.5 Cultural services

Flowing and dry periods within intermittent and ephemeral streams provide cultural benefits to diverse groups through scientific, educational, entertainment, and aesthetic engagement (Datry et al., 2017). During flowing phases, ephemeral streams play roles within society similar to the cultural, recreational, and spiritual roles played by perennial streams. When flows cease, dry riverbeds can serve as areas to hike, camp, and enjoy the natural world (Steward et al., 2012). Moreover, ephemeral streams contribute to overall human well-being through the other ecosystem services they provide (Boulton, 2014).

More broadly, the ecosystem services supplied by intermittent and ephemeral streams are crucial for the cultural value of downstream waterbodies. Lakes and rivers treasured for swimming, fishing, and other forms of outdoor recreation rely on intact networks of intermittent and ephemeral streams for their overall water quality and quantity, as illustrated in Section 7.2 and 7.3. Without these services, problems with water quality and quantity can greatly diminish the cultural value of large waterbodies, with impacts ranging from swimming restrictions to eutrophication-driven fish kills.

Intermittent and ephemeral streams also have a place in indigenous American culture. Native Zuni Americans used dams on ephemeral streams to strategically and periodically irrigate their crops in adjacent floodplains (Norton et al., 2002). These streams have also subtly pervaded American culture, written about by the likes of American poet Robert Frost in "Hyla Brook" in the early 20th century (Frost, 1920).

8 Case Studies of Stream Burial

8.1 Impaired, unrestored buried streams

Streams, of any type, are not pipes that merely transport water downstream; they instead function as active transformers of solutes and habitat for fish, invertebrates, and microbes. They mitigate floods, maintain water quality, and provide cultural benefits. These services are largely derived from the interactions between groundwater and surface water, which is especially true for intermittent and ephemeral streams (Cerling et al., 1990). However, piping streams underground and disrupting intact riparian environments can eliminate these ecosystem services (Beaulieu et al., 2014). Burial results in a loss of riparian and groundwater connection, which provides the foundation for many of those critical stream benefits (Groffman et al., 2002).

Streams in the southeastern U.S. are especially imperiled due to both modification of streams in urban areas and mountaintop mining which results in burial of streams, especially intermittent and ephemeral streams (Bernhardt and Palmer, 2011). Streams in urban areas experience many negative effects due to human activity including increased erosion, sedimentation, elevated nutrient concentrations, elevated conductivity, increased bacterial concentrations, and harmful algal blooms (Walsh et al., 2005; Wenger et al., 2009). One study in the Chesapeake Bay found that 20 percent of all streams are buried, with some catchments experiencing burial rates of up to 70% of all headwaters (Elmore and Kaushal, 2008). In sum, burial to streams occurs in the Southeast for primarily two reasons: urbanization and valley fills from mountaintop mining.

8.1.1 Urbanization

Urbanization threatens the health, function, and biodiversity of intermittent and ephemeral streams. Around 60 percent of the world's population will reside in an urban area by 2030 (UN, 2016), and the fast-growing Southeastern U.S. is expected to see similar urbanization increases (Terando et al., 2014). Cities and urbanization are not developed in isolation; much of their environmental footprint has external repercussions. Anthropogenically-altered landscapes load high nitrogen concentrations into streams (Vitousek et al., 1997), transforming urban streams into large contributors of nitrogen (nitrate and ammonia) exports (Walsh et al., 2005), which can lead to eutrophic conditions and contribute to harmful algal blooms in downstream ecosystems (Howarth et al., 2002). Via the taming and domestication of urban waters, streams are hydrologically modified disconnected from their floodplains and increasingly channelized or buried (Grimm et al., 2005; Vietz et al., 2014; Elmore and Kaushal, 2008). As towns and cities grow, streams are often paved over and placed in corrugated steel pipes or concrete culverts so development can occur where the streams once ran, altering key ecosystem services (Paul and Meyer, 2001). Burial entails a loss of groundwater-surface water interaction and a subsequent loss of critical sediment and processing, a loss of light, and complete riparian disconnection. These modifications impair microbial processing (Beaulieu et al., 2014), lower stream productivity (Pennino et al., 2014), and reduce or eliminate key habitats for fish and wildlife. The most critical loss of services following burials comes in the form of a loss of nutrient pollution reduction, which is essential to the maintenance of water quality (Beaulieu et al., 2014). The reduction of nitrogen retention as a result of burial exacerbates nitrate export (Pennino et al., 2014), decreases a stream's ability to remove nitrogen (Beaulieu et al., 2014; Grimm et al., 2005), and ultimately lowers stream metabolism (Pennino et al., 2014), which has been increasingly used as a metric for stream health (Young et al., 2008). These supporting services, which craft the foundation for the remaining ecosystem services, are not the only components impacted by stream burial.

Regulating services are similarly affected. The gravel that forms the bottom of many intermittent streams contributes to sediment retention (Cerling et al., 1990). The absence of this ecosystem service can impair water quality and aquatic habitat, while increasing the likelihood of downstream floods and poorer water quality (Buchholz and Younos, 2007). Piping and burying streams stunts the natural ability of a stream to follow its more uniform course. The culverts often act as a dam that spreads the stream's water out beyond its natural floodplain and thereby inundate adjacent riparian areas. This can lead to blockages, backups, and uncontrolled overflow before the piped reach (Wild et al., 2011). Additionally, stream burial is a maintenance liability, and often more expensive to operate than open water counterparts (Wild et al., 2011), due to difficult access and aging, leaky infrastructure (Kaushal et al., 2015).

Stroubles Creek, Blacksburg, Virginia

Stroubles Creek is a 14,336-acre sub-watershed of the New River watershed in Montgomery County, southwest Virginia. It flows for 9.2 miles through a gradient of development and urbanization, including rolling agricultural hills, pastures, urban landscapes, and forested areas, before draining into the New River (Buchholz and Younos, 2007; Hession, 2017). The catchment includes most of the Virginia Polytechnic Institute (Virginia Tech) campus and the Town of Blacksburg. The watershed can be split into Upper and Lower Stroubles catchments. The Upper Stroubles watershed is 6,119 acres and drains the large urban area claimed by the Town of Blacksburg and Virginia Tech campus (Benham et al., 2003). It is characterized as a pool-riffle channel (Buchholz and Younos, 2007), where pools provide opportunities for fish habitat and nutrient retention, and riffles serve as microhabitats for macroinvertebrates. Due to changes in land use, Stroubles Creek receives an influx of fine sediment and nutrient pollution derived from fertilizers and livestock, and has been buried beneath much of the town.

This headwater stream, formed via tributaries that are often expanding and contracting seasonally and with precipitation, was the driver behind the founding of the Town of Blacksburg in 1798 in its current location (Parece et al., 2010). Currently, the stream has been relegated to subterranean flow in favor of development. Contamination from cultivated fields, pastures, campus and town development, and coal mining increased (Buchholz and Younos, 2007), with impairments such as burial inhibiting the natural ability of the stream to mitigate this pollution. Contamination, coupled with rapid residential growth and the expanding local university (Parece et al., 2010), have influenced stormwater management initiatives along the creek (Buchholz and Younos, 2007). As development continues, water quality issues persist and multiply as more stream segments are buried and surrounded by impervious surfaces, including those intermittent and ephemeral tributaries (Buchholz and Younos, 2007).

Stroubles Creek has been designated as "impaired" by the Virginia Department of Environmental Quality because of the decline of critical benthic macro-invertebrate populations in the stream due to agricultural and urban pollution (Benham et al., 2003). Stream burial can inhibit the mitigation and filtration of nutrients and pollutants (Beaulieu et al., 2014), likely contributing to the impairment designation. The EPA approved a Total Mass Daily Load plan for Stroubles in 2004 (Buchholz and Younos, 2007), which limits the incoming sediment load to a stream. Approximately 27% of sediment loading came from bank erosion (Buchholz and Younos, 2007), which can be catalyzed by burial (Elmore and Kaushal, 2008).

The burial of intermittent, ephemeral, and perennial headwater streams of Stroubles Creek has contributed to widespread environmental degradation including the loss of macroinvertebrate populations, declines in stream health, impairment of water quality, and an excessive export of pollutants. Blacksburg community leaders have emphasized the historical importance of Stroubles, and called for the exploration of daylighting to restore this stream and surrounding ecosystem (Town of Blacksburg, 2016).

8.1.2 Mountaintop mining

Mountaintop mining presents the largest threat to Appalachian watersheds. The rock waste from mountain ridge and summit explosions are disposed of in adjacent valleys and create fills that bury headwater streams under up to hundreds of cubic meters of waste (Bernhardt and Palmer, 2011). Mountaintop mining is the largest driver of land use change in the central Appalachian ecoregion (Townsend et al., 2009), where hundreds of headwater streams have been impacted, and more than 1,180 miles [8] of stream miles have been buried beneath coal mining waste (Bernhardt et al., 2012; Palmer and Hondula, 2014).

Mountaintop mining fills heavily reduce, if not entirely destroy, biodiversity and function in the areas where streams are covered by fill. The streams below the fill also experience reduced biodiversity and function. Valley fills impair stream salamander abundance in streams that flow downstream of fills, likely due to serious degradation of water quality (Wood and Williams, 2013; Price et al., 2016). Fish species distributions are also negatively influenced by valley fills (Hopkins and Roush, 2013). Additionally, macroinvertebrate communities are also detrimentally impacted when located downstream of valley fills (Pond et al., 2014). The impediments to the streams from valley fills represent both an elimination of habitat from physical obstruction due to waste and impairment due to degraded water quality (Palmer et al., 2010).

Streams buried by mountaintop mining waste release alkaline mine drainage into the bodies of water that receive them, as well as greater concentrations of cations and anions that can exceed toxicity requirements (Bernhardt et al., 2012; Lindberg et al., 2011; U.S. EPA, 2011). Burying streams beneath mountaintop removal waste increases pH, specific conductance, chloride, sulfate, and total dissolved solids, all of which negatively impact the ecological health of the system (Wood and Williams, 2013). Macroinvertebrate communities, for instance, have been extremely impacted by mountaintop mining practices (Pond et al., 2014). Conductivity levels of streams impacted by mountaintop mining commonly exceed 300 $\mu S\ cm^{-1}$, which is the level the EPA has determined to be harmful to aquatic life (Lindberg et al., 2011). Reclamation of mine land has had limited success (Hopkins et al., 2013), suggesting that preemptive conservation of streams may be the best course of action to preserve stream health and water quality near mountaintop mining activities.

8.2 Restored streams following daylighting

8.2.1 Little Sugar Creek, Charlotte, North Carolina

Little Sugar Creek begins as intermittent, headwater tributaries in Mecklenburg County, North Carolina and flows for about 20 miles through uptown Charlotte to the South Carolina state line (Arendt, 2015). It is a major tributary of the Catawba River (Arendt, 2015). The name of Little Sugar Creek comes from the indigenous tribe Sugartree, which roughly translates to either "group of huts" or "people of the river of water which is unfit to drink" (Mecklenburg County, 2003). In the 1980s, Little Sugar Creek was one of the most polluted waterways in North Carolina. Additionally, two 100-year floods occurred within two years in 1995 and 1997 (Mecklenburg County, 2003), creating millions of dollars in damage and spurring the county to create a restoration plan to reestablish floodplains (Arendt, 2015).

[8] converted from reported 1,900 km

Restoration entailed the removal of about 1,500 feet of concrete from atop the creek by removing parking lots from strip retail lots (Arendt, 2015). An estimated 6,000 feet of streambed was restored, with approximately 6,300 feet of greenway built alongside (Arendt, 2015). Four rain gardens were created, two wetlands constructed in the floodplains, and one pedestrian footbridge was built (Caplanides, 2014). Over 7 miles of trails were created, and over 3,000 acres of riparian and adjacent floodplains were restored (Arendt, 2015).

The goals of restoration and construction of the greenway alongside unearthed, restored sections were to improve water quality and create miles of trails to serve as hotspots for cultural services, yielding increased tourism and more recreational opportunities (Burroughs, 2002; Caplanides, 2014). Additional goals of restoration included creating signature parks, presenting alternative transportation routes, and generating economic opportunity (Mecklenburg County, 2003). Every dollar spent on the greenway (an estimated $42 million) is projected to yield at least $3 of private development. The potential payback is approximately $82 million (Caplanides, 2014).

8.2.2 Shoal Creek, Dekalb, Georgia

Shoal Creek rises in Dekalb, Georgia and is a 11.94 mile long tributary of the Soque River, which flows into the Chattahoochee River. The Dekalb County Parks Department installed a culvert over a 200m reach of a tributary of the creek. It is likely that the stream was ephemeral or intermittent (Pinkham, 2000). The culvert that the Parks Department installed caused sinkholes over the next decade (Pinkham, 2000). The 200 foot long culvert was removed in 1994 and the stream was daylighted (Pinkham, 2000). For this stream and others, the maintenance of culverted or piped streams can be costlier than the resources required for managing open systems (Wild et al., 2011). This is especially true when Clean Water Act grants are available to perform such projects. In the end, the town ended up with a less expensive and more ascetically pleasing fix (Pinkham, 2000). The riparian areas planted along the stream banks flourished, and serves as a successful example of daylighting for those advocating further stream restoration activities in the Atlanta area (Pinkham, 2000).

8.2.3 Rocky Branch, Raleigh, North Carolina

Rocky Branch is a headwater stream rising in Raleigh, North Carolina, and eventually draining into the Neuse River (Doll, 2010). It runs through more than a mile of North Carolina State University's (NC State) campus (Doll, 2010), and its watershed is comprised of 260 *ha* that drain the entire campus (Jennings, 2003). In recent years, a burst of development and construction of impervious surfaces has created artificial perennial headwaters on parking lots and gutter systems (Bratt et al., 2017). These alterations eliminate potential for riparian retention (Groffman et al., 2002) and increase nutrient pollution and sediment load (Elmore and Kaushal, 2008). Impervious areas, coupled with stream burial, cause channel incision downstream (Elmore and Kaushal, 2008), where erosion along the streambanks was so severe that it caused concern among adjacent businesses who thought that the banks might collapse (Duda and Lenat, 1979). Burial also contributed to high sediment concentrations, even in the absence of ongoing construction (Duda and Lenat, 1979).

The North Carolina Division of Water Quality classified Rocky Branch as one of North Carolina's most polluted streams in 1978 (Doll, 2010). Algal blooms occurred seasonally, and the creek was found to be devoid of macroinvertebrates, indicative of pollution to a toxic level (Duda and Lenat, 1979; Jennings, 2003). Due to water quality impairment, the North Carolina Sea Grant and NC State formed a partnership to restore Rocky Branch. They implemented an extensive stream restoration project, including the daylighting of a significant portion that runs through campus. The restoration has enabled further growth and connection of the town's Capital Area Greenway System (Doll, 2010), a network of interconnected trails for recreation, including walking, jogging, picnicking, hiking, and bird watching (Raleigh Parks and Resources, 2017).

To daylight part of Rocky Branch, the project participants exhumed 235 feet of buried stream (Doll, 2010). The stream was taken out of culverted pipes, and the floodplain and streambed were reconstructed (Doll, 2010). The ultimate project goals included restoring floodplain accessibility, vegetated riparian buffers, and a habitable streambed of riffles and pools (Doll, 2010). Once culverts were removed, the bed of the stream was elevated to access adjacent floodplains (Jennings, 2003), restoring potential for riparian mitigation of nutrients (Groffman et al., 2002).

Below is a list of the most relevant peer-reviewed studies, books, government publications, and non-government publications that we found discussing the functions and values, prevalence, and importance of geographically isolated wetlands and intermittent and ephemeral streams.

Resources

Peer-Reviewed Sources

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